The Independent and Combined Influence of Metropolitan- and Local-Accessibility on Station Boardings

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Study Purpose & Literature Review

Purpose

1-Explore the potential influence of composite indicators of accessibility at *local* and *metropolitan* scales on rapid-transit ridership and the potential of interaction effects, if any.

2-Improve direct-demand models' (DDM) predictive power.

$$\text{AWB}^{station} = f(\text{SE, LU.BE, TS, NT, ACC}_{\text{loc | met}})$$

$$ln\,\mu_{ij} = (n_{ij} + e_{ij}) = \gamma_0 + \sum_{h=1}^{r} \gamma_h x_{hij} + R_{ij} + U_{0j}$$

Literature Review

- Relatively few station-level transit studies incorporate *metropolitan accessibility* composite indicators as part of their DDM specifications
- Even fewer station-level studies incorporate both ***local*** and ***metropolitan*** accessibility composite indicators, and none have explored potential interactions
- When both indicators are included, their operationalization is not consistent and often applied in different units of analyses and/or different sub-set of observations
- On the other hand, in all reviewed studies local and metropolitan accessibility measures emerge as statistically significant for ridership (e.g., boardings at station-level)

Hypotheses

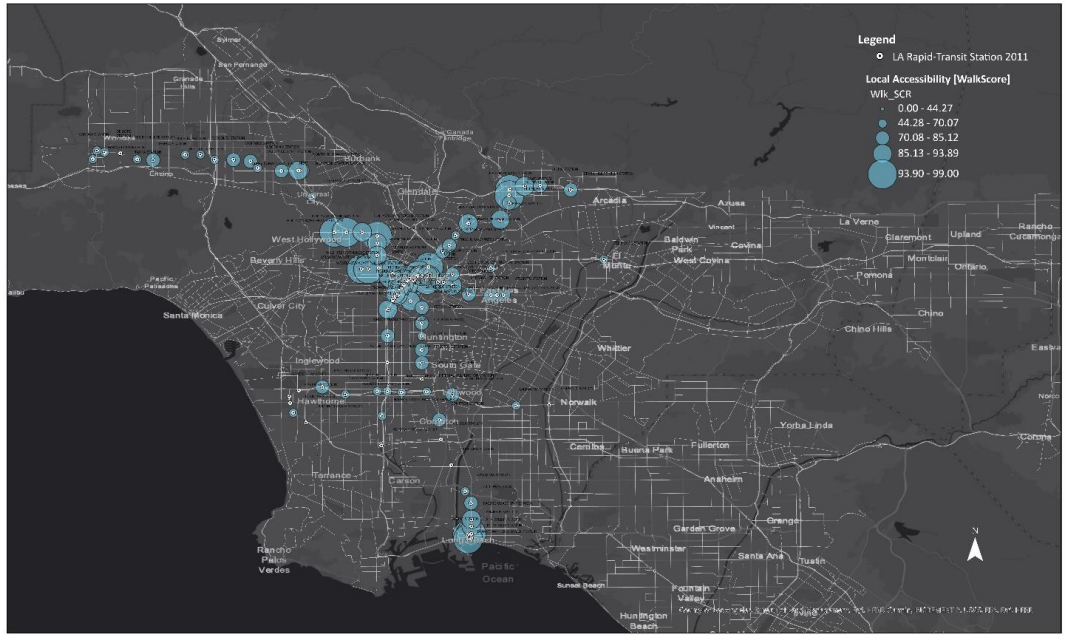
H1: *metropolitan accessibility* is a significant trip production factor at station-level in **Los Angeles** multimodal rapid-transit transit network

H2: *metropolitan accessibility* and *local accessibility* synergistically **interact** in producing more boardings at station-level, when compared to their independent effects. This proposition is framed within a utilitarian theoretical framework along two potential mechanisms: 1- reduced overall multimodal travel time (on foot + on transit) and/or; 2- increased aggregate number of opportunities at stations' pedestrian service area and along the rapid-transit network

metropolitan accessibility - 2012

×

local accessibility - 2012



Construct Definitions and Operationalization

- ***Composite indicators:*** individual components that are compiled into a single index, based on an underlying model of the multi-dimensional concept that is being measured (e.g., accessibility)

- ***Accessibility*** *: "*… the ease of reaching goods, services, activities, and destinations, which together are called opportunities" (Litman 2021).

    1. **Metropolitan** accessibility: ease of reaching goods, services, activities, and destinations along LAs **rapid-transit** network. Access *from* the station.

    2. **Local** accessibility: ease of reaching goods, services, activities, and destinations within stations' pedestrian service area + ease of reaching the station **on foot**. Access *to* the station on foot and access to opportunities *within* a stations' Pedshed.

Hansen gravity-based cumulative-opportunities model

$$A_i = \sum_{j,j \neq i} O_j \; T_{ij}^{-\alpha}$$

metropolitan

$$A_i = \sum_{j,j \neq i} O_j \; f(tt_{ij})$$

Friction functions:

inverse power $f(tt_{ij}) = tt_{ij}^{-2}$

exponential $f(tt_{ij}) = e^{-m * tt_{ij}}$

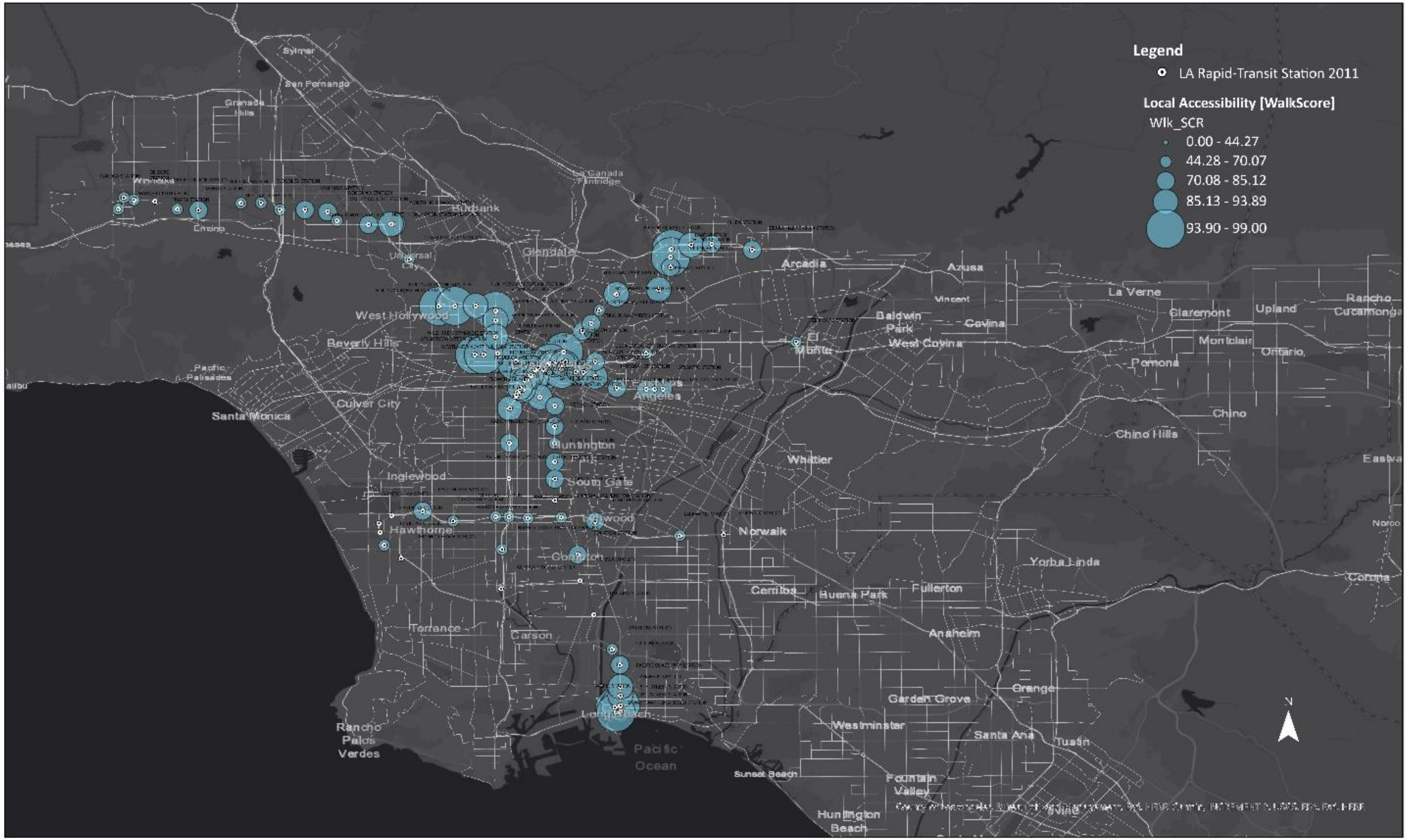
gamma $f(tt_{ij}) = a * tt_{ij}^{-b} * e^{-c * tt_{ij}}$

local

WalkScore®

Hypotheses 1

Hypotheses 1, 2



Research Design & Methods

- ***Single Case Study****:* Los Angeles Rapid-Transit Network, which includes heavy-rail (HRT), light-rail (LRT), and Bus Rapid Transit (BRT); complemented with a large, multi-jurisdictional, and variegated set of feeder bus networks (local, express, limited-stop, circulators, rapid)

- **Unit of analysis**: rapid-transit station

- ***Methods*** *:* set of multi-level generalized linear regression models (negative-binomial distribution)

    - ML-NBREG

$$\ln \mu_{ij} = (n_{ij} + e_{ij}) = \gamma_0 + \sum_{h=1}^{r} \gamma_h x_{hij} + R_{ij} + U_{0j}$$

H.RT

heavy-rail

L.RT

light-rail

B.RT

Bus rapid-transit

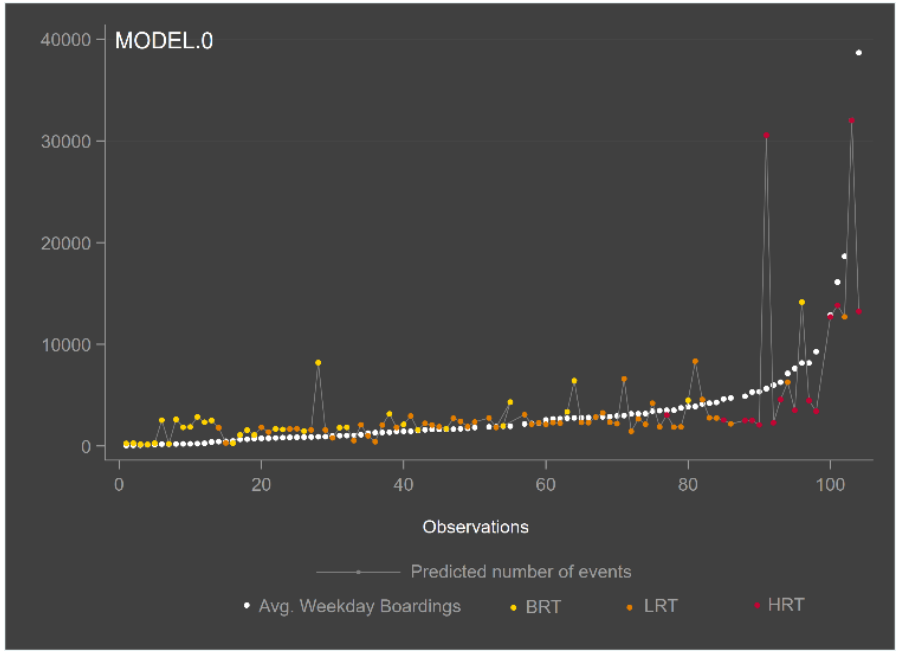
Dependent and Independent Variables – Year 2012

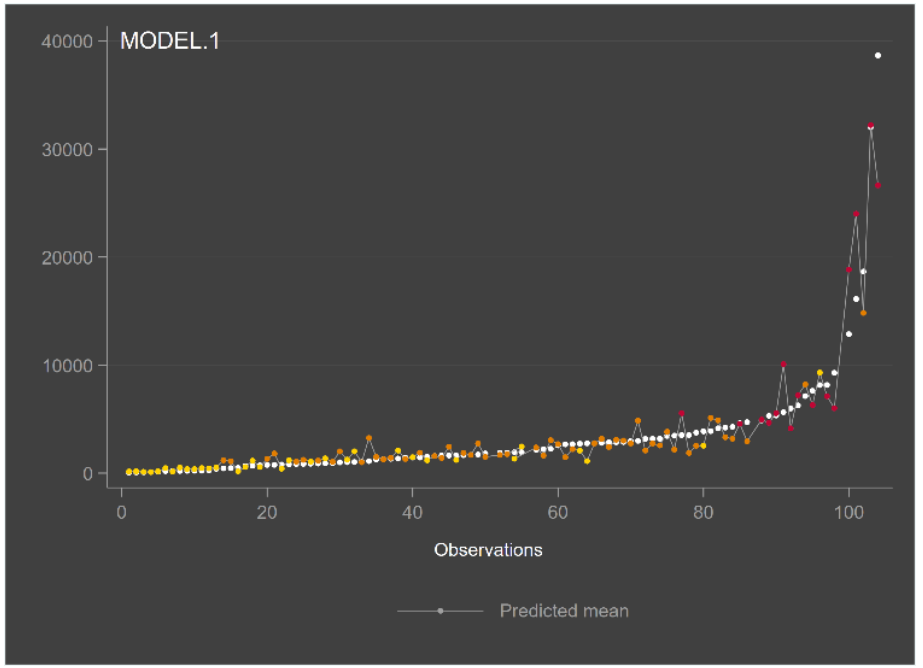
Variable	Mean	Std. Dev.	Min	Max
Dependent:				
Avg. Weekday Boardings	3420	5519	50	38665
Independent:				
Population (centered + scaled)	0.119	13.421	-75.796	23.204
Jobs (centered + log-transformed)	-0.013	1.096	-2.394	2.944
Local Accessibility (WalkScore©, centered)	0.400	18.701	-52.477	21.523
Metropolitan Accessibility (centered + scaled)	-0.360	20.377	-14.581	85.419
Local Bus Lines (centered)	-0.019	0.955	-1.939	1.932
Parking Spaces at Station	327.059	564.585	0.000	3030.000
One-Way Service Station [a]	0.228	0.421	0.000	1.000
Terminal	0.109	0.313	0.000	1.000
note: a. BRT- lower service hybrid 'Silver Line'				

$$\ln \mu_{ij} = (n_{ij} + e_{ij}) = \gamma_0 + \sum_{h=1}^{r} \gamma_h x_{hij} + R_{ij} + U_{0j}$$

Results.1

	interaction term (i)	MODEL 0 Restricted FIXED-EFFECTS ONLY			MODEL 1 Restricted MIXED-EFECTS		
Model-fit:							
N:		100			100		
LR test vs. nbinomial model:		chi2(01) = 1.3e+05, Prob >= chi2 = 0.000			chi2(2) = 85.60, Prob > chi2 = 0.0000		
Likelihood-ratio test:		n.a.			[m0 nested in m1]: LR chi2(2)=85.6 Prob > chi2=0.0000		
AIC:		1733.715			1652.116		
BIC:		1757.162			1680.773		
[a] Fixed-effects only Pseudo-R^2		0.66			0.66		
[a] Total-effects Pseudo-R^2		n.a.			0.86		
DV: Avg. Weekday Boardings		IRR	p	sig.	IRR	p	sig.
Fixed-effects:							
Population		1.020	0.000	***	1.014	0.000	***
Jobs		1.128	0.092	*	1.166	0.003	***
Number of Parking Spaces		1.001	0.000	***	1.001	0.000	***
OneWay Service		0.116	0.000	***	0.355	0.000	***
Terminal		6.537	0.000	***	3.084	0.000	***
Transfer Hub		3.665	0.000	***	3.064	0.000	***
Union Station		12.276	0.001	***	1.752	0.019	**
Metro-Access							
Population x Metro-Access	i						
Jobs x Metro-Access	i						
Local-Access							
Local Access x Metro-Access	i						
Bus Connectivity							
Bus Connectivity x Metro-Access	i						
_cons		1974.306			2269.131		
/lnalpha		-0.676	0.132		-1.683	0.149	
Random-effects:							
Rapid-Transit Line					**var.**	**std. err**	
var (BRT_Silver)		n.a.	n.a.		2.859	4.508	
var (_cons)		n.a.	n.a.		0.265	0.190	





Results.2*α*

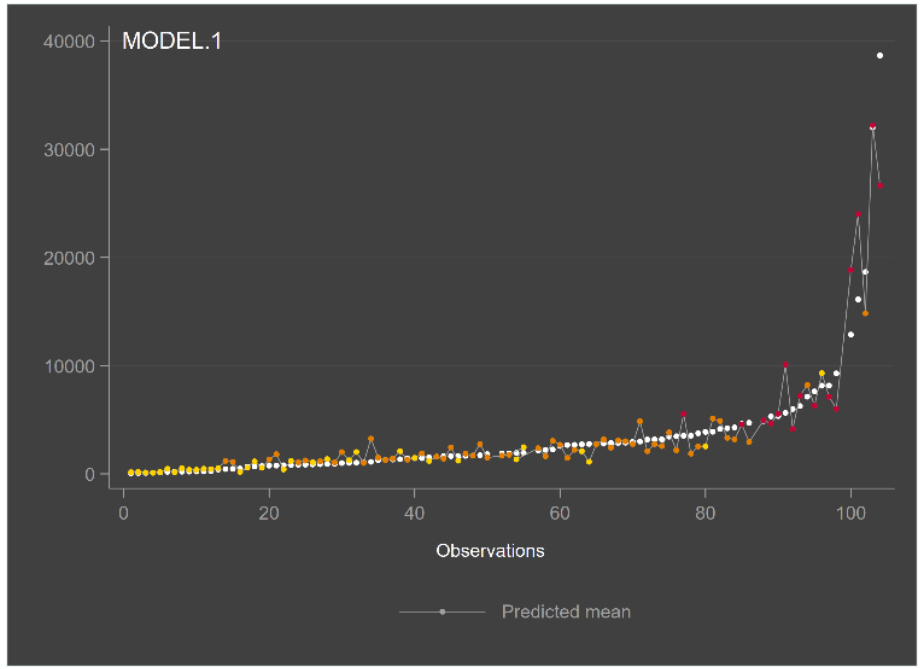
	interaction term (i)	MODEL 1 Restricted MIXED-EFECTS			**MODEL 2** Un-restricted MIXED-EFECTS w/ Metro-Accessibility			**MODEL 3** Un-restricted MIXED-EFECTS Interaction: Population **X** Metro-Accessibility			**MODEL 4** Un-restricted MIXED-EFECTS Interaction: Jobs **X** Metro-Accessibility		
Model-fit:													
N:		100			100			100			100		
LR test vs. nbinomial model:		chi2(2) = 85.60, Prob > chi2 = 0.0000			chi2(2) = 85.92, Prob > chi2 = 0.0000			chi2(2) = 83.60, Prob > chi2 = 0.0000			chi2(2) = 89.66, Prob > chi2 = 0.0000		
Likelihood-ratio test:		[m0 nested in m1]: LR chi2(2)=85.6 Prob > chi2=0.0000			[m1 nested in m2] LR chi2(1)=5.64 Prob > chi2=0.0176			[m2 nested in m3] LR chi2(1)=0.14 Prob > chi2=0.7109			[m2 nested in m4] LR chi2(1)=3.82 Prob > chi2=0.0507		
AIC:		1652.116			1648.476			1650.339			1646.659		
BIC:		1680.773			1679.738			1684.206			1680.526		
[a] Fixed-effects only Pseudo-R^2		0.66			0.68			0.69			0.68		
[a] Total-effects Pseudo-R^2		0.86			0.86			0.86			0.87		
DV: Avg. Weekday Boardings		IRR	p	sig.	IRR	p	sig.	IRR	p	sig.	IRR	p	sig.
Fixed-effects:													
Population		1.014	0.000	***	1.014	0.000	***	1.014	0.000	***	1.013	0.000	***
Jobs		1.166	0.003	***	1.105	0.067	*	1.100	0.085	*	1.095	0.085	*
Number of Parking Spaces		1.001	0.000	***	1.001	0.000	***	1.001	0.000	***	1.001	0.000	***
OneWay Service		0.355	0.000	***	0.323	0.000	***	0.320	0.000	***	0.332	0.000	***
Terminal		3.084	0.000	***	3.693	0.000	***	3.746	0.000	***	3.741	0.000	***
Transfer Hub		3.064	0.000	***	2.623	0.000	***	2.562	0.000	***	2.394	0.000	***
Union Station		1.752	0.019	**	2.922	0.033	**	2.973	0.031	**	3.160	0.020	**
Metro-Access					1.010	0.018	**	1.010	0.020	**	1.006	0.120	
Population x Metro-Access	i							1.0001	0.710				
Jobs x Metro-Access	i										1.005	0.048	**
Local-Access													
Local Access x Metro-Access	i												
Bus Connectivity													
Bus Connectivity x Metro-Access	i												
_cons		2269.131			2272.255			2274.364			2046.995		
/lnalpha		-1.683	0.149		-1.764	0.151		-1.764	0.151		-1.822	0.152	
Random-effects:													
Rapid-Transit Line		var.	std. err		var.	std. err		var.	std. err		var.	std. err	
var (BRT_Silver)		2.859	4.508		3.527	5.603		3.511	5.577		3.302	5.447	
var (_cons)		0.265	0.190		0.357	0.270		0.353	0.270		0.455	0.343	

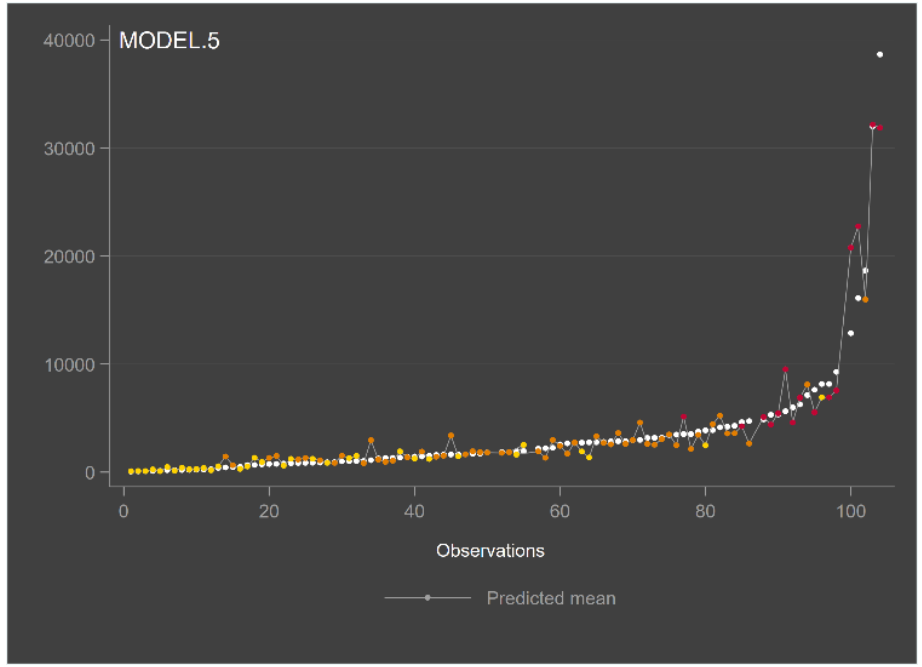
Results.2*b*

	interaction term (i)	MODEL 1.b Restricted MIXED-EFECTS			MODEL 2.b Un-restricted MIXED-EFECTS w/ Metro-Accessibility			MODEL 3.b Un-restricted MIXED-EFECTS Interaction: Population X Metro-Accessibility			MODEL 4b Un-restricted MIXED-EFECTS Interaction: Jobs X Metro-Accessibility		
Model-fit:													
N:		100			100			100			100		
LR test vs. nbinomial model:		chi2(2) = 80.49, Prob > chi2 = 0.0000			chi2(2) =96.12, Prob > chi2 = 0.0000			chi2(2) = 85.56, Prob > chi2 = 0.0000			chi2(2) = 98.77, Prob > chi2 = 0.0000		
Likelihood-ratio test:		[m0b nested in m1b]: LR chi2(2)=##.## Prob > chi2=#.####			[m1.b nested in m2.b] LR chi2(1)=15.63 Prob > chi2=0.0001			[m2.b nested in m3.b] LR chi2(1)=3.63 Prob > chi2=0.0568			[m2b nested in m4b] LR chi2(1)=7.44 Prob > chi2=0.0064		
AIC:		1682.515			1668.881			1667.253			1663.444		
BIC:		1708.567			1697.538			1698.515			1694.706		
[a] Fixed-effects only Pseudo-R^2		0.56			0.55			0.61			0.68		
[a] Total-effects Pseudo-R^2		0.80			0.830			0.836			0.842		
DV: Avg. Weekday Boardings		IRR	p	sig.	IRR	p	sig.	IRR	p	sig.	IRR	p	sig.
Fixed-effects:													
Population		1.019	0.000	***	1.016	0.000	***	1.018	0.000	***	1.015	0.000	***
Jobs		1.232	0.000	***	1.115	0.073	*	1.094	0.134		1.112	0.062	*
Number of Parking Spaces		1.000	0.000	***	1.001	0.000	***	1.001	0.000	***	1.000	0.000	***
OneWay Service		0.448	0.000	***	0.362	0.000	***	0.341	0.000	***	0.348	0.000	***
Terminal		3.223	0.000	***	**4.264**	0.000	***	**4.525**	0.000	***	4.511	0.000	***
~~Transfer Hub~~		*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*	*Not used*
Union Station		7.505	0.000	***	**4.594**	0.004	***	4.739	0.003	***	**5.152**	0.001	***
Metro-Access					1.018	0.000	***	1.020	0.000	***	1.011	0.009	***
Population x Metro-Access	i							1.000	0.049	**			
Jobs x Metro-Access	i										1.008	0.005	***
Local-Access													
Local Access x Metro-Access	i												
Bus Connectivity													
Bus Connectivity x Metro-Access	i												
_cons		3222.029			2904.313			2801.378			2340.527		
/lnalpha		-1.437	0.145		-1.615	0.148		-1.645	0.148		-1.702	0.148	
Random-effects:													
Rapid-Transit Line		var.	std. err		var.	std. err		var.	std. err		var.	std. err	
var (BRT_Silver)		3.317	5.955		4.477	7.892		4.192	7.374		3.668	7.029	
var (_cons)		0.760	0.449		0.948	0.580		0.873	0.549		1.110	0.680	

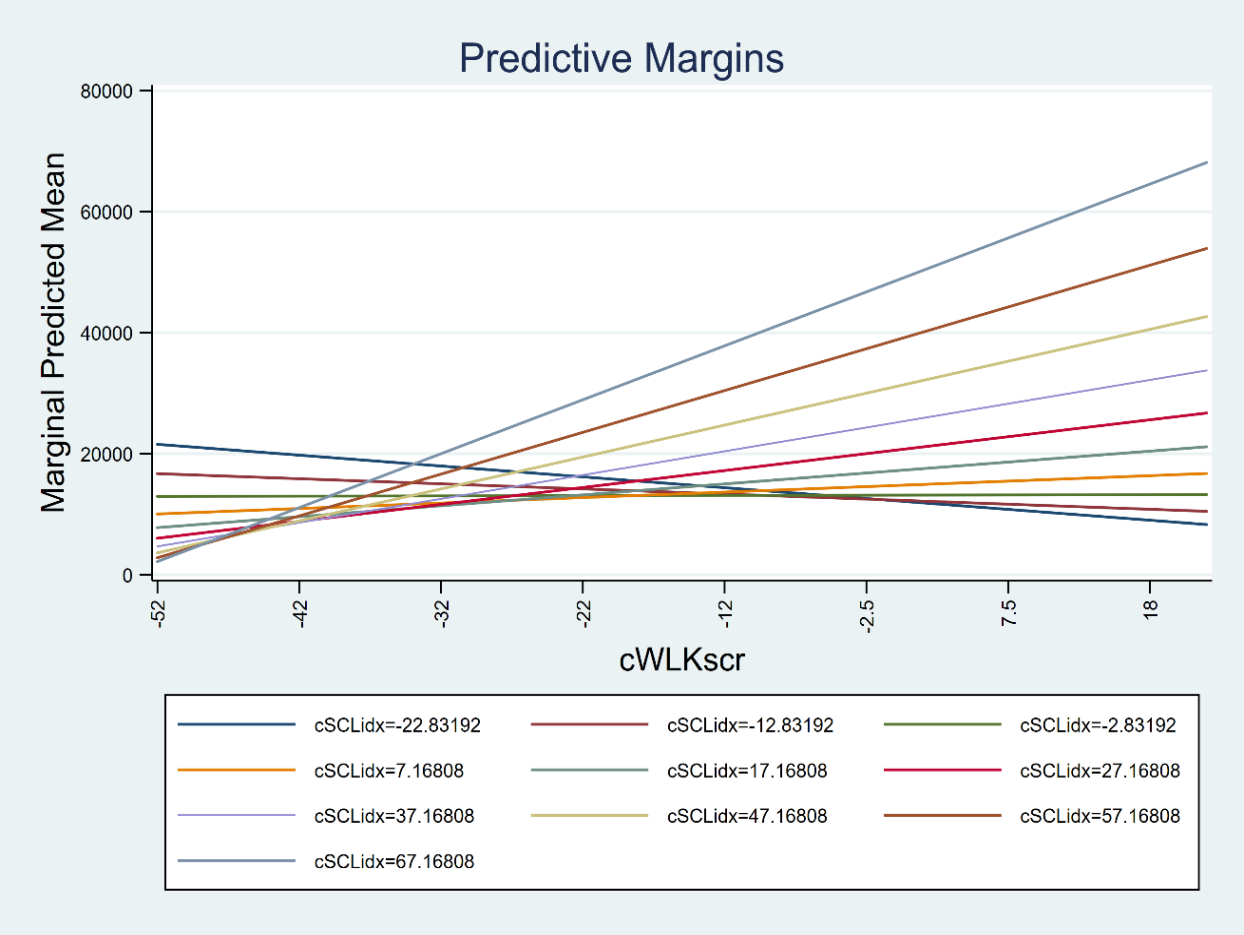
Results.3

	interaction term (i)	MODEL 5 Un-restricted MIXED-EFECTS Interaction: Local-Accessibility (Walkcore®) X Metro-Accessibility			MODEL 6 Un-restricted MIXED-EFECTS Interaction: Bus Connectivity X Metro-Accessibility		
Model-fit:							
N:			100			100	
LR test vs. nbinomial model:		chi2(2) = 89.96, Prob > chi2 = 0.0000			chi2(2) = 93.84, Prob > chi2 = 0.0000		
Likelihood-ratio test:		[m2 nested in m5] LR chi2(1)=28.01 Prob > chi2=0.0000			[m2 nested in m6] LR chi2(1)=15.19 Prob > chi2=0.0005		
AIC:		1622.469			1637.286		
BIC:		1656.337			1673.758		
[a] Fixed-effects only Pseudo-R^2		0.75			0.70		
[a] Total-effects Pseudo-R^2		0.90			0.88		
DV: Avg. Weekday Boardings		IRR	p	sig.	IRR	p	sig.
Fixed-effects:							
Population		1.015	0.000	***	1.015	0.000	***
Jobs		[b] not used	[b] not used	[b] not used	1.088	0.093	*
Number of Parking Spaces		1.001	0.000	***	1.001	0.000	***
OneWay Service		0.197	0.000	***	0.241	0.000	***
Terminal		5.552	0.000	***	4.347	0.000	***
Transfer Hub		2.673	0.000	***	2.782	0.000	***
Union Station		24.371	0.000	***	4.037	0.003	***
Metro-Access		0.968	0.000	***	0.983	0.032	**
Population x Metro-Access	i						
Jobs x Metro-Access	i						
Local-Access [Walkscore]		1.030	0.000	***			
Local Access x Metro-Access	i	1.003	0.000	***			
Bus Connectivity					1.387	0.000	***
Bus Connectivity x Metro-Access	i				1.016	0.001	***
_cons		1292.879			1864.328		
/lnalpha		-2.037	0.151		-1.900	0.151	
Random-effects:							
Rapid-Transit Line		var.	std. err		var.	std. err	
var (BRT_Silver)		2.403	3.902		3.383	5.270	
var (_cons)		0.289	0.194		0.277	0.200	





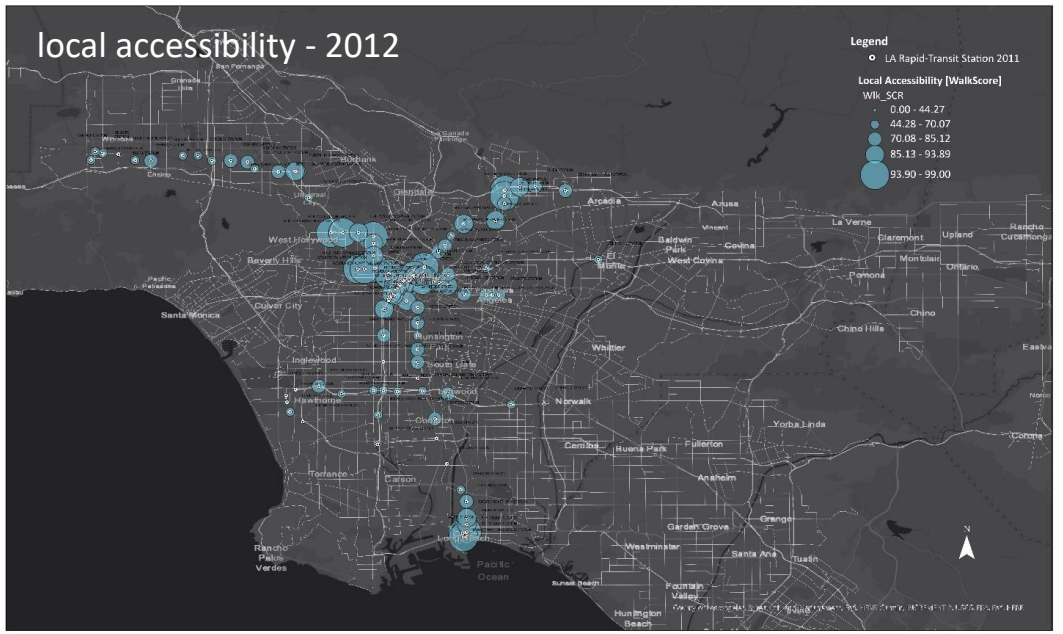
Results.4 Simple Slope Cross-Effect [non-conclusive]



Conclusions and Implications.1

- **H1*:*** **Model-2** results indicate that a station's nodal *metropolitan accessibility* is highly significant and associated with more boardings at station-level. **Models 3-6** indicate that stations' nodal *metropolitan accessibility* also has significant interactions with several local attributes: population, jobs, bus connectivity, and *local accessibility,* all of which would synergistically increase transit patronage and improve DDM model fit when compared to a base model with no interactions.

- **H2: Model-5** indicates that *local accessibility* (access *to* and *within* a station's Pedshed; ~ walkability) has a significant global **cross-over** interaction with a station's *metropolitan accessibility* (access *from* the station to others along LAs rapid-transit network). However, a basic slope assessment yielded non-conclusive results for this and the other interactions, likely because of the relative low number of observations in the data.



Conclusions and Implications.2

- It appears that rapid-transit users in LA value both, the accessibility allowed by the network at a metropolitan scale, as well as the ease of access to and access to opportunities within a stations' pedestrian service area. And when higher values for both measures coincide at a station the combined effect on aggregate ridership is augmented.

- Transit planners, land-use planners, and researchers would benefit from including multi-scalar composite indicators of accessibility in station-level DDM models, and relevant interactions. This will improve models' explanatory power, accuracy of predictions, and could help in TOD (Transit Oriented Development) scenario planning by taking into consideration the entire transit network and complex interactions with the built-environment at both *local* and *metropolitan* scales.

Limitations and Future Research Extensions

- Increase station sampling to explore combined effects of multiple interaction terms and re-assess basic slope-level significance
- Identify threshold levels of interest for practical applications (e.g., Walkscores)
- Develop an integrated multi-modal *local accessibility* indicator that includes pedestrian, bus, and bicycle mode.

THANK YOU FOR LISTENING!