

Technical Appendix 6

Integrated Behavioral Modeling in Support of Chapter 6

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INTRODUCTION AND STRUCTURE

This Technical Appendix is structured in two parts. First, a technical description is presented describing the new Integrated Choice Latent Variable Scenario Forecasting Model developed for this TCRP project. Second, a technically oriented description is presented of the Structural Equations Model created for the analysis of preferences and attitudinal factors influencing possible futures for public transportation in North America.

PART ONE: A NEW INTEGRATED SCENARIO FORECASTING MODEL FOR TRANSIT

DEVELOPMENT OF THE INTEGRATED CHOICE LATENT VARIABLE MODEL

Advanced hybrid choice models, also often referred to as Integrated Choice and Latent Variable (ICLV) models were used to analyse the data from the stated choice survey. These models account for the differences across individual respondents in their preferences, both in terms of how they react to the level of service variables such as time and cost, and in their baseline preferences for given modes of transport. The heterogeneity specification in our work used three separate components. First, we sought to explain a substantial share of the heterogeneity by linking it to observed characteristics of the respondents, such as age and education, as well as the trip, such as purpose. Secondly, we allowed for additional random heterogeneity, i.e. differences in preferences across individual respondents that cannot be easily linked to observed characteristics of the respondents. These two types of heterogeneity were allowed for in both the marginal sensitivities to level of service variables (e.g., time and cost) as well as in the baseline mode preferences. Finally, we allowed for further heterogeneity in these modal constants that is linked to attitudinal constructs. These latent attitudes vary both deterministically (e.g., as a function of age) and randomly (i.e., due to unobserved factors) across individuals. At the same time as explaining a share of the heterogeneity in modal preferences across respondents, they are also used to explain the answers that these same respondents give to a set of attitudinal questions.

MODEL SPECIFICATION

Attitudinal constructs

In our model, we have five separate latent attitudes. Let $\alpha_{n,1}$ be the first such latent construct for respondent n . It is defined to have both an observed and a random component, with:

$$\alpha_{n,1} = \gamma_1 z_n + \xi_1$$

where γ_1 is a vector of estimated parameters that explain the impact of respondent characteristics z_n (e.g., age) on the latent attitude, and where ξ_1 is a random error term which follows a standard Normal distribution. The preceding equation is a structural equation for the first latent variable, where one such equation is used for each latent attitude.

Measurement Model

The data used in our analysis contains responses to a large number of attitudinal statements. Let $I_{n,k}$ give the answer that respondent n gives to the k^{th} such question, commonly referred to as an *indicator*. The ICLV structure hypothesises that the answers to these questions are driven by the latent attitudes. If for example α_1 is used to explain the value of $I_{n,k}$, then we would write:

$$I_{n,k} = \delta_k + \beta_{k,1}\alpha_{n,1} + \epsilon_{n,k}$$

In our analysis, we rely on a continuous treatment of the indicators and further centre them on zero, meaning that the estimation of δ_k is no longer required. We make the assumption that the indicators are normally distributed, and estimate the standard deviation of the error term $\epsilon_{n,k}$ as σ_k . The likelihood of the observed value for $I_{n,k}$ is then given by a normal density, say $(I_{n,k})$.

Choice Model

The choice model explains the preferences expressed by respondents between the different modes of transport (car, bus, train, TNC and shared) in the stated choice survey. The choice model explains the deterministic component of utility of a given mode i for respondent n in choice situation t as:

$$V_{i,n,t} = \delta_i + \beta_{n,i}x_{i,n,t} + \tau_i\alpha_n$$

In this expression, δ_i is a mode specific constant (normalised to zero for car), $\beta_{n,i}$ is a vector of coefficients representing the sensitivities to explanatory variables (such as time and cost) of mode i for respondent n and τ_i is a vector of parameters explaining the impact of the five latent attitudes on the utility of mode i (normalised to zero for car).

We allow for both deterministic and random heterogeneity in the mode specific constants (δ) and the marginal utility coefficients (β).

For the mode specific constants, we specify the baseline constants to follow a Normal distribution, estimating a mean and a standard deviation. In addition, we estimate shifts on the means of these constants for a number of person and trip characteristics (e.g. education and purpose).

For the marginal utility coefficients, we specify the coefficients to follow negative Lognormal distributions, respecting the fact that these are all undesirable attributes (e.g. time and cost). We each time estimate the mean and standard deviation of the underlying Normal distributions (a negative Lognormal is a negative exponential of a Normal). We use separate coefficients for work and non-work respondents, while for the different sub-purposes for non-work, we allow for additional shifts in the underlying mean. Finally, we estimate an income elasticity on the cost sensitivity.

MODEL ESTIMATION

Model estimation jointly maximises the likelihood of the observed choices and observed answers to the attitudinal questions for a given respondent. This creates the link between the two parts of the data. Bayesian estimation was used, and the quasi-t values give an indication of the stability of the chains in estimation (in a role similar to classical t-ratios).

RESULTS

Outputs for Measurement Model and Structural Model

We first look at the outputs of the model estimation process for the structural equations and measurement model. This helps us to clarify the role and meaning of the five attitudinal constructs which we use to explain the answers respondents provide to 17 separate attitudinal questions. The grouping used relies on the insights of an earlier factor analysis.

Latent Variable 1: Transit and Sharing Attitude

Our first latent construct is used to explain the answers to five separate attitudinal statements. Below, we show the estimates for the γ parameters (measuring the impact of the latent variable on the indicator), the σ parameters (measuring the variance of the indicators in the sample) and the γ parameters (measuring the role of socio-demographics in explaining the value of the latent attitudes). The γ measure the impact of the latent variable (LV) on the attitudinal statements. The positive signs show that a higher value for this LV means stronger agreement with the attitudinal statement, identifying this LV as a pro-transit and sharing LV. Two socio-demographic characteristics, age and education, were used to explain the value of the LV, where 4-year college and aged 50 to 65 were used as the base for education and age, respectively. We see that lower education makes respondents less pro- transit and sharing (the value for graduate is essentially the same as for 4-year college), while younger respondents are more pro- transit and sharing.

TABLE 1: TRANSIT AND SHARING ATTITUDINAL STATEMENTS

ATTITUDINAL STATEMENT	γ		σ	
	EST	QUASI T	EST	QUASI T
Rather than owning a car, I would prefer to borrow, share, or rent a car just for when I need it.	1.30	120.33	1.21	153.31
I am a person who likes to participate in programs like carshare and bikeshare.	1.19	169.48	1.19	183.81
My family and friends typically use public transportation.	1.17	189.07	1.22	179.19
If they had to make a trip, most people who are important in my life would take public transportation.	1.16	122.70	1.18	157.20
Because of new services helping me make trips, I feel less need to own a car.	1.21	136.04	1.21	164.36

TABLE 2: TRANSIT AND SHARING DEMOGRAPHICS

DEMOGRAPHICS	Γ	
	EST	QUASI T
Low Education	-0.33	-49.31
Some College	-0.19	-42.96
Four-Year College	0.00	base
Graduate	-0.02	-4.63
Aged Under 30	0.79	87.88
Aged 30 to 50	0.36	29.58
Aged 50 to 65	0.00	base
Aged 65 and Over	-0.45	-29.56

Latent Variable 2: Privacy and Safety Attitude

Our second latent construct is used to explain the answers to five separate attitudinal statements. The positive signs of the γ show that a higher value for this LV means stronger agreement with the attitudinal statement, identifying this LV as a concern for privacy and safety LV. We see that the 30-50 age group and the under 30 age group (though less so) are more concerned about privacy and safety, while this is lower for the older age groups.

TABLE 3: PRIVACY AND SAFETY ATTITUDINAL STATEMENTS

ATTITUDINAL STATEMENT	Z		Σ	
	EST	QUASI T	EST	QUASI T
I worry about personal safety/disturbing behavior on a bus or train.	1.35	183.40	0.99	289.46
It would be easier for me to use public transportation more if I were not so concerned about traveling with people I do not know.	1.20	181.36	1.29	105.26
The idea of being on a train or a bus with people I do not know is uncomfortable.	1.37	227.30	1.12	94.52
It might be unsafe to make a trip by public transportation.	1.34	301.44	0.99	159.13
I worry about crime or other disturbing behavior on public forms of transportation.	1.30	101.40	0.99	138.24

TABLE 4: PRIVACY AND SAFETY DEMOGRAPHICS

DEMOGRAPHICS	Γ	
	EST	QUASI T
Low Education	0.29	55.66
Some College	0.12	11.24
Four-Year College	0.00	base
Graduate	-0.26	-11.95
Aged Under 30	0.11	7.29
Aged 30 to 50	0.25	55.88
Aged 50 to 65	0.00	base
Aged 65 and Over	-0.26	-17.11

Latent Variable 3: Environment Attitude

Our third latent construct is used to explain the answers to three separate attitudinal statements. The positive signs of the γ show that a higher value for this LV means stronger agreement with the attitudinal statement, identifying this LV as a pro-environment LV. We see that younger and more educated respondents are more concerned about the environment than older and less educated respondents.

TABLE 5: ENVIRONMENT ATTITUDINAL STATEMENTS

ATTITUDINAL STATEMENT	Z		Σ	
	EST	QUASI T	EST	QUASI T
Protecting the environment should be given top priority, even if it means an increase in taxes.	1.44	148.29	1.03	174.41
I think I should be more active in doing my part to protect the environment.	1.10	165.54	1.02	120.98
I am concerned about global warming and/or climate change.	1.52	201.84	0.99	267.93

TABLE 6: ENVIRONMENT DEMOGRAPHICS

DEMOGRAPHICS	Γ	
	EST	QUASI T
Low Education	-0.25	-16.37
Some College	-0.11	-16.75
Four-Year College	0.00	base
Graduate	0.13	12.15
Aged Under 30	0.25	41.21
Aged 30 to 50	0.05	9.72
Aged 50 to 65	0.00	base
Aged 65 and Over	-0.10	-8.02

Latent Variable 4: Technology Attitude

Our fourth latent construct is used to explain the answers to two separate attitudinal statements. The positive signs of the γ show that a higher value for this LV means stronger agreement with the attitudinal statement, identifying this LV as a pro-tech LV. We see that younger and more educated respondents are more pro-tech than older and less educated respondents.

TABLE 7: TECHNOLOGY ATTITUDINAL STATEMENTS

ATTITUDINAL STATEMENT	Z		Σ	
	EST	QUASI T	EST	QUASI T
Being able to freely perform tasks while traveling, including using a laptop, tablet, or smartphone is important to me.	1.27	155.42	1.18	194.72
It is important for me to have access to communication technology throughout the day.	0.92	113.87	1.29	155.74

TABLE 8: TECHNOLOGY DEMOGRAPHICS

DEMOGRAPHICS	Γ	
	EST	QUASI T
Low Education	-0.23	-31.00
Some College	-0.14	-6.87
Four-Year College	0.00	base
Graduate	0.00	-3.17
Aged Under 30	0.61	77.09
Aged 30 to 50	0.30	44.23
Aged 50 to 65	0.00	base
Aged 65 and Over	-0.45	-26.70

Latent Variable 5: Transit Attitude

Our fifth and final latent construct is used to explain the answers to two separate attitudinal statements. The positive signs of the γ show that a higher value for this LV means stronger agreement with the attitudinal statement, identifying this LV as a pro-transit LV. We see that younger and more educated respondents are more pro-transit than older and less educated respondents (where the difference between the two highest age groups is negligible).

TABLE 9: TRANSIT ATTITUDINAL STATEMENTS

ATTITUDINAL STATEMENT	Z		Σ	
	EST	QUASI T	EST	QUASI T
Compared to driving, I would be less tired and stressed if I took the trip by transit.	1.28	147.04	0.99	156.36
Riding public transportation is less stressful than driving on congested highways.	1.36	81.51	0.87	166.98

TABLE 10: TRANSIT DEMOGRAPHICS

DEMOGRAPHICS	Γ	
	EST	QUASI T
Low Education	-0.26	-47.82
Some College	-0.03	-32.68
Four-Year College	0.00	base
Graduate	0.12	11.88
Aged Under 30	0.14	18.46
Aged 30 to 50	0.05	1.48
Aged 50 to 65	0.00	base
Aged 65 and Over	0.02	7.21

Impact of Latent Variables on Utilities in Choice Model

We next look at the impact of the five LVs on the mode specific utilities in the choice model. Each time, the τ for car is normalised to zero, meaning that we see the impact on the other four modes relative to car.

For LV1 (transit and sharing attitude), we see that a higher value for this latent attitude increases the utility (and hence probability) for all non-car modes, where this is somewhat surprisingly strongest for TNC, with relatively even effect on the three other non-car modes.

For LV2 (privacy and safety attitude), we see a negative impact on all non-car modes except for TNC, where we notice a small positive impact on utility as a result of a higher value for the LV. The negative impact is strongest for train.

For LV3 (environment attitude), we observe a positive impact on all non-car modes, where, in line with expectations, this is strongest for the two transit modes, and slightly stronger for shared rides than for TNC.

For LV4 (technology attitude), there is a positive impact on all non-car modes, which is weaker for the two transit modes, especially bus.

Finally, for LV5 (transit attitude), we observe a strong positive impact on the two transit modes compared to car, with a weaker impact for shared rides, while the impact on TNC is very small.

Table 11: LATENT VARIABLES

	LV1		LV2		LV3		LV4		LV5	
	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T
τ_{bus}	0.65	87.26	-0.45	-52.24	0.41	22.43	0.14	0.08	0.62	114.80
τ_{train}	0.61	50.92	-0.74	-145.76	0.33	17.76	0.23	12.92	0.61	88.93
τ_{uber}	0.89	97.14	0.06	12.61	0.12	20.02	0.36	20.85	0.08	7.90
τ_{shared}	0.61	40.46	-0.35	-82.86	0.17	45.94	0.43	38.27	0.29	46.09

Other Deterministic and Random Heterogeneity in Mode Specific Constants

We next look at the baseline mode constants. We observe a positive mean for train, meaning that all else being equal, train is preferred to car (the base). The means for the other modes, especially TNC, are negative, showing all else being equal, a lower utility than for car. We see strong random heterogeneity for all four modal preferences, along with a number of significant shifts related to trip (purpose and area) as well as respondent (education and age) characteristics.

TABLE 12: MEAN MODE CONSTANTS

	BUS		TRAIN		TNC		SHARED	
	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T
base mean	-0.15	-252.78	0.12	134.83	-1.29	-3.23	-0.35	-103.19
base standard deviation	1.02	138.09	1.43	89.81	2.10	279.36	1.29	276.28
shift in mean for school trips (vs work)	-0.16	-9.39	0.07	6.83	-0.22	-18.32	-0.02	-39.85
shift in mean for shopping trips (vs work)	-0.09	-13.14	-0.23	-7.28	-0.35	-13.57	-0.24	-17.54
shift in mean for entertainment trips (vs work)	0.14	10.72	0.32	20.56	0.29	100.14	0.16	26.24
shift in mean for other non-work trips (vs work)	-0.02	-106.31	0.18	40.22	-0.42	-28.65	0.02	34.72
shift in mean for NE area trips	0.13	38.15	-0.14	-13.75	-0.03	-42.40	-0.07	-12.64
shift in mean for NC area trips	-0.14	-47.68	0.10	38.62	-0.41	-3.18	-0.47	-48.15
shift in mean for NW area trips	0.27	40.79	0.44	126.80	-0.33	-34.98	-0.32	-14.92
shift in mean for SW area trips	-0.15	-12.52	-0.18	-4.96	0.07	3.13	-0.16	-38.42
shift in mean for heavy rail equipped city trips	-0.26	-7.22	-0.10	-32.03	-0.41	-4.24	-0.40	-33.02
shift in mean for low education respondents (vs 4 year college)	0.28	42.67	-0.18	-8.12	-0.18	-32.12	-0.42	-8.19
shift in mean for respondents with some college (vs 4 year college)	-0.09	-30.62	-0.08	-10.34	-0.56	-22.66	-0.43	-26.48
shift in mean for respondents with graduate degree (vs 4 year college)	0.26	111.92	0.30	38.33	-0.13	-1.68	0.07	17.92
shift in mean for respondents aged under 30 (vs 50-65)	0.26	59.17	0.17	45.25	-0.45	-96.42	-0.21	-5.32
shift in mean for respondents aged 30-50 (vs 50-65)	-0.16	-40.47	-0.20	-28.65	-0.45	-8.08	-0.37	-14.12
shift in mean for respondents aged 65 and over (vs 50-65)	-0.16	-2.15	-0.52	-19.42	-0.18	-64.94	-0.25	-1.98

Estimates Relating to Explanatory Variables

We finally look at the parameters explaining the sensitivities to the explanatory variables, namely cost, access time, in vehicle time and waiting time, as well as headway, transfers and the number of extra passengers for shared rides.

These sensitivities were all specified to follow negative Lognormal distributions, as discussed earlier, with separate coefficients for work and non-work trips and different means for different non-work trips. A lower mean parameter for the underlying Normal means a less negative coefficient after exponentiation. We see significant heterogeneity (standard deviations) for all coefficients and for both work and non-work, along with some shifts between non-work purposes. Finally, we see a strong income elasticity, showing that for a 10% increase in income, we see a 4.6% reduction in cost sensitivity.

TABLE 13: EXPLANATORY VARIABLES

	ACCESS TIME		COST		EXTRA PASSENGERS		HEADWAY		TRANSFERS		TRAVEL TIME		WAITING TIME	
	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T	EST	QUASI T
underlying Normal mean for non-work	-2.19	-383.20	-2.08	-108.18	-2.46	-304.50	-4.81	-657.99	-2.06	-213.74	-3.65	-616.10	-2.32	-222.61
shift for entertainment trips	0.00	0.53	-0.21	-37.77	-0.09	-57.80	0.17	38.90	-0.12	-26.99	0.10	51.68	-0.08	-75.66
shift for school trips	-0.26	-17.99	0.40	47.39	-0.05	-15.79	-0.25	-2.61	0.07	54.63	0.11	34.74	-0.29	-11.86
shift for other nonwork trips	0.28	19.99	0.35	2.47	-0.14	-1.19	-0.21	-23.12	0.38	93.27	-0.03	-0.77	0.32	3.31
underlying Normal std dev for non-work	1.62	249.73	1.65	89.92	0.57	98.27	1.58	266.10	2.34	322.68	1.00	139.59	2.24	143.28
underlying Normal mean for work	-2.29	-203.95	-1.77	-121.75	-2.10	-442.53	-4.50	-597.85	-1.90	-341.94	-3.36	-588.90	-2.27	-346.42
underlying Normal std dev for work	1.46	380.51	1.77	124.27	0.94	104.02	1.32	244.73	2.01	566.23	0.86	63.93	1.58	171.87
elasticity in relation to income			-0.46	-17.77										

Implied Monetary Valuations

While not a core focus of this study, we can use the results from the model estimation to compute monetary valuations for different journey components. We report median valuations. Access time and waiting time are valued substantially more highly than in vehicle time, while headway is valued less highly, possibly due to high frequency of urban transit making headway less important. Somewhat surprisingly, access time and waiting time are valued more highly for non-work than for work, while the opposite is the case for in vehicle time. However, it should be noted that here, work is commuting rather than business travel. Similarly, these valuations incorporate an income effect, and the average income for respondents on entertainment trips was almost as high as that for respondents on work trips.

TABLE 14: MEDIAN MONETARY VALUATIONS

	ALL	WORK	NONWORK	SCHOOL	SHOPPING	ENTERTAINMENT	OTHER
reduction of in vehicle time (\$/hr)	11.05	12.01	10.76	7.24	11.26	16.04	7.53
reduction of access time (\$/hr)	44.19	34.70	48.23	20.88	48.29	63.89	44.45
reduction of headway (\$/hr)	3.36	3.78	3.22	1.46	3.50	5.57	1.95
reduction of waiting time (\$/hr)	40.29	35.15	42.60	17.55	43.21	52.41	41.41
reduction by 1 transfer (\$)	0.91	0.85	0.93	0.57	0.92	1.07	0.94
reduction by 1 extra passenger (\$)	0.57	0.69	0.55	0.33	0.61	0.72	0.37

Role of Attitudinal Constructs

In line with best practice, our model specification allows for deterministic and random heterogeneity that is independent of the attitudinal constructs so as to avoid erroneously identifying attitudes as the source for all the heterogeneity. It is then possible to identify what part of the heterogeneity can be linked to the attitudinal constructs.

We first look at the random component of heterogeneity, i.e. that which cannot be explained on the basis of socio-demographic characteristics. We see first that the total variance for each of the four mode specific constants (car being normalised to zero as the base) is large compared to the mean values for the constants reported earlier, reflecting the high level of heterogeneity in mode

preferences across individuals. For bus and train, the split between pure random heterogeneity and random heterogeneity which can be linked to the underlying attitudes is relatively even (54.7% for attitudes for bus, and 41.71% for train). We also modelled both individual rides provided by the Transportation Network Companies (e.g. the standard services from Uber, Lyft etc.), which we label as a “TNC, and similar services with multiple parties in given trip-- here labelled “shared.” For TNC and shared services, only a smaller share of the random heterogeneity can be linked to the attitudes. This is however largely a result of the fact that the pure random heterogeneity is much higher for TNC. Furthermore, we see the pro-environment and pro-tech LVs only account for a very small share of the heterogeneity.

TABLE 15: EFFECT OF ATTITUDES

	TOTAL VARIANCE	SHARE OF PURE RANDOM VARIANCE	SHARING LV EFFECT	SAFETY LV EFFECT	ENV LV EFFECT	TECH LV EFFECT	TRANSIT LV EFFECT	COMBINED SHARE OF VARIANCE DUE TO LV
bus	2.20	48.20%	19.45%	9.04%	7.76%	0.85%	17.60%	54.70%
train	3.49	58.85%	10.81%	15.56%	3.16%	1.57%	10.61%	41.71%
TNC	5.26	82.99%	15.05%	0.07%	0.25%	2.52%	0.11%	18.00%
shared	2.45	67.75%	15.42%	5.09%	1.22%	7.48%	3.49%	32.70%

Further insights can be gained by looking at the components of the ASC variance that can be attributed to the LVs. Here, we see differences across modes and LVs, reflecting that some LVs matter more some modes than for others.

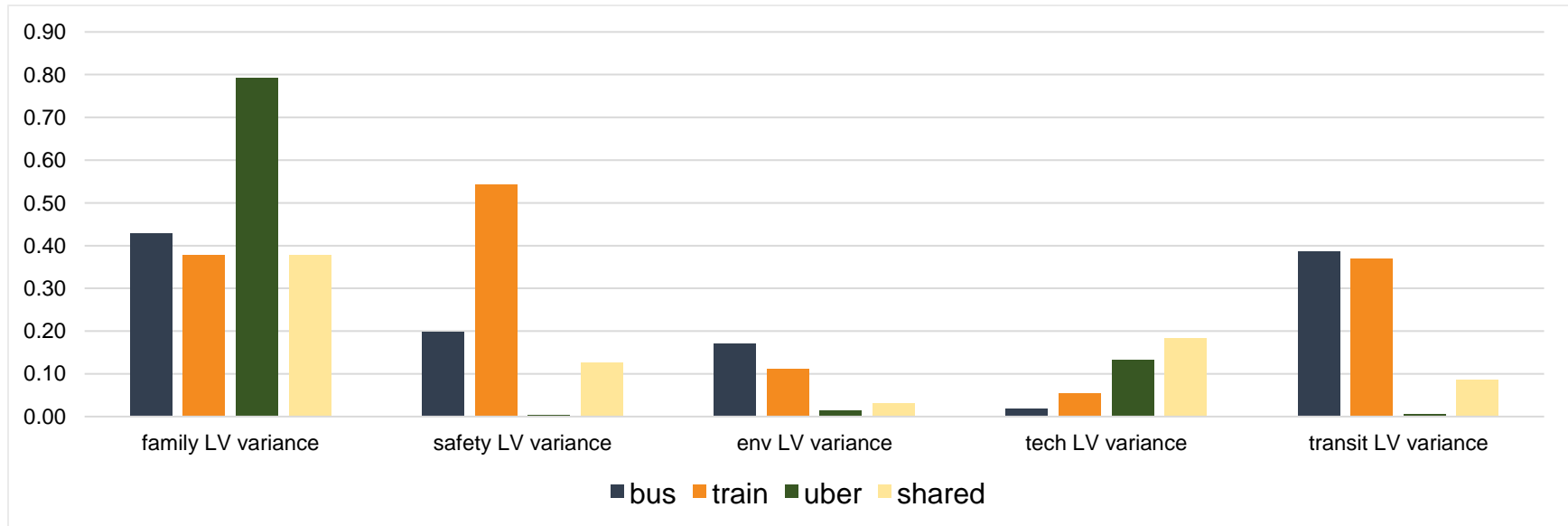


FIGURE 1. COMPONENTS OF ASC VARIANCE ATTRIBUTED TO LATENT VARIABLES

We can similarly see the impact of socio-demographic characteristics (education and age) on the modal constants, both directly and through the latent attitudes. What is important to note here is that each socio-demographic characteristic has an impact through each of the five latent variables, and in some cases these have opposite signs and thus cancel each other out. However, a number of interesting conclusions can be reached, which are most clearly visible from the plot comparing direct effects and impacts through the latent variables. First, we see that for 7 out of the 24 cases, the sign of the impact of the socio-demographic variable differs between the direct effect and the impact through the latent variable. Secondly, we see that on average, the impact through the latent variables is substantially larger than the direct impact, on average the relative (absolute) magnitude is 1.88. Thirdly, it is interesting to look at the pattern across the levels of a socio-demographic characteristic. Here, we see a clear monotonic trend for 7 out of the 8 mode-covariate combinations (e.g. for bus and education, there is clear increase across the four categories), where the only exception is for education and TNC, where the highest level of education is marginally negative compared to the base level of 4 year college. On the other hand, when looking at the direct effects, we see a monotonic trend only for education and train, and (ignoring the small difference between the two lowest levels) for education and shared services.

Overall, these two findings (size of impact and monotonic trend) show that the recovery of socio-demographic impacts is more successful through the latent attitudes than through direct impact, justifying the additional model complexity.

TABLE 16: EFFECT OF ATTITUDES BY DEMOGRAPHICS

	SOCIO	MODE	DIRECT EFFECT	SHARING LV EFFECT	SAFETY LV EFFECT	ENV LV EFFECT	TECH LV EFFECT	TRANSIT LV EFFECT	COMBINED LV EFFECT
Education Impacts	Low education	bus	0.28	-0.22	-0.13	-0.10	-0.03	-0.16	-0.65
	Some college		-0.09	-0.12	-0.05	-0.04	-0.02	-0.02	-0.26
	Graduate		0.26	-0.01	0.11	0.05	0.00	0.08	0.23
	Low education	train	-0.18	-0.20	-0.22	-0.08	-0.05	-0.16	-0.72
	Some college		-0.08	-0.12	-0.09	-0.04	-0.03	-0.02	-0.29
	Graduate		0.30	-0.01	0.19	0.04	0.00	0.07	0.29
	Low education	TNC	-0.18	-0.30	0.02	-0.03	-0.08	-0.02	-0.41
	Some college		-0.56	-0.17	0.01	-0.01	-0.05	0.00	-0.23
	Graduate		-0.13	-0.02	-0.02	0.01	0.00	0.01	-0.01
	Low education	shared	-0.42	-0.20	-0.10	-0.04	-0.10	-0.08	-0.53
	Some college		-0.43	-0.12	-0.04	-0.02	-0.06	-0.01	-0.25
	Graduate		0.07	-0.01	0.09	0.02	0.00	0.04	0.13
Age Impacts	Under 30	bus	0.26	0.52	-0.05	0.10	0.08	0.09	0.74
	30-50		-0.16	0.23	-0.11	0.02	0.04	0.03	0.22
	65 and over		-0.16	-0.29	0.11	-0.04	-0.06	0.01	-0.27
	Under 30	train	0.17	0.49	-0.08	0.08	0.14	0.09	0.72
	30-50		-0.20	0.22	-0.18	0.02	0.07	0.03	0.15
	65 and over		-0.52	-0.27	0.19	-0.03	-0.11	0.01	-0.21
	Under 30	TNC	-0.45	0.71	0.01	0.03	0.22	0.01	0.97
	30-50		-0.45	0.32	0.01	0.01	0.11	0.00	0.45
	65 and over		-0.18	-0.40	-0.02	-0.01	-0.16	0.00	-0.58
	Under 30	shared	-0.21	0.49	-0.04	0.04	0.26	0.04	0.80
	30-50		-0.37	0.22	-0.09	0.01	0.13	0.01	0.28
	65 and over		-0.25	-0.27	0.09	-0.02	-0.19	0.00	-0.39

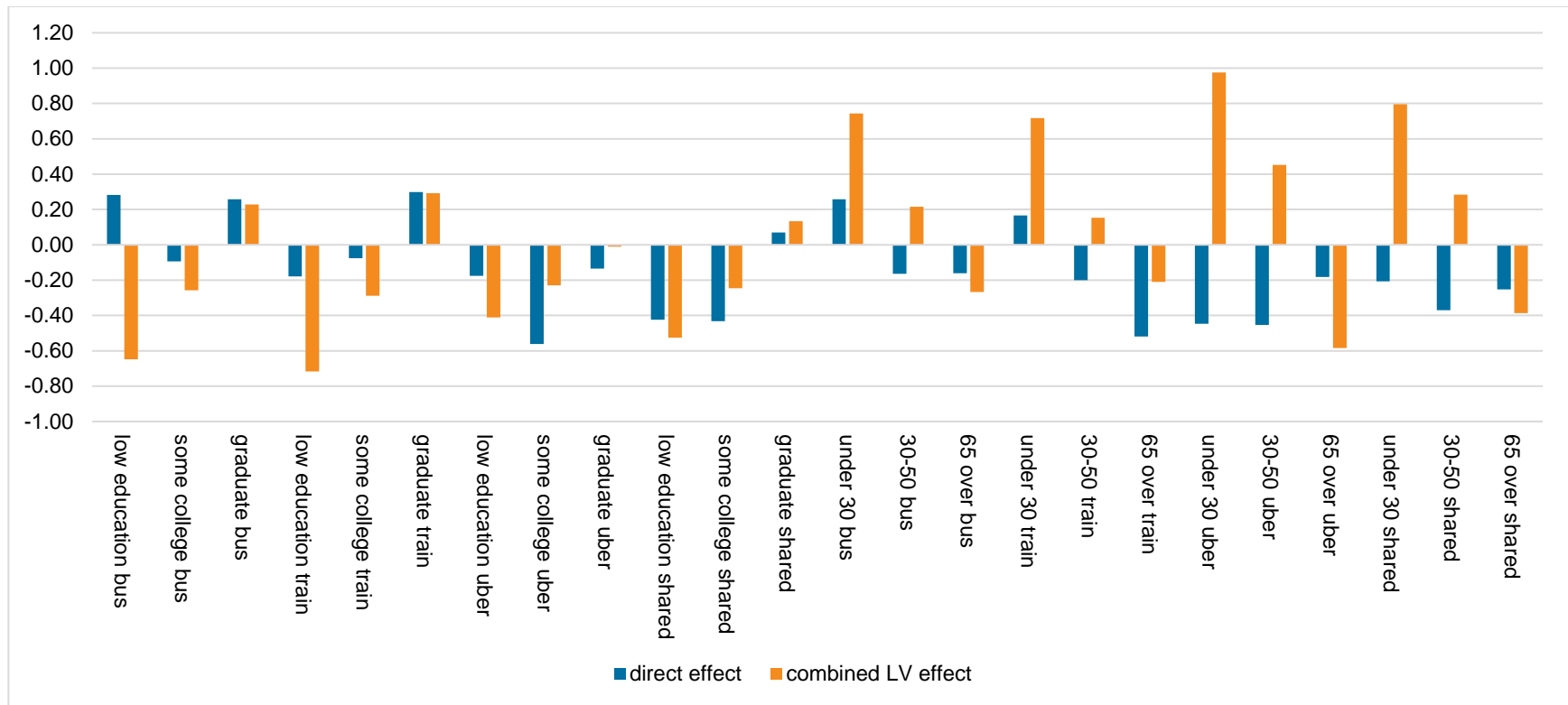


FIGURE 2: DIRECT EFFECTS VS EFFECTS THROUGH LATENT VARIABLES

PART TWO: THE PROJECT STRUCTURAL EQUATIONS MODEL

Chapter 6 of the Final Report includes a summary description of a new SEM model to better understand the relationships between and among factors in the explanation of transit use. In the interests of clarity and brevity, not all the technical documentation of the model was presented in the body of the report. That technical material is presented here as Part Two of Technical Appendix 6.

MODELING FOR VALUES, ATTITUDES, AND PREFERENCES

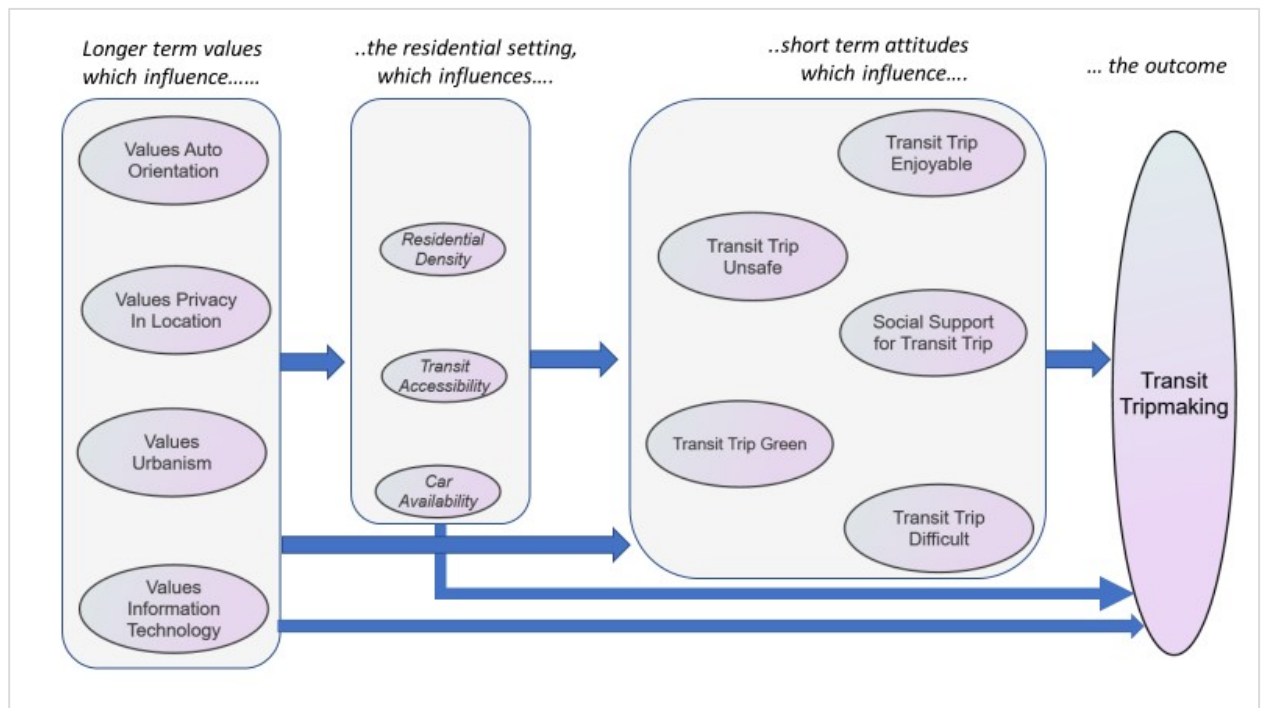


FIGURE 3. CONCEPTUAL DIAGRAM OF THE STRUCTURAL EQUATION MODEL DEVELOPED TO OPERATIONALIZE THE ANALYTICAL FRAMEWORK, ILLUSTRATING BOTH DIRECT AND INDIRECT EFFECTS OF KEY FACTORS

ELEMENTS OF THE MODEL

The 2016 TCRP Model has four major component parts, as shown in Figure 3.

- On the leftmost side of the diagram, four longer term values have been defined which are hypothesized to cast influence on the next three component parts, both directly and through intervening factors.
- Next, the residential setting of the participant is examined in terms of density, design, accessibility, and car ownership. These indices of residential setting are

hypothesized to influence transit use directly, and indirectly through shorter term attitudes, which in turn influence propensity to use transit.

- Five latent variables have been developed representing shorter term attitudes with direct impact, including four concerning the evaluation of the transit trip, and one representing perceived normative influence and peer influence.
- A latent variable representing the outcome factor has been developed.

Latent factors concerning longer term values and preferences

Using the application of factor analysis and the published literature in this area, four latent factors were developed to represent factors presumably representing preferences on issues with a longer-term time frame than those concerning the evaluation of a transit trip and its attributes (Figure 4). (See, for example, NCRRP Report #4, National Cooperative Rail Research Program, Transportation Research Board, Washington DC, 2016.) Each of the latent factors were created using empirically observed variables, in this case with three observed variables supporting each of the four latent factors.

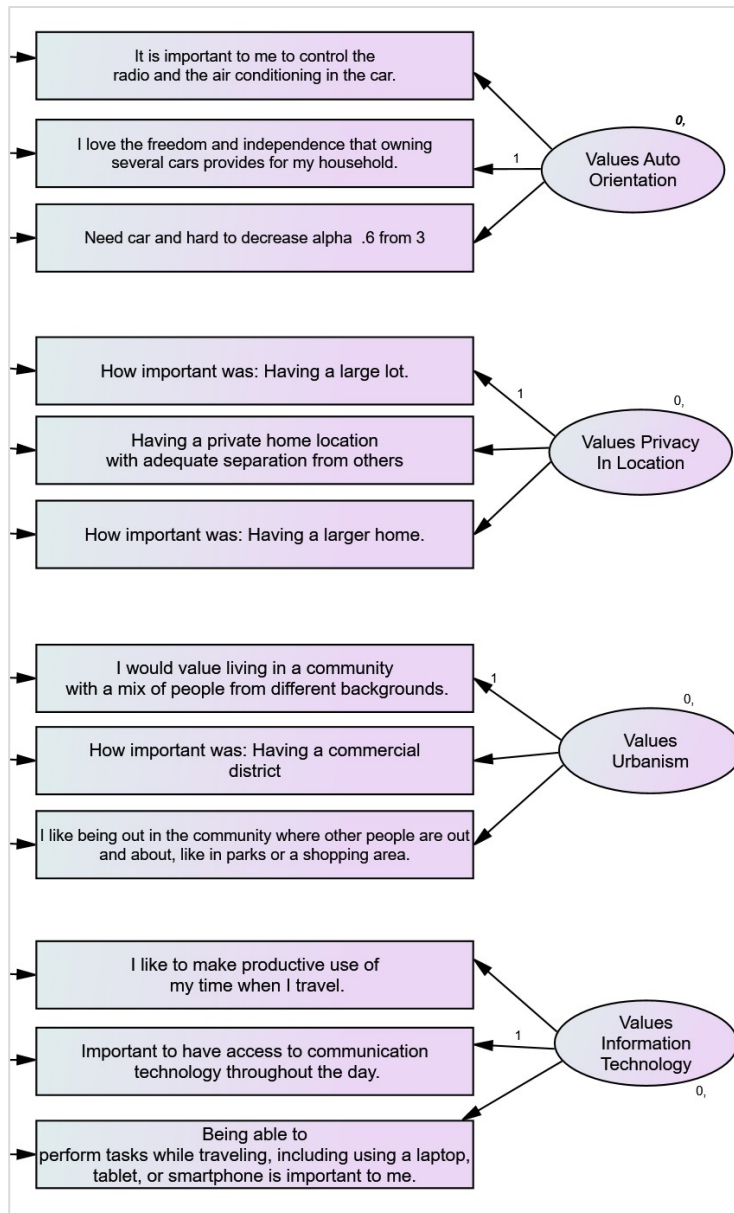


FIGURE 4. RELATIONSHIP OF OBSERVED VARIABLES (RECTANGLES) TO LATENT FACTORS (OVALS) FOR LONGER TERM VALUES AND PREFERENCES

A latent auto factor was created representing hedonic considerations (e.g., love for the auto); an observed variable representing the desire to control one's own space in the car; and a composite index representing three questions of need for, and difficulty of living without, the car: (the three questions combined well, resulting in a Cronbach's alpha of .6, which is an acceptable level of reliability).

A latent factor representing preference for the "suburban-spaciousness" characteristics of home size, with a large lot, with spacing to ensure privacy was created using three observed survey questions.

A latent factor representing preferences for the attributes of ‘valuing urbanism’ in neighborhoods was created with the use of three questions about the importance of walking to a commercial district, being outside with people, and having a mix of people from different backgrounds.

Finally, the importance of being productive, and staying connected all day was explored in one latent factor based on the three related survey responses.

Characteristics of the residential setting

The final model includes three latent factors Figure 5 to reflect the characteristics of one’s residential setting. A latent factor to reflect density was created, as was a latent factor reflecting car availability.

A third latent factor, Design, and Accessibility, includes the density of intersections, an observed variable representing overall transit accessibility, and a variable based on the ratio of the transit accessibility factor divided by the auto-accessibility factor, both from the EPA’s Smart Land Database project.

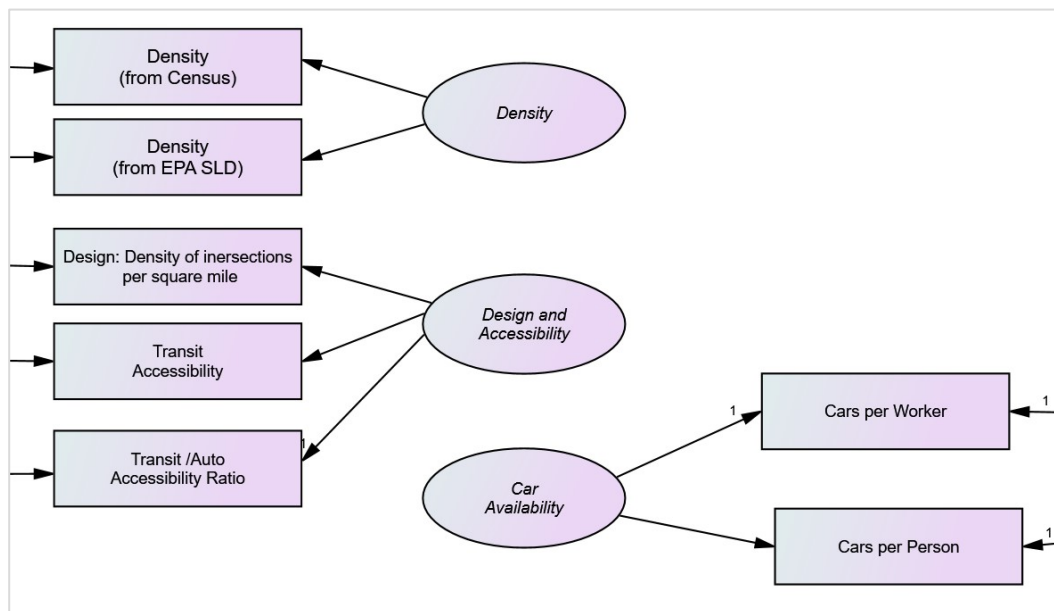


FIGURE 5. RELATIONSHIP OF OBSERVED VARIABLES (RECTANGLES) TO LATENT FACTORS (OVALS) TO DESCRIBE ATTRIBUTES OF THE RESIDENTIAL SETTING POTENTIALLY INFLUENCING TRANSIT USE

Short term attitudes and preferences

The model contains five latent factors Figure 6 representing shorter term attitudes towards the transit trip. A latent factor was created to represent concerns about disturbing or unruly behavior and the general need for privacy in making the trip.

A second latent factor was created to reflect the view that the making the trip by transit could improve the environment, and that considerations about such environmental impact could influence their choice of mode.

In addition, three more factors were created. One represents the concept that this behavior is in the interest of the participant, or even a pleasurable experience. This parallels work in this area done to operationalize the theory of planned behavior, often using the term “Attitude Towards the Behavior.” This Latent Factor was created using the observed variables that the transit trip might be more pleasant, less stressful, more efficient, and provide the opportunity to meet people.

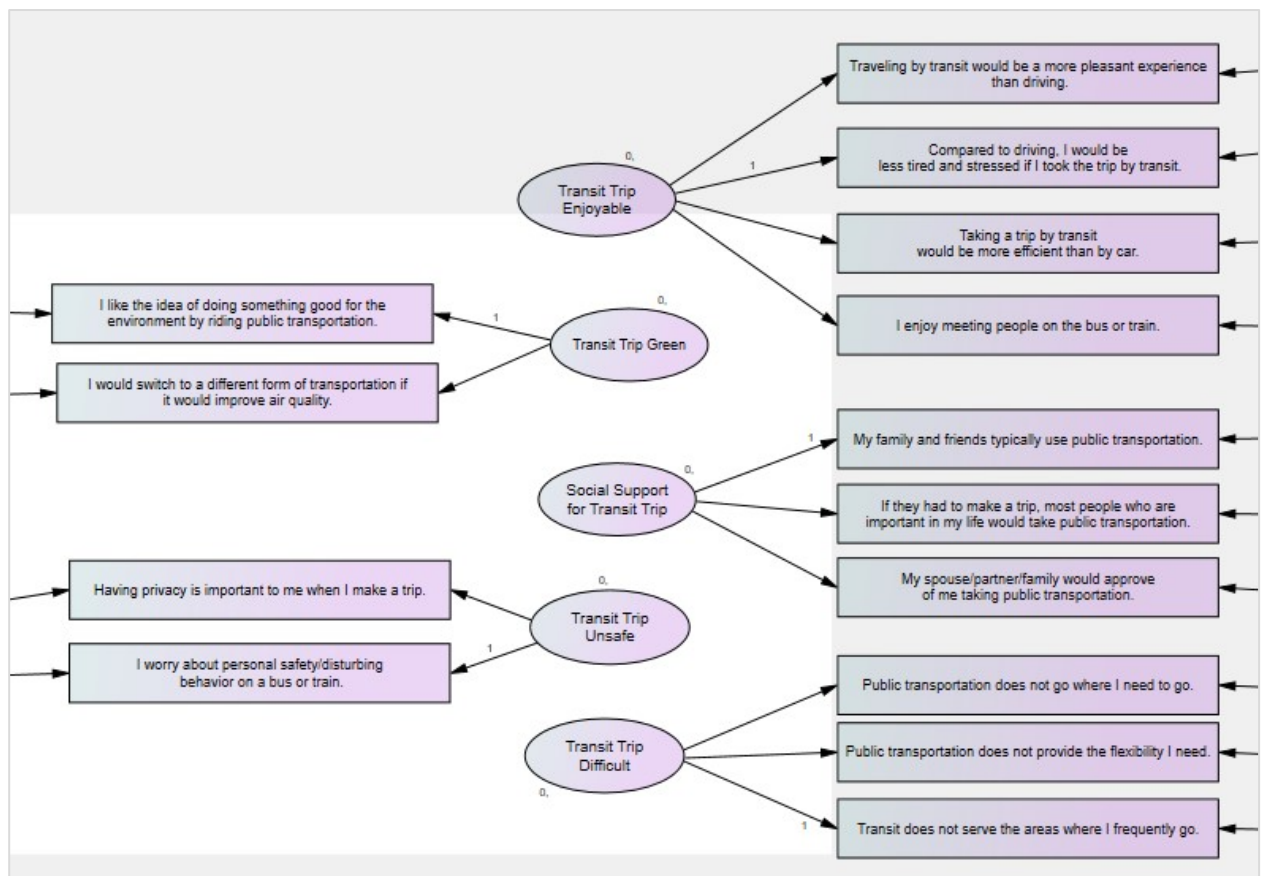


FIGURE 6. SHORTER TERM ATTITUDES TOWARDS THE TRANSIT TRIP WERE EXPLORED WITH THE CREATION OF FIVE LATENT VARIABLES (OVALS) REFLECTING THE CONTENT OF 14 OBSERVED VARIABLES, (RECTANGLES)

The next latent factor was created to help explore the concept of normative factors, in which the view of the participant is influenced by her/his interpretation of how others would view her/his use of public transportation, and how significant others would act themselves. In the Theory of Planned Behavior, this factor is called Subjective Norm, (sometimes, Social Norm).

The final latent factor was created to reflect the concept that taking public transportation may be difficult, or, even impossible – simply something that one would not have the control to do. In the Theory of Planned Behavior, the concept that one may not be able to carry out the behavior is called “Perceived Behavioral Control.” For this latent factor, three observed variables were used which reflect the difficulty, or impossibility of choosing transit.

THE OUTCOME FACTOR

The use of public transportation was operationalized in a latent factor which explores the same pattern in several, very similar ways. As shown in Figure 7, slightly differing aspects of transit use are utilized for number of days using transit, number of days using it for work, use for nonwork and use of transit at all in the last month.

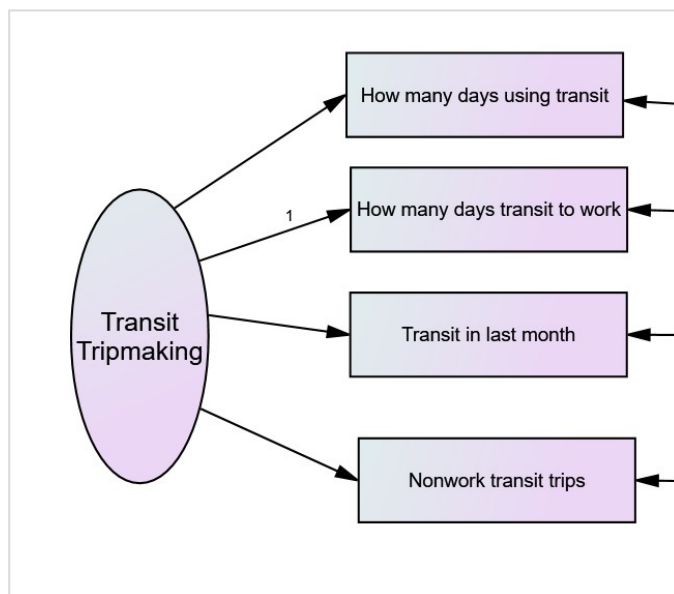


FIGURE 7. A COMPOSITE LATENT FACTOR (OVAL) TO REPRESENT OVERALL TRANSIT USE WAS CREATED WITH THE USE OF FOUR OBSERVED VARIABLES (RECTANGLES)

THE STRUCTURAL REGRESSION PORTION OF THE FULL MODEL

The above paragraphs have described the component elements used in the creation of the 12 latent factors. The interaction between and among those latent factors are shown in the structural regression portion of the full model.

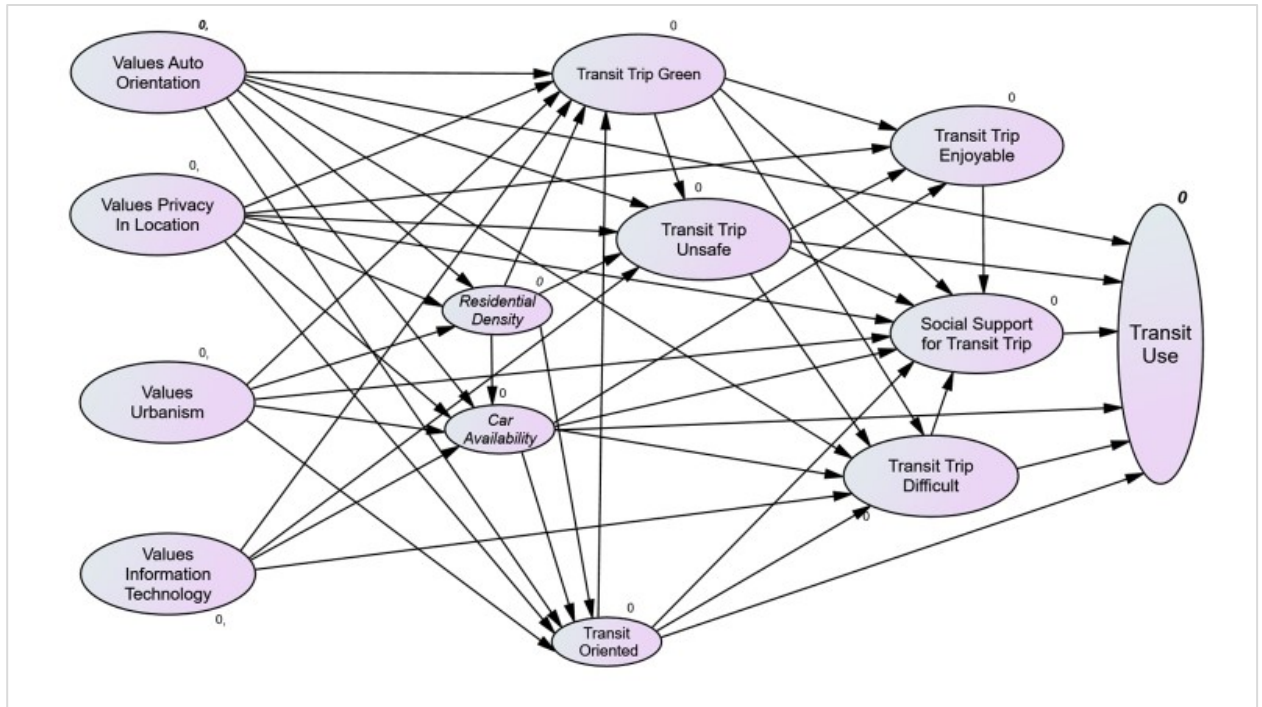


FIGURE 8. THE STRUCTURAL REGRESSION PORTION OF THE FULL SEM MODEL

The structural regression portion of the model includes the calculated values for the arrows displayed in Figure 8. Both the unstandardized and standardized coefficients for those values are presented here as Table 17.

TABLE 17: UNSTANDARDIZED AND STANDARDIZED COEFFICIENTS IN THE STRUCTURAL REGRESSION MODEL, WITH STANDARD ERROR AND P VALUES

		Unstandardized			P	Standardized
			Estimate	S.E.		Estimate
Value Auto	--->	Density	-0.11	0.01	***	-0.22
Value Urban	--->	Density	0.13	0.01	***	0.21
Value Privacy	--->	Density	-0.03	0.01	***	-0.08
Value Urban	--->	Car Available	-0.14	0.03	***	-0.23
Value Auto	--->	Car Available	0.12	0.02	***	0.23
Value Privacy	--->	Car Available	-0.05	0.01	***	-0.14
Density	--->	Car Available	-0.14	0.02	***	-0.14
Productivity/ ICT	--->	Car Available	-0.1	0.02	***	-0.18
Car Available	--->	Accessibility	-0.38	0.08	***	-0.13
Value Urban	--->	Accessibility	0.32	0.04	***	0.18
Value Privacy	--->	Accessibility	-0.07	0.02	0.001	-0.07
Value Auto	--->	Accessibility	-0.17	0.04	***	-0.11
Density	--->	Accessibility	1.6	0.05	***	0.53
Value Privacy	--->	Trip Green	0.06	0.02	0.001	0.07
Value Urban	--->	Trip Green	0.99	0.06	***	0.62
Productivity/ ICT	--->	Trip Green	0.33	0.05	***	0.23
Value Auto	--->	Trip Green	-0.39	0.04	***	-0.29
Accessibility	--->	Trip Green	-0.07	0.02	***	-0.08
Value Privacy	--->	Trip Unsafe	0.1	0.02	***	0.15
Productivity/ ICT	--->	Trip Unsafe	0.24	0.04	***	0.21
Value Auto	--->	Trip Unsafe	0.39	0.04	***	0.38
Density	--->	Trip Unsafe	0.19	0.04	***	0.09
Trip Green	--->	Trip Unsafe	-0.1	0.03	***	-0.13
Value Auto	--->	Inconvenient	0.72	0.05	***	0.48
Trip Unsafe	--->	Inconvenient	0.15	0.04	***	0.1
Value Privacy	--->	Trip Enjoyable	0.05	0.01	0.001	0.06
Trip Green	--->	Trip Enjoyable	0.59	0.02	***	0.67
Productivity/ ICT	--->	Inconvenient	-0.21	0.05	***	-0.12
Car Available	--->	Inconvenient	0.33	0.08	***	0.11
Trip Green	--->	Inconvenient	0.15	0.03	***	0.14
Trip Unsafe	--->	Trip Enjoyable	-0.09	0.02	***	-0.08
Accessibility	--->	Inconvenient	-0.17	0.03	***	-0.17
Trip Enjoyable	--->	Normative	0.48	0.03	***	0.47
Inconvenient	--->	Normative	-0.05	0.02	0.002	-0.06
Car Available	--->	Normative	-0.46	0.06	***	-0.19
Value Urban	--->	Normative	0.2	0.06	***	0.14
Value Privacy	--->	Normative	0.12	0.02	***	0.15
Trip Unsafe	--->	Normative	-0.13	0.02	***	-0.11
Accessibility	--->	Normative	0.1	0.02	***	0.12
Trip Green	--->	Normative	0.18	0.04	***	0.19
Normative	--->	Transit Use	0.28	0.02	***	0.46
Trip Unsafe	--->	Transit Use	0.05	0.01	***	0.07
Car Available	--->	Transit Use	-0.32	0.04	***	-0.22
Inconvenient	--->	Transit Use	-0.05	0.01	***	-0.1
Accessibility	--->	Transit Use	0.07	0.01	***	0.15

THE MEASUREMENT PORTION OF THE MODEL

The loadings of each observed variable on the relevant Latent Factor are shown in Table 18.

TABLE 18: LOADINGS OF OBSERVED VARIABLES ON LATENT FACTORS

			Unstandardized	Standardized
			(All p values < .01)	
Observed Variable	Latent Factor	Estimate	S.E.	Estimate
Freedoms and Independence	<--- Values Auto Orientation	1		0.58
Control air conditioning	<--- Values Auto Orientation	0.68	0.034	0.44
Need car from 3	<--- Values Auto Orientation	0.948	0.035	0.75
Large lot	<--- Values Privacy	1		0.81
Adequate spacing	<--- Values Privacy	0.802	0.031	0.68
Larger home	<--- Values Privacy	0.861	0.032	0.70
Mix of people	<--- Values Urbanism	1		0.59
Walk to commercial dist.	<--- Values Urbanism	1.214	0.05	0.58
People out and about	<--- Values Urbanism	0.841	0.036	0.54
Access to connected	<--- Values Information Technology	1		0.62
Productive Use of Time	<--- Values Information Technology	0.964	0.034	0.67
Perform tasks	<--- Values Information Technology	1.372	0.046	0.75
Density Log epa	<--- Residential Density	1		0.99
Density Log Census	<--- Residential Density	1.006	0.005	0.99
Cars per Worker	<--- Car Available	1		0.70
Cars per Person	<--- Car Available	0.522	0.029	0.54
Transit Accessibility	<--- Transit Oriented	1		0.75
T.A.R.	<--- Transit Oriented	0.801	0.01	0.81
Intersections	<--- Transit Oriented	5.043	0.21	0.51
Trip good for environment	<--- Transit Trip Green	1		0.87
Would change mode	<--- Transit Trip Green	0.852	0.018	0.77
Disturbing behavior	<--- Transit Trip Unsafe	1		0.66
Personal Safety a Concern	<--- Transit Trip Unsafe	0.952	0.045	0.70
Privacy on trip important	<--- Transit Trip Unsafe	0.787	0.04	0.61
Trip less stressful	<--- Transit Trip Enjoyable	1		0.77
Trip more efficient	<--- Transit Trip Enjoyable	0.931	0.025	0.69
Trip more pleasant	<--- Transit Trip Enjoyable	1.141	0.024	0.87
Enjoy meeting people	<--- Transit Trip Enjoyable	0.735	0.022	0.58
Family/friends use transit	<--- Social Support for Transit Trip	1		0.72
People would approve	<--- Social Support for Transit Trip	0.868	0.025	0.66
Family would approve	<--- Social Support for Transit Trip	0.948	0.02	0.71
Not serve area where I go	<--- Transit Trip Difficult	1		0.91
Not Provide Flexibility	<--- Transit Trip Difficult	0.749	0.016	0.76
Does not go where I need	<--- Transit Trip Difficult	0.903	0.021	0.84
Days of transit to work	<--- Transit Use	1		0.60
Days using transit	<--- Transit Use	2.019	0.046	0.88
Transit ever	<--- Transit Use	0.474	0.016	0.75
Transit for non work	<--- Transit Use	0.862	0.03	0.70

THE FULL MODEL

The diagram in Figure 9 has been created to show the full interaction between and among the 13 latent variables and the 35 observed variables on which the latent variables are based.

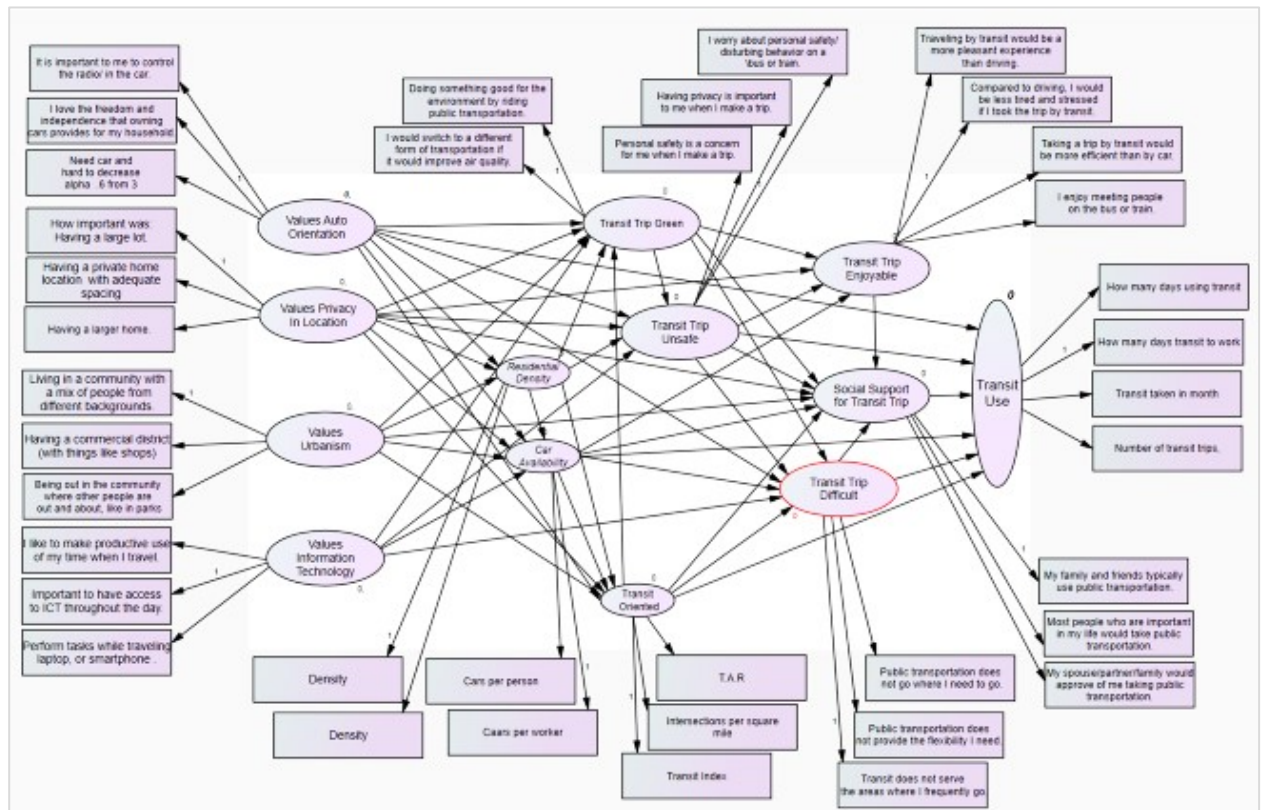


FIGURE 9. THE COMPLETE STRUCTURAL EQUATION MODEL FOR TCRP H-51

Performance of the full model

The model was run as a structural equation model (SEM), using AMOS Version 22 software, which is part of the SPSS set of modeling software packages. The sample included 3,492 respondents. The final model shows the relationships between and among the 13 latent factors of the model, based on the application of the 35 observed variables portrayed as rectangles in the figures above. The SEM which results from the inclusion of the component parts of the Analytical Framework has very positive overall evaluative characteristics. The model has a RMSEA of .04, where any value below .05 is considered a very good fit. It has a comparative fit index (CFI) and a Tucker Lewis Index (TLI) of .94 and .93, where values above .90 are considered to reflect a good model fit. All the coefficients in the model are significant with p values of less than or equal to .001. The r^2 for the outcome factor was .50.

INTERPRETING THE RESULTS FROM RUNNING THE FULL MODEL

The model is not designed to predict behavior, but to contribute to understanding of the relationship between and among factors, given the relationships hypothesized in Figure 8 and Figure 9 SEM models allow the ability to look at the combination of direct and indirect effects of one factor upon another, called the ‘Standardized Total Effect’ (STE). For example, to explain the meaning of the bottom left cell in Table 19, the Amos software program states:

“The standardized total (direct and indirect) effect of Auto Orientation on Transit Use is -.264. That is, due to both direct (unmediated) and indirect (mediated) effects of Auto Orientation on Transit Use, *when Auto Orientation goes up by 1 standard deviation, Transit Use goes down by 0.264 standard deviations.*

TABLE 19: TABLE SHOWING THE INFLUENCE OF LATENT FACTORS IN COLUMNS ON LATENT FACTORS IN ROWS, EXPRESSED IN STANDARDIZED TOTAL EFFECT. TOTAL SAMPLE, N= 3492; R² =.50

	Values Auto	Values Urban	Values Suburban	Productivity ICT	Density	Car Available	Design and Accessibility	Trip Green	Trip Unsafe	Trip Enjoyable	Trip Inconvenient	Normative Influence
Density	-0.22	0.21	-0.08									
Car Available	0.26	-0.25	-0.13	-0.18	-0.14							
Design/Access.	-0.26	0.32	-0.10	0.02	0.55	-0.13						
Trip Green	-0.27	0.59	0.08	0.23	-0.04	0.01	-0.08					
Trip Unsafe	0.40	-0.06	0.13	0.18	0.10	0.00	0.01	-0.13				
Trip Enjoyable	-0.21	0.40	0.10	0.14	-0.04	0.01	-0.05	0.68	-0.08			
Inconvenient	0.55	-0.01	0.03	-0.10	-0.11	0.14	-0.18	0.12	0.10			
Normative	-0.31	0.53	0.21	0.13	0.06	-0.21	0.09	0.52	-0.15	0.47	-0.06	
Transit Use	-0.26	0.35	0.12	0.13	0.16	-0.35	0.21	0.22	<i>n.s.</i>	0.21	-0.13	0.46

Table 19 shows that the strongest factor in the explanation of transit use is the idea that those in my social network would approve of me taking transit, and that they would take it themselves. This “normative” factor itself was influenced highly (STE =0.53) by the latent factor representing valuing urbanism and the urban lifestyle, shown on the next row above Transit Use. Table 20 repeats the results presented in the bottom row of Table 19, this time rank-ordered by the absolute scale of the STE value.

TABLE 20: RANK ORDER OF IMPORTANCE FACTORS IN THE EXPLANATION OF TRANSIT USE

Rank Order (by Absolute Value of STE)	Standardized Total Effect (STE)	Factor
1	0.46	Normative
2	-0.35	<i>Car Available</i>
3	0.35	<i>Values Urban Setting</i>
4	-0.26	<i>Values Auto</i>
5	0.22	Transit Trip Green
6	0.21	Transit Trip Enjoyable
7	0.21	<i>Design and Accessibility</i>
8	0.16	<i>Density</i>
9	0.13	<i>Values Productivity, ICT</i>
10	-0.13	Transit Trip Inconvenient
11	0.12	<i>Values Suburban House</i>
12	<i>Not Significant</i>	Transit Trip Unsafe

N.B. Latent Factors for the four Basic Values are shown in ***Italic Bold***, for the three concerning residential setting shown in *Italic* font, and for the five short-term attitudes shown in regular font.

The data in Table 20 can be interpreted in several ways. While the Standardized Total Effect is usually expressed in the scale of a 100% increase in the independent factor, a more realistic interpretation can be stated in terms of a 10% increase in the independent factor. By way of example Table 20 shows that:

- A 10% increase in the value of the factor “Values Urban Setting” would be associated with a 3.5% **increase** in the Outcome Factor, “Transit Use.”
- A 10% increase in the value of the factor “Values Auto” would be associated with a 2.6% **decrease** in the Outcome Factor, “Transit Use.”
- A 10% increase in the value of the factor “Transit Trip Enjoyable” would be associated with 2.1% **increase** in the Outcome Factor, “Transit Use.”

Additional exploration of differences by age and gender

During the analysis process additional models were developed and tested. In specific, a simpler model was developed that would support the examinations of differences between (1) Millennials vs Older, and (2), Males vs Females. The strongest impact on transit use in this smaller model was, again, from normative influences. Higher values in this dimension were reported for Millennials over Olders, and Males more than Females. The

concept that the transit trip might help the environment, or influence choice of mode was a stronger explanatory factor for Millennials over Olders, and for Males over Females. The idea that the transit trip is enjoyable and pleasurable is a stronger explanatory factor for Males than Females, with Millennials reporting no significant influence from this explanatory factor.

In this additional analysis, the traditional concepts of density design and accessibility seem to be more powerful explanatory factors for the Older group than for the Millennials. This model shows that for Millennials, holding an attitude that the trip is unsafe is a statistically significant positive predictor of transit use; for the Older group, it is not. The Millennial's belief that the trip may be disturbing is positively associated with more transit use. Thus, it is worth noting that, although they are using transit, they are also concerned with certain aspects of the trip.