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The Value of Travel Time

CIVIL 586 TERM PROJECT

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ABSTRACT

The value of travel time (VoTT) is a major factor to consider in forecasting travel demand and providing the primary base for estimating transportation benefits. This paper aims to explain the importance of the value of travel time and the explanatory factors impacting its estimation. It then proceeds to develop a contextual and mathematical foundation that are widely used in value of travel time studies, and describes the challenges and opportunities associated with the VoTT. Finally, three case studies based on different data collection and analysis methods are presented, along with a small-scale application of VoTT using a stated preference survey conducted at the University of British Columbia (UBC).

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1. Discussion

1.1. Introduction

The value of time (VOT) is defined as a value that captures travelers' willingness to pay for savings under a certain circumstance. The value of travel time (VoTT) specifically refers to the amount of monetary value travelers are willing to place to reduce their travel times. As time has no intrinsic value and cannot be purchased, the value of time refers to the value of goods, services, or utilities that can be produced within a given period. Travel time is considered to be a disutility. As such, reducing travel time increases utility. The amount of money that is required to keep utility constant then is the VoTT. Over the years, VoTT has been a core input to cost-benefit analysis (CBA) (Abir et al., 2017). In the section 1 of the report, we will introduce the value of travel time in detail, provide background information on its emergence, discuss the theoretical foundations, and highlight considerations and challenges. Section 2 discusses the mathematical foundations developed in the literature to quantify VoTT as well as consequences and extensions of the result. In section 3, three case studies highlighting the various applications of VoTT in different cities will be presented. Lastly, in section 4 we conduct a stated preference (SP) survey to estimate the VoTT for commute trips by personal vehicle, transit and active transportation using a sample from Vancouver, BC.

1.2. Background

In 1844, Dupuit was the first person to incorporate the concept of VoTT into his studies on CBA. It was referenced to service the price that people were willing to pay to move from stagecoach to train. The VoTT referenced today originated in the UK in the early 1960s. A graphical approach was developed by Beesley (1965) and quantitative models were developed by Quarmby (1967) and Dalvi and Lee (1969). The initial research was done for the empirical evaluation of the theory of time allocation and to develop a justified and improved CBA for the implementation of motorways. Initial empirical studies were conducted in the US and in the UK in the mid to late 1960s. In the 1970s, random utility theory developed the basis for methodologies involving disaggregate choice modeling, which advanced the VoTT analysis. In the early stages, VoTT for CBA was considered to be a fixed fraction of the wage rate, which varied across different purposes, meaning that as income went up, you'd be willing to pay more. Once empirical studies developed, data collection was based on real choice, through revelaed preference surveys (RP). In 1980, studies started including hypothetical choices through stated preference surveys (SP), which remains the main method to this day. Once the first national VoTT study in the UK, countries came out with their own national VoTT studies then went onto publishing one or more updated VoTT studies or more recently, moved onto VTTR studies. (de Jong & Kouwenhoven, 2020) (Wardman, 1998) (Mackie et al., 2003)

1.3. Framework

A conceptual framework for capturing worthwhile or wasted travel time was developed based on understanding that experience factors can facilitate travel activities which then unlock value, as demonstrated in the figure below (Cornet et al., 2021). The worthwhileness level experienced by a traveler is reflected by three types of perceived value: enjoyment, productivity, and fitness. Perceived value is subjective, and it depends on travel activities, which can be the activity of conducting the trip itself or the ability to conduct add-on activities while on-the-move. The personal efforts necessary to conduct an activity can be physical, cognitive or emotional, and can be wanted or unwanted. These are based on experience factors, which are travel conditions as experienced by the traveler that depend on the availability and quality of transport services, or on other external factors. To best understand why and how people value their trips, explanatory variables are considered. They represent the contextual factors that can also influence a trip's perceived worthwhileness, such as door-to-door trip characteristics, the traveler's personal characteristics and attitude, as well as spatial and temporal characteristics.

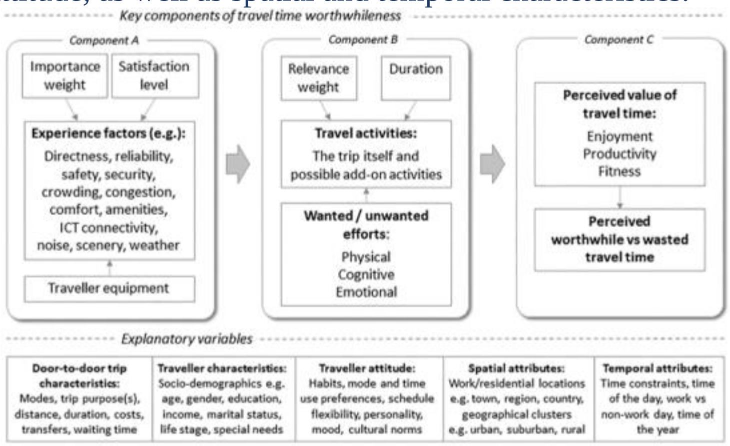

Figure 1: S1 respondent demographics (Cornet et al., 2021).

It is also important to consider the "time well spent" dimension in the scope of VoTT, which aims to capture the ability to carry out certain activities while traveling (MoTiV, n.d.). Traditionally, travel time has been interpreted as non-productive time. This relies on the assumption that people would like to spend as little time as possible traveling to reach their destination. However, studies show that travel experience is almost as significant as time savings, thus is being prioritized.

1.4. Challenges & Considerations

Traditional approaches taken face challenges when attempting to depict VoTT. The first challenge involves the inability to accurately capture VoTT. VoTT tends to assume that people's VoTT are within 35% to 80% of the average income, which was found to be far from the truth. Travelers were found to most likely prefer to save money in exchange for time. Thus, overestimations of VoTT are considered in the project planning stages, when in fact, most travelers are willing to pay a lot less for time savings. There's also the issue of failing to consider a variety of values such as comfort and convenience, mainly for public transportation and active travel. When time savings comes at the expense of inconvenience and discomfort using a facility or mode, one is less likely to value their time.

Another challenge is that increased VoTT is typically associated with increased travel speeds. The issue here is that it fails to consider that people have fixed travel time budgets that they are not willing to relax and that increased travel speeds cause people to travel greater distances. When you increase speed, urban sprawl will rise since people are more willing to move away to increase their time savings and personal benefits. However, they end up spending more time traveling, thus reinforcing the Travel Time Paradox condition. Lastly, external costs are not factored into the VoTT, such as parking costs, parking availability, emissions, crash risk, safety, and the delays, discomfort, and access restrictions that vehicular traffic inflicts on active travel modes. These external costs are typically worsened by increased vehicle travel and urban sprawl. (Victoria Transport Policy Institute, 2023)

2. Mathematical Foundation

In this section, we will outline the basic formulation for the value of travel time which follows from decision theory and optimization. The basic concept is attributed to Becker (1965) and considers a rational consumer that must allocate their time according to some constraints. This section is based on the work of Small (2012) which the reader is encouraged to review for further details.

2.1. Problem Description

Consider this time allocation problem within a period $\bar{T}$. Let K be the set of all non-work activities that can be carried out by the consumer, and T_k be the time allotted to activity $k \in K$. We require that $T_k \geq \bar{T}_k$, where $\bar{T}_k$ is the necessary amount of time to be spent on activity k (which can be zero). Moreover, we also require that $T_w + \sum_{k \in K} T_k \leq \bar{T}$ where T_w is the time allotted to work and $\bar{T}$ is our total time budget.

In Figure 2 we see an example of what a rational consumer's day might look like in a 24-hour period. This representation of the problem essentially allows for all time to be valued at the prevailing wage rate, as any time saved from one activity could feasibly be translated into work time.

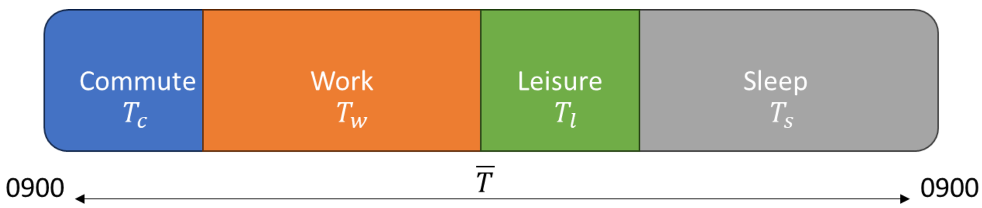

Figure 2: Example of a rational consumers day spent on various activities.

Furthermore, we know that a rational consumer will attempt to maximize their utility (or minimize their disutility in the transportation context). Utility can be derived from a variety of sources, and in this context, we can model the consumer's utility $U(G, T_k, T_w)$ as a function of goods consumed and time spent on work and non-work activities. This allows us to pose the problem as an optimization problem that can be solved using the Lagrangean method. It is stated as follows, where G is goods consumed, w is wage rate and Y is unearned income.

$$\max \qquad U(G, T_k, T_w)$$

$$\text{subject to:} \quad T_k \geq \bar{T}_k \quad \forall k \in K \quad (1), \quad T_w + \sum_{k \in K} T_k \leq \bar{T} \quad (2), \quad G \leq Y + wT_w \quad (3)$$

Let ϕ_k, μ and λ be the Lagrange multipliers for the activity-specific time constraints on k, the total time constraint and the budget constraint, respectively. We can then write the Lagrangean as follows:

$$\mathcal{L} = U(G, T_k, T_w) - \phi_k(1) - \mu(2) - \lambda(3)$$

This can be solved to obtain an indirect utility function of the form $V(Y, w, \bar{T}, \bar{T}_k)$. From the definition, we have that the value of travel time is the marginal rate of substitution between travel time and budget for which a traveler remains indifferent. This can be expressed mathematically as follows:

$$v_T = \frac{dY}{d\bar{T}_T} = -\frac{\partial V / \partial \bar{T}_T}{\partial V / \partial Y} = \frac{\phi_T}{\lambda}$$

Where the last equality comes from the properties of Lagrange multipliers and the linear form of utility functions (Ortúzar et al., 2011). We can write down some of the first-order conditions to obtain two expressions of ${}^{\phi_T}/_{\lambda}$ which are typically referred to as the 'fundamental starting point' for the value of travel time.

$$\partial\mathcal{L}/_{\partial T_w} = \mathrm{MU}_{T_w} + \lambda w - \mu = 0, \quad \partial\mathcal{L}/_{\partial T_T} = \mathrm{MU}_{T_T} - \mu + \phi_T = 0$$
$$\Longrightarrow \frac{\phi_T}{\lambda} = v_T = \frac{\mu - \mathrm{MU}_{T_T}}{\lambda} = w + \frac{\mathrm{MU}_{T_w} - \mathrm{MU}_{T_T}}{\lambda}$$

2.2. Consequences and Extensions

This functional form allows for two intuitive interpretations of the value of travel time. The first, $v_T = \frac{\mu - \mathrm{MU}_{T_T}}{\lambda}$ is composed of a 'pure' value of travel time ${}^{\mu}/_{\lambda}$ which is modulated by the marginal utility of travel time MU_{T_T}. The 'pure' value represents a baseline of how much a consumer is willing to pay to increase their overall time constraint. This is then modified by how much the consumer derives utility from travelling – the less they are inconvenienced by travel time, the lower their VoTT. The second, $v_T = w + \frac{\mathrm{MU}_{T_w} - \mathrm{MU}_{T_T}}{\lambda}$ highlights a proportional relationship between VoTT and the wage rate and suggests this relationship is offset by the relative utility of work time compared to travel time $\mathrm{MU}_{T_w} - \mathrm{MU}_{T_T}$. Therefore, if someone enjoys traveling more than working, their VoTT would be lower than their wage.

We can observe several consequences from this functional form for VoTT. If we empirically estimate the value of travel time for a population and find it to be greater than the prevailing wage rate, we can conclude that the population tends to enjoy working more than traveling and vice versa. Additionally, longer trips are typically associated with higher values of travel time compared to shorter trips. If we propose that longer trips have lower (more negative) marginal utility compared with shorter ones, the first equation would agree with empirical evidence. This supports the evidence that people are deterred by longer travel times. Moreover, many transportation service providers attempt to make traveling more enjoyable by offering in-service amenities, such as WiFi. In doing so, they are increasing the marginal utility of travel time to decrease the perceived cost that customers incur by using their service.

This is only the most basic formulation for VoTT and it has been extended in various ways to provide insight into additional trip making factors. Some examples include modelling the relationship between VoTT and wage non-linearly or including socioeconomic factors. These approaches typically yield additional terms in the expression for VoTT which further modulate its value.

3. Case Studies

The evaluation of VoTT involves two primary approaches: Revealed Preference (RP) data and Stated Preference (SP) data. Both methods follow a common sequence of steps, starting with collecting panel data incorporating travel-related factors and personal characteristics.

Subsequently, the utility function and logit models are determined, ultimately leading to the calculation of VoTT based on the estimated coefficients of the travel time and cost variables. RP data analyzes choices in real-world scenarios, capturing decisions in authentic environments influenced by gains and losses. Despite its strengths, RP data faces challenges, requiring substantial external knowledge and yielding highly correlated outcomes. Its infrequent use is attributed to experimental design complexities (Small, 2012).

SP data involves analyzing choices made in hypothetical situations, offering valuable insights into preferences for non-existent scenarios. Challenges include biases arising from treating hypothetical scenarios differently than real-world situations. It is noteworthy that SP data yields VOT estimates about half as large as those derived from RP data (Brownstone & Small, 2005). In subsequent sections, the report will delve into specific studies based on the RP and SP data, providing a comprehensive understanding of VoTT.

3.1. Public Transport Services, the Madrid-Barcelona Corridor

The Madrid-Barcelona Corridor study focuses on estimating the VoTT within the Spanish transportation market, specifically examining the competition between three major modes of transportation: air, high-speed rail, and bus (Román et al., 2014).

An RP survey involving 1043 travelers was conducted to collect the real choices made by travelers within the Madrid-Barcelona corridor. Specifically, this survey gathered detailed data on traveler characteristics, trip attributes, and factors influencing mode choice. Several discrete choice models using multinomial logit and mixed logit specifications were built to consider traveler background and income effects on VoTT. Notably, the utility functions were specified with various time and cost components, incorporating interactions to capture the nuanced factors influencing mode choice.

One of the study's highlights is identifying substantial differences in the VoTT based on the chosen mode and traveler characteristics. High-speed rail and air users exhibited a higher VoTT compared to bus users, aligning with trends seen in the transportation market. Furthermore, the study revealed that the VoTT is distinctly higher for business trips than for leisure trips. This difference is attributed to the fact that business travelers, not responsible for ticket costs, demonstrate a higher willingness to pay for time savings.

The study also indicates that saving waiting time is more important than saving access time and saving access time is more important than saving in-vehicle travel time. Based on this finding, the authors recommend that authorities focus on improving access and waiting times to enhance the competitiveness of air transport within the Madrid-Barcelona corridor.

3.2. Managed Lanes, Katy Freeway in Huston

The second study focuses on estimating the VoTT based on the revealed preferences of travelers on the Katy Freeway in Houston, delving into the impact of trip length and past experiences on lane choice (Abir et al., 2017).

The research is based on the RP data collected from Katy Freeway travelers through automated vehicle identification sensors. This dataset encompassed millions of situations where individuals chose either toll-free general-purpose lanes (GPLs) or paid a toll for access to managed lanes (MLs). Several binary logit models were developed, incorporating variables related to travel time, tolls, and other relevant measures.

The results revealed a VoTT for Katy Freeway travelers ranging from $1.96 to $8.06 per hour for all monthly trips. This valuation appears considerably lower than typical research outcomes and practical applications. The authors attribute this difference to the uneconomic behavior among travelers. Notably, around 11% of travelers chose to pay for managed lanes, even when they offered lower speeds than the toll-free general-purpose lanes. Additionally, the study suggests that easier accessibility at the end of managed lanes compared to midpoints might contribute to this observed difference.

The authors propose that most travelers exhibit habitual lane choices, seemingly unaffected by prevailing conditions such as time and toll fees. This challenges the previous assumption that lane choices are primarily based on these factors. In conclusion, this study underscores the complexity of traveler behavior and lane choice, emphasizing the need to reconsider traditional assumptions to better align with observed habits and decisions.

3.3. Vehicle Automation, the Netherlands

The introduction of full automation raises the possibility of passengers engaging in non-driving tasks during travel, potentially changing the passenger experience and, consequently, the VoTT. The primary objective of the third study is to gain new insights into the impacts of fully automated vehicles on the VoTT specifically for commute trips (de Looff et al., 2018).

A stated preference survey involving 252 respondents in the Netherlands was conducted. Three alternatives were presented: AV-office (designed for work), AV-leisure (for non-working activities), and a conventional car. Attributes included travel time, costs, walking time, company, and activity. Multiple discrete choice models, including multinomial, mixed, and nested logit models, were developed to analyze the survey data. The models were compared through a likelihood ratio test, revealing that the extended mixed logit model, incorporating socio-demographic variables, outperformed other models.

The study reveals that the VoTT for productive use, such as commuting between home and the office in AVs, is lower (6.26€/h) than the VOTT for a conventional car (8.37€/h). Interestingly, the study challenges expectations by revealing that leisure activities in AVs do not reduce the value of travel time as expected. One potential explanation is that people may not prefer to engage in leisure activities while in a vehicle. However, the study acknowledges a possible limitation related to the reliability of stated preference surveys for new technologies. Participants in the survey may have failed to fully capture the benefits of having leisure time in AVs.

4. Stated Preference Survey

To compare and explore the results discussed in the report thus far, we completed a stated preference survey to estimate the value of travel time amongst a small group of participants in Vancouver, BC. We designed two surveys which asked sociodemographic questions as well as scenario-based questions to ascertain the value of travel time for each individual under varying circumstances. These surveys were distributed to friends and family of each team member and thus should not be considered as a representative sample of the travelling population.

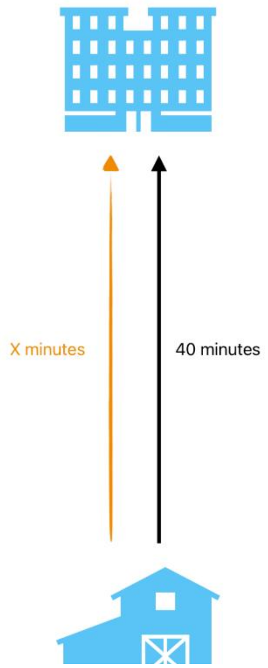

Figure 3: S2 state preference survey. Base commute option is 40 minutes by personal vehicle – how much time should the new option save you?

4.1. Survey Development

As we have established throughout the report, sociodemographic factors can play a critical role in an individual's value of travel time. As such, we included the questions to be able to segment our results and highlight any insights based on the following indicators: age, gender, working status, typical mode of transportation for commuting, and typical length of commute.

We then posed three scenarios to the respondent in which a new transportation mode is established connecting them to their place of work or school with an associated cost. We asked, for them to use it, how much time would this new option need to save them on their commute.

In survey 1 (S1), we simply posed the three new options each at a cost of $2.50. In survey 2 (S2), we added to the scenario that each respondent was to assume they commuted 40 minutes to work by personal vehicle. From this perspective, the same options were presented at a cost of $3.00. Therefore, in S1 the responses would be relative to their own personal commuting habits and in S2 the base commute time and mode for everyone was consistent.

4.2. Respondent Demographics

S1 had 51 total responses with a 65/35 percent split between male and female. A majority of respondents (51%) commute by personal vehicle, while public transit and active transportation represent 35% and 14% respectively. 53% were full-time workers and 35% were students with the remaining spread across part-time, unemployed and retired working statuses. Furthermore, there was a roughly equal split between people who lived within 0-30 minutes and 30-60 minutes of their workplace or school. From Figure 6 (in the appendix), we observe that most young adults (18-30 years of age) commute via public transit, while a large majority of people above the age of 30 opt for a personal vehicle. Furthermore, we can see that students prefer public transit for commuting versus full-time employees who tend to take a personal vehicle.

S2 had 35 total responses with a roughly even representation of male and female respondents as well as a few non-disclosed. Again, we had many personal vehicle commuters, though still a good representation of public transit users. There was an even number of full-time workers and students as well as part-time, unemployed and retired respondents. In S2, we also had some folks who lived further than 60 minutes from their place of work or school. From Figure 7 (in the appendix), we see that most public transit and all active transport users are in the 18-30 age range. We also have a similar trend of students preferring public transit, with full-time employees preferring personal vehicles.

4.3. Results

We notice that the stated travel time savings appear to be normally distributed, however negative values for travel time savings are unintuitive. This type of distribution is well characterized by a gamma probability density, therefore we fit each scenario from S1 and S2 assuming gamma-distributed data. Using a chi-squared goodness of fit test, we find all models agree with the data at a 95% confidence level except for the personal vehicle time savings in S1. We then take the mean value for each distribution as the expected value of time for an individual using that mode. See Figure 4 (and **Error! Reference source not found.** in the appendix) for visualizations of the results.

Table 1: Values of travel time for surveys 1 and 2.

Survey	$\bar{v}_{sov}$ (\$)	$\bar{v}_{transit}$ (\$)	$\bar{v}_{bike}$ (\$)	$\bar{v}$ (\$)
S1	7.71	7.68	7.64	*7.68*
S2	10.05	10.61	9.86	*10.22*

Some interesting trends that emerge from both surveys include increasing VoTT for personal vehicles as age increases and for public transit as distance increases. It is also worth noting that we observe high values of travel time for the new bicycle facility option amongst those who typically use active transportation. This may suggest that active transport users are highly sensitive to small time savings – though we are skeptical of the willingness of people to pay for a bicycle facility in the real world. Stated preference surveys often yield non-intuitive results and we suspect this to be an instance of such.

Finally, we find from S2, which controls for the most external factors, that the VoTT for public transit is highest among the three provided options. Therefore, we propose that time savings on public transit may yield the most cost benefits to travelers.

Figure 4: S1 results.

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Appendix

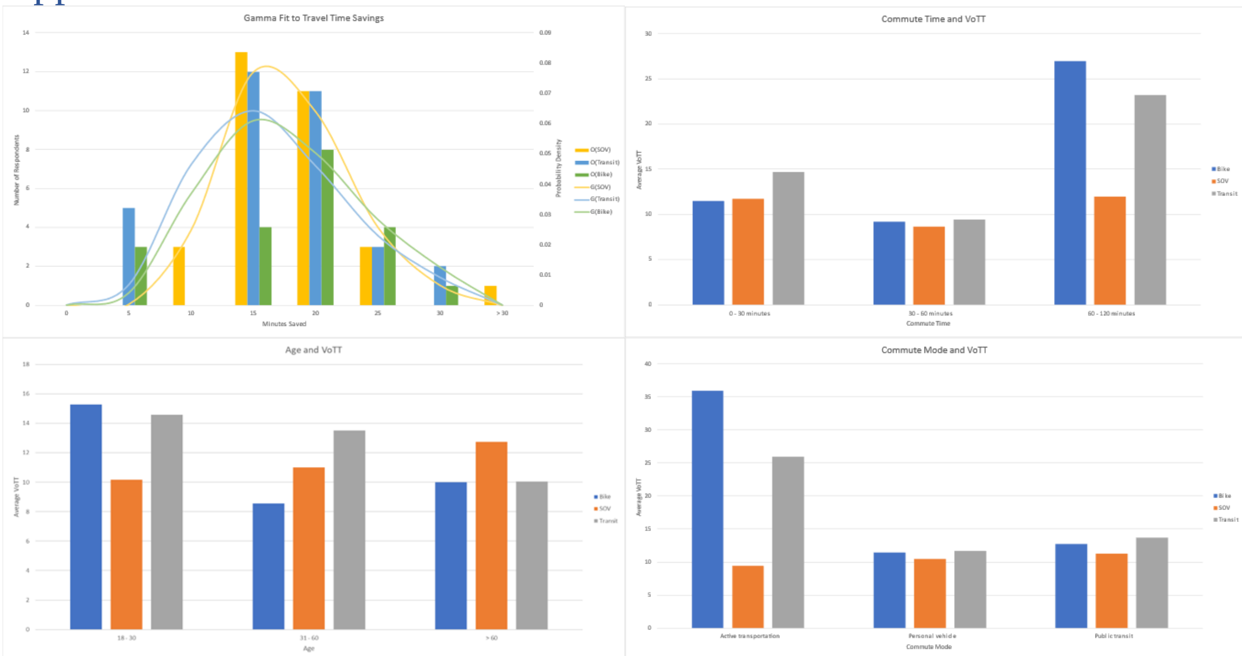

Figure 5: S2 results.

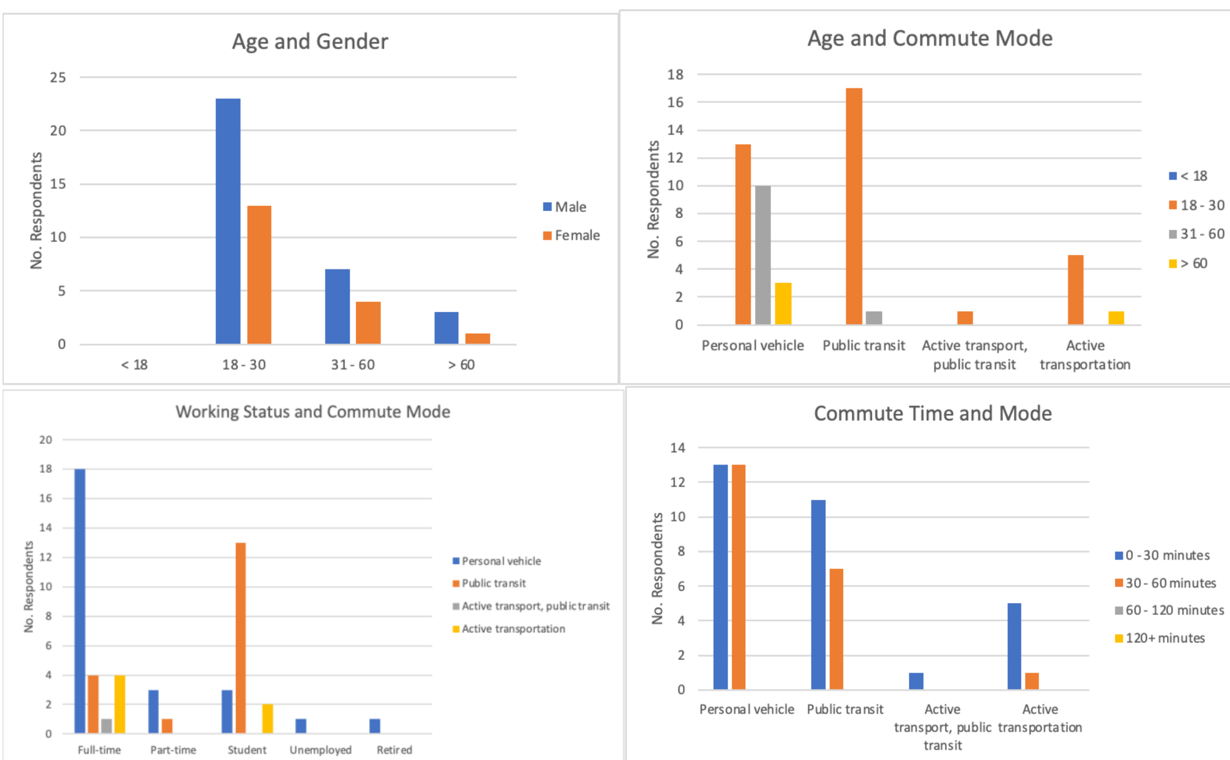

Figure 6: S1 respondent demographics.

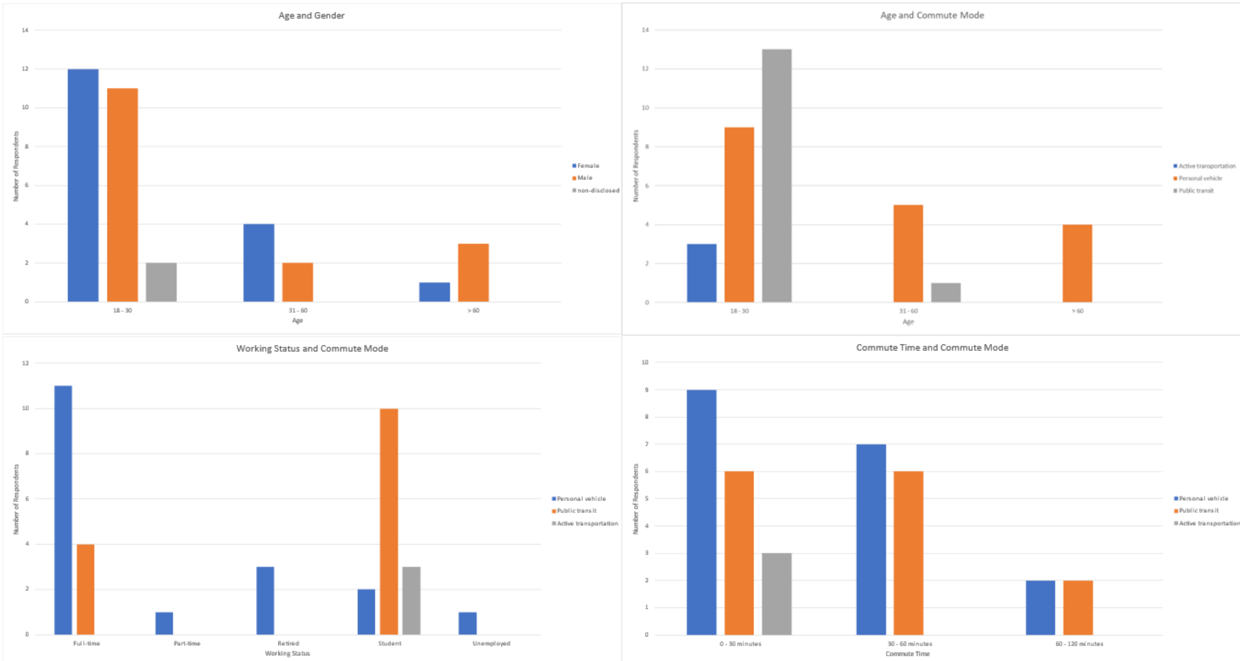

Figure 7: S2 respondent demographics.