Title: Understanding the level of integration of light rail transit into communities in the Denver region

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ABSTRACT

While many studies evaluate travel behavior associated with specific elements of transit-oriented development (TOD) with varying conclusions, most assess built environment factors in isolation, preventing a comprehensive understanding of the interrelated nature of the fabric of transit-oriented communities. Our research begins to address this gap by accounting for the “level of integration” between transit and the built environment. We aim to identify key factors associated with integration as a first step towards developing composite measures that account for level of integration. As a means of testing the level of integration concept, we also assess the importance of various integration factors in explaining the travel behavior of station area residents. We evaluate areas served by light rail transit in the Denver Metropolitan Area. In studying Denver, we provide much-needed insights into “second-generation” light rail systems in cities characterized by auto-dependence. We develop four final models in order to identify those variables that best explain four travel outcomes: car ownership, vehicle miles traveled, and use of LRT and alternative modes. The explanatory variables included in the models represent those that are most important for consideration in future measures of integration. Three variables appear to hold the most promise: Miles of bicycle facilities, pedestrian shed (the percent of the area within ½-mile of stations that can be walked along the network in ½-mile), and access to “other” amenities. Results of our analysis also clearly indicate that socio-demographic variables and self-selection effects must be accounted for in future investigations of the effects of level of integration. While the variables used in the present analysis are helpful in exploring the viability of a “level of integration” measure, they do not represent perfect measures. Future work will develop more nuanced composite measures of integration, and will test the effects of these measures on travel behavior using more sophisticated modeling techniques. Ultimately, we expect that station areas with characteristics representative of high levels of integration between transit and the built environment are more likely to foster positive travel outcomes

INTRODUCTION AND BACKGROUND

While transit and what we now call transit-oriented development (TOD) has been a staple in the United States since well before automobiles existed, TODs did not start receiving significant attention from the research community until the late twentieth century. At that time, the majority of reports and research papers are best categorized as general assessments or critiques of TODs (*1,2,3,4*), or efforts to understand the impact of the transit system on adjacent land uses (*5,6*). Since then, research questions have primarily related to how transit and land use influence travel behavior (*7,8,9,10*). This line of inquiry aims to understand the travel behavior of people living near TODs that are characterized by certain types of adjacent built environments. Research often asks whether station area residents exhibit the behaviors that transit advocates hope to see - namely whether residents use light rail transit (LRT) with increased frequency, drive less, own fewer cars, and/or walk and bike more often. Because transit infrastructure and associated development often require substantial investment, this strand of research provides important insights to decision makers.

A large body of literature exists on the relationship between travel behavior and the built environment. Ewing and Cervero (2010) provide a comprehensive overview of these studies, which have employed increasingly sophisticated methods, models, and measurements (*21*). However, despite years of such improvements, there is still considerable debate concerning findings. On one hand, abundant studies suggest that the built environment significantly impacts travel behaviors (*11-,12,13,14,15,16,17,18,19,20,21*). On the other hand, the elasticities of the significant findings are generally small (*21*). Several studies have found no significant impact (*15, 22*) and researchers often attribute significant results to socio-demographic differences more than those related to land use or transit (*23)*. Moreover, many studies finding significant influence of land use on travel behavior do not account for issues of self-selection, thereby undercutting the validity of findings. When these studies are dismissed, the seemingly high ratio of studies finding significant influence to those that do not find significance drops even lower (*24,25,26,27,28*).

Despite somewhat inconsistent findings, the existing research generally suggests that TODs are supportive of the beneficial travel behaviors espoused by transit advocates. It appears that transit, in combination with certain built environment characteristics, is positively linked to less driving, increased transit use and active transportation, and fewer household automobiles. Researchers have continued to deconstruct measures of the built environment to the point where studies such as the meta-analysis study conducted by Ewing and Cervero (2010) are able to calculate pooled elasticities of individual built environment variables (*21*). For example, the weighted average elasticity of transit use with increasing intersection density is found to be 0.23 based upon four studies identified by Ewing and Cervero (none of which, in this example, account for self-selection).

While we could conduct a study that adds to this grand list of literature – by marginally improving upon a methodology, accounting for self-selection, and/or investigating a second-generation system such as light rail in the Denver region – we intend to step back from efforts to assess built environment factors in isolation. Our literature review makes it clear that, even after almost two decades of research, it is still difficult for travel behavior researchers to fully understand outcomes by simply placing isolated transportation, land use, and socio-demographic variables into a model and accounting for as many potentially confounding factors as possible. TODs and the people that live near them are infinitely more complex than they have generally been given credit for. In reality, many variables are highly interrelated and therefore need to be considered as such in order to begin to realize appreciable differences in terms of travel behavior and quality of life outcomes. We conceptualize the harmony between isolated variables as the "level of integration" between rail transit and the fabric of the community. A lack of integration may indeed be contributing to the fact that many of existing TODs in the U.S. are considered to be underperforming (*29,30*). In order to begin to fill what we think is a considerable research gap, and eventually develop a quantitative set of metrics, this research aims to better understand the level of integration between transit and the surrounding built environment. We ultimately expect to find that the more integrated a transit system is with its surrounding community, the more that benefits related to travel behavior and the broader goals of livability and sustainability will be realized.

In order to begin identifying possible means of measuring level of integration with respect to transit and community design, we considered some common definitions of TOD and found that current notions of TOD do not explicitly account for level of integration. For example, Boarnet and Crane (1997) focus on intensifying development around the stations and define TOD as "the idea that land near rail transit stations should be developed or redeveloped in ways that encourage the best use of the transit system and that leverage the public investment in rail transit" (*31*). In the book *The New Transit Town*, Dittmar and Poticha (2004) add a bit more in terms of land use specifics by defining TOD as "a mix of uses, at various densities, within a half-mile radius around each transit stop" (*29*) while Calthorpe (1993) takes a step further with respect to land use by suggesting that the TOD "…concept is simple: moderate and high-density housing, along with complementary public uses, jobs, retail and services, are concentrated in mixed-use developments at strategic points along the regional transit systems" (*32*). While these definitions differ slightly, their main themes focus on land uses in terms of both variety and density. Other perspectives, such as the one espoused by the Center for Neighborhood Technology, stress the need for "high levels of pedestrian and bicycle accessibility," but the concept of integrating the transit system into the community fabric is rarely acknowledged (*33*).

Bernick and Cervero (1997) provide one notable outlier to standard TOD definitions. Preferring the term "transit village," they describe their concept of TODs as places where the built, social, and economic environments "embrace and evolve" around the transit system (*34*). In their words: "the transit village is about increasing choice – opening up more options in how to travel, where to live and work, places to go, and how to spend one's free time" (*34*). They argue that transit villages must emerge from our large-scale infrastructure investments in order for transit to become fundamental to transportation in the U.S. Our research considers Bernick and Cervero's description as fundamental to our efforts in measuring the level of integration between rail transit and the built environment. While there might be some level of agreement in terms of how specific TOD elements may or may not contribute to positive travel outcomes, there is clearly a need to better understand how built environment characteristics should be integrated with the transit system and the surrounding community in order to maximize travel and quality of life benefits. The present research aims to quantify these concepts using a set of factors that examine the level of integration of transit stations in the Denver Metropolitan region with respect to the fabric of surrounding communities.

Although many studies have tested some of the same variables that we employ, very few studies have specifically investigated the issue of integration. In one very recent study, Calimente (2012) identifies ten indicators of integration – transit ridership, quality of service (frequency, hours of service, passenger load, and cost per passenger), mode share from travel between home and station, the number of mode connections, the number of auto and bicycle parking spaces provided at stations, housing and population density, property values within and beyond 500 meters of the station, quality of streetscape design, pedestrian safety, and crime rates – and evaluates them using descriptive comparisons of several stations in Tokyo, Japan (*35*). While Calimente provides a reasonable conceptual basis for possible measures of integration, the research fails to identify those factors which best explain travel behavior outcomes. Furthermore, the focus on Tokyo limits generalizability to most North American cities, which tend to have vastly different patterns of land use and transit service.

Our research aims to expand the understanding of factors that contribute to integration between transit and the community and begin to examine how the consideration of level of integration might improve our understanding of travel outcomes. To do so, we evaluate areas served by light rail in the Denver Metropolitan Area. In studying Denver, we provide much-needed insights into "second-generation" LRT systems in cities characterized by auto-dependence. Therefore, our research is widely applicable to many auto-oriented North American cities with, or contemplating the implementation of, rail transit. The Denver Metro Region is home to 2.7 million people with more than 50% growth predicted by 2035 for an expected population of 4.2 million people (*36*). Three of the eight counties in the Denver Metro are currently served by a 35-mile, four corridor light rail transit system with 36 stations.

The first corridor was implemented in 1994, followed by three others in 2000, 2002, and 2006. The existing system connects downtown Denver with the Five Points Business District (north of downtown), Auraria Campus (which serves as the home of three higher education institutions), Denver Union Station in Denver's Lower Downtown district, the Pepsi Center and Sports Authority Field at Mile High sporting centers, and communities in the southwest and southeast of the Denver Metro. Twenty-five of the 36 existing stations are located in the City and County of Denver (CCD), which are selected here for analysis. In 2004, voters approved funding for 122 new miles of rail, 18 miles of bus rapid transit, and 57 new rapid transit stations as part of the FasTracks Program which is currently in the planning and construction phase. Once completed, FasTracks will constitute one of the country's largest investments in rail transit (*37*). Our research is therefore particularly timely, as planners and policymakers begin to approach the design of TODs and surrounding communities in the Denver Metro, as well as in communities across the U.S. that share characteristics with Denver. In developing a better understanding of the level of integration between rail transit and the community fabric, our research begins to shed light on ways in which positive travel and quality of life outcomes might be optimized in communities investing in rail transit.

RESEARCH QUESTIONS

This research aims to identify key factors associated with the integration of transit and the community fabric in order to contribute to the development of measures accounting for "level of integration." In order to test the level of integration concept, we also assess the importance of various integration factors in explaining the travel behavior of station area residents. We define three categories of integration measures:

- Built environment characteristics
- Transit level of service (LOS)
- Access to amenities such as grocery stores, restaurants, schools, and other destinations.

The analysis also includes several socio-demographic variables commonly associated with travel behavior, as well as variables that account for possible self-selection effects. We hypothesize that a range of variables associated with the level of integration between LRT and the community are important in explaining travel outcomes. We also expect that socio-demographic variables will be important to travel behavior, as has been shown consistently in previous research. The variables identified through the present analysis will provide a basis from which to develop more nuanced composite measures of integration. Future research will link these composite measures to travel behavior using more sophisticated modeling techniques. Ultimately, we expect that station areas with characteristics representative of high levels of integration between transit and the built environment are more likely to foster positive travel outcomes.

DATA AND METHODS

In this analysis, we develop a series of models in order to identify those variables that best contribute to the quantification of "level of integration" and explain a variety of travel outcomes. Four travel outcomes related to car ownership, vehicle miles traveled (VMT), regular use of LRT, and regular use of "alternative" modes of transport. The purpose of the research is not to assess the effects of specific variables on travel behavior; rather, we intend to identify the range of variables that are important in explaining a variety of travel behavior outcomes and could be important as part of a "level of integration" composite variable. Therefore, the outcome variables assessed here are not meant to exhaustively capture all aspects of travel behavior. They instead provide a range of possible travel outcomes from which to test the "level of integration" concept and identify those factors that are most important in explaining travel outcomes. As shown in Figure 1, a total of 12 independent variables related to "level of integration" in three categories are included in the analysis: built environment characteristics, transit LOS, and access to amenities. These integration variables, along with several other measures meant to account for socio-demographics and possible self-selection effects, were used in an iterative model-building process resulting in a final best-fit model for each of the four travel outcomes. The variables included in each of the final models are identified as the measures that are most important to future analyses evaluating the integration between rail transit and the fabric of the community. Data and methods employed in the present study are described in more detail in the following section.

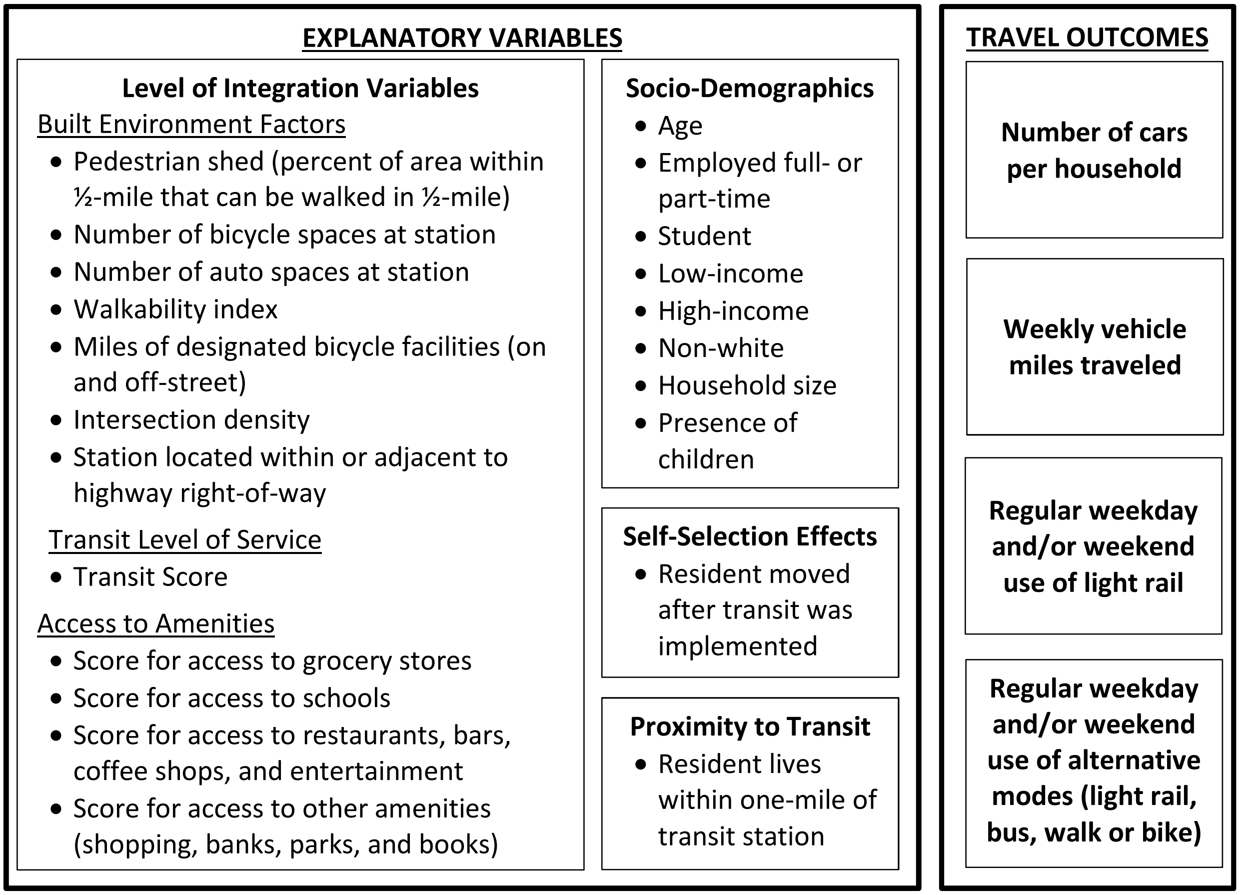

FIGURE 1 Explanatory and outcome variables

Data

Independent Variables: "Level of Integration" Measures

We evaluate three categories of variables associated with the "level of integration" between light rail transit and the fabric of the community developed using a variety of data sources.

Built Environment Factors Six variables measuring characteristics of the built environment are included. All were developed using geographic information system (GIS) data obtained from the City and County of Denver (CCD) and the Regional Transportation District (RTD) in fall 2011. The variable "pedestrian shed" represents the percent of the total area within ½-mile of a station that can be reached by walking along the network for ½-mile. Higher values for "pedestrian shed" are expected to increase the level of integration. The variables "park and ride parking spaces" and "park and ride bicycle spaces" represent the total number of parking spaces available at the LRT station for automobiles and bicycles, respectively. We expect that less auto parking and more bicycle parking will contribute to higher levels of integration. The variable "walkability index" is an index measuring the quality of walking facilities within one-mile of the station. The index was created following the methodology outlined by Frank et al. (2010) (*38*). Four measures are included in the index: net residential density (number of households per acre of residential land use), retail floor-area ratio (total retail building square footage divided by retail land area square footage), intersection density (number of intersections per acre), and land use mix (a normalized value where 0 indicates single-use and 1 indicates even distribution across five uses). The index is a composite score of summed z-scores of the four measures, with intersection density weighted twice that of the other three measures. The variable "miles of bicycle facilities" indicates that number of miles of on-street and off-street bicycle facilities within 2-miles of stations. Higher values for walkability index and miles of bicycle facilities are expected to contribute positively to the level of integration. The variable "intersection density" represents a commonly used measure in walkability research (*39*). Intersection density is calculated as intersections per square mile in the area within 1.5-mile of the station. Higher intersection densities are expected to be associated with higher levels of integration. The final built environment variable, "highway ROW" is a dummy variable indicating whether the station is located within or adjacent to U.S. interstate and/or highway right-of-way (ROW). We expect that stations located outside of highway ROW will exhibit higher levels of integration.

Transit Level of Service (LOS) Transit LOS is measured through the variable "transit score," which is derived from Transit Score, a patent-pending measure developed by Walk Score that assigns a score based on how well a location is served by public transit on a scale from 0 to 100 (*40*). The algorithm accounts for three factors: the distance to the nearest transit stop(s), frequency of the route(s), and type of route(s) with heavy and light rail weighted more heavily than bus service (*41*). While not a perfect measure, in combination, these factors serve as a strong indicator of the usefulness of transit at a particular location. Higher transit scores are expected to be associated with higher levels of integration.

Access to Amenities Destination accessibility is widely acknowledged to be an important factor in assessing travel behavior (*13, 16, 21, 25, **Error! Bookmark not defined.***). While both local and regional accessibility is likely to affect travel behavior in station areas, the present study is focuses on accessibility to local amenities (i.e. amenities within station areas. Further work is required in order to integrate measures of regional accessibility. Variables accounting for walking access to four categories of amenities – grocery stores, schools, food and entertainment, and other amenities – are derived from the Street Smart Walk Score and included in analysis (*42*). Walk Score uses data from several sources to calculate scores for nine different amenity categories based on the number of destinations in each category and the street network distance to those destinations (*43*). The amenity scores included in the present analysis were selected because of their importance to the level of integration between transit and the community. Research shows that walk accessibility to grocery stores is strongly associated with walking behavior (*44*). Research similarly identifies restaurants and bars, as well as coffee shops and entertainment businesses to be common walking destinations (*44,45*). We therefore use the score for grocery amenities as one variable ("grocery score"), and the combined scores for restaurants, bars, coffee shops, and entertainment as another variable ("food and entertainment score"). Walk Score also recognizes schools as important walking destinations, the score for which we include as "school score." The remaining four categories calculated by Walk Score – shopping, banks, parks, and books – are included in the variable "other score." We expect that higher scores for all categories of amenities will be associated with higher levels of integration.

Independent Variables: Socio-Demographic Controls

Six socio-demographic variables are also included in order to account for individual characteristics commonly associated with travel behavior. These variables were obtained from a survey of residents in the Denver Metro undertaken in spring and summer of 2011. A mail-out/mail-back survey tool was distributed to randomly selected households in two counties, Denver and Arapahoe, which contain 34 of the 36 LRT stations. The survey effort achieved a response rate of 14%, with over 250 responses. The survey included questions related to housing, household, and socio-demographic factors, as well as about travel behavior both before and after light rail transit was implemented, or before and after the resident moved to the neighborhood. Attitudes related to travel, land use, and the environment were also queried. The present analysis includes data obtained only from those respondents residing within two-miles of the 25 LRT stations located in the City and County of Denver, a sample of 124 surveys. The analysis presented here includes several measures developed based on survey data including dummy variables accounting for full- or part-time employment ("employed"), status as student ("student"), and annual household incomes less than $25,000 ("low income") and more than $100,000 ("high income"). Persons of color are also identified through the dummy variable "non-white." The number of individuals reported to live together as part of the same household "household size" is also included, along with the respondent's age ("age"). A dummy variable for the presence of at least one child under the age of 18 ("presence of children") is also included.

Independent Variables: Self-Selection and Proximity to Transit

Possible effects of self-selection are also accounted for through the inclusion of the dummy variable "moved after transit." Self-selection describes the phenomenon in which households choose to live in a neighborhood expressly to satisfy their desired travel behavior. For instance, self-selection exists when a resident wishing to commute to work by light rail chooses (self-selects) to live in a neighborhood served by light rail. Self-selection is considered to be important to travel behavior research because the impact of transit access and the built environment may be over-estimated when individual's residential location and travel preferences are not accounted for (*46*,*47*). Through their review of 38 empirical studies, Cao et al. (2009) identify nine methodological means for addressing self-selection, ranging from simply asking respondents whether their travel and land use preferences influenced their residential location decision to rigorous joint and structural equation modeling techniques. We follow the most straightforward approach by accounting for whether respondents moved to station areas after the implementation of transit service. Although the survey tool did not directly ask about preferences guiding residential location decisions, we are still able to identify whether status as an in-mover has an effect on travel behavior outcomes. If final best-fit models include the variable, it is possible that self-selection may affect the outcome variables. If the model does not include the variable, self-selection effects are not likely. It should be noted that accounting for self-selection is most important in studies that aim to precisely estimate the impact of policies governing the built environment and land use on travel behavior, fuel consumption and emissions (*47*). Although it is important to account for self-selection in all travel behavior research, it is less important in the present analysis since we are primarily interested in understanding the key factors involved in explaining travel outcomes, not in specifically estimating the effects of variables on travel outcomes.

A final dummy variable, "within one-mile" identifies those survey respondents that live within one-mile of a transit station. The variable is included in order to account for whether respondents living within one-mile of stations exhibit different travel outcomes than those living between one and two miles from stations.

Dependent Variables

Four outcome variables derived from survey data are assessed in this analysis:

- Number of cars available within a household ("number of cars")
- Weekly VMT ("weekly VMT"),
- Binary variable identifying individuals who report using LRT regularly on weekday and/or weekend days ("LRT use")
- Binary variable identifying individuals who report using "alternative" modes (LRT, bus, walking, and/or biking) regularly on weekday and/or weekend days ("alternative mode use").

Each of these variables are derived from responses to questions in the survey tool. The first two variables were directly asked in the survey ("how many motor vehicles are available for regular use by the individuals in your household?" and "about how many miles per week (both work/school and non-work/non-school trips) do you usually drive (car or motorcycle)?"). The latter two variables are derived from questions that asked respondents to indicate whether if they "use light rail" regularly on average weekdays and weekend days. For those who did not report using light rail, another question asked if they regularly use other modes on average weekdays and weekend days.

Methods

Data for respondents residing within two-miles of the 25 LRT stations located in the City and County of Denver (CCD) was employed in the analysis, with the individual respondent as the unit of analysis (n=124). Only stations located in CCD are analyzed due to a lack of available data for other areas in the metro. A series of best-fit models were developed in order to identify the variables related to "level of integration" that best explain the four travel behavior outcome variables. Ordinary Least Square (OLS) regression was used to model continuous dependent variables ("number of cars" and "weekly VMT") and logistic regression was used to model the binary variables ("LRT use" and "alternative mode use"). All models were fit iteratively using R statistical software. The best fit OLS models were selected based on adjusted R-squared statistics, while logistic models were selected based on Akaike information criterion (AIC) statistics. Best fit models are used to identify the integration factors, socio-demographic controls, and possible self-selection effects that best explain each of the four dependent variables.

Spearman's Ranked Correlation Coefficients for non-normal distributions were tested for all pairs of independent variables to identify sources of multi-collinearity. Pairs of explanatory variables with correlations 0.60 and higher were flagged and prevented from being jointly present in final models. Five pairs meeting this criteria were identified: "school scores" and "intersection density" (rho=0.78), "food and entertainment score" and "transit score" (rho=0.65), "other score" and "highway ROW" (rho=-0.62), "pedestrian shed" and "intersection density" (rho=0.62), and "miles of bicycle facilities" and "highway ROW" (rho=-0.80). The variable in each of these pairs that provided the most explanatory power was retained in the models, while the remaining variable in the pair is omitted such that none of the pairs exhibiting multi-collinearity are included jointly in the final best-fit models.

RESULTS

Results from the four final best-fit models are presented in Table 1.

TABLE 1 Best-Fit Model Results

Independent Variables	Regression Coefficients *(standard error)* for Dependent Variables			
	Model 1: Number of Cars	**Model 2: Weekly VMT**	**Model 3: LRT use**	**Model 4: Alternative Mode Use**
Intercept	1.285 *(0.421)* **	254.730 *(70.858)* ***	-11.887 *(5.248)* *	0.546 *(2.076)*
Level of Integration Variables				
Built Environment Factors				
Pedestrian shed	--	-1.220 *(0.399)* **	0.107 *(0.039)* **	--
Park and ride parking spaces	--	-0.040 *(0.024)*	--	--
Park and ride bicycle spaces	0.017 *(0.006)* **	--	0.132 *(0.046)* **	--
Walkability index	-0.152 *(0.126)*	--	--	--
Miles of bicycle facilities	--	-52.071 *(12.234)* ***	1.651 *(0.872)*	1.045 *(0.468)* *
Intersection density	--	--	--	--
Highway ROW	--	--	--	--
Transit LOS				
Transit Score	--	--	--	--
Access to Amenities				
Grocery score	--	--	--	--
School score	-0.043 *(0.410)* **	--	--	--
Food/entertainment score	--	1.789 *(1.059)*	--	--
Other score	--	1.886 *(1.837)*	-0.207 *(0.075)* *	-0.167 *(0.078)* *
Socio-Demographic Controls				
Age	-0.001 *(0.005)*	--	-0.065 *(0.040)*	--
Employed	--	--	--	-0.171 *(0.844)*
Student	--	-58.748 *(26.862)* *	5.951 *(2.161)* **	--
Low income	--	-22.129 *(20.380)*	2.555 *(1.214)* *	17.917 *(1386.4)*
High income	--	--	3.646 *(1.259)* **	--
Non-white	--	503.380 *(16.105)* **	-6.183 *(2.907)* *	-2.968 *(1.218)* *
Household size	0.387 *(0.069)* ***	--	-0.034 *(0.393)*	--
Presence of children	--	--	1.976 *(1.382)*	0.997 *(0.782)*
Self-Selection Effects and Proximity to Transit				
Moved after transit	--	--	1.151 *(0.986)*	--
Within one-mile	--	16.060 *(12.028)*	--	--
Degrees of freedom	112	97	81	82
Adjusted R-squared	0.291	0.203	N/A	N/A
AIC	N/A	N/A	77.316	104.24

*p<0.05, **p<0.01, ***p<0.001

DISCUSSION

While findings are not entirely conclusive, our research provides insight into the key factors that should be considered in future analyses of the level of integration between rail transit and the community fabric. These observations are outlined below for each level of integration variables, socio-demographic factors, and self-selection effects.

Key "Level of Integration" Factors

Several integration variables appear to be important to numerous travel outcomes. Miles of bicycle facilities is included in the three of four models with higher numbers miles associated with lower weekly VMT and higher likelihoods of LRT and alternative mode use. Access to "other" amenities (shopping, banks, parks, and books) is also included in three of the models (weekly VMT, LRT use, and alternative mode use). This finding suggests the need to disaggregate the "other amenities" scores in order to disentangle the effects of each category. The percent of total area within ½-mile of a station that can be reached by walking along the network for ½-mile (variable "pedestrian shed") is an important explanatory variable, with larger pedestrian sheds linked to lower VMT and higher likelihoods of using LRT. The number of bicycle spaces at stations is important to number of cars and LRT use. Three pairs of variables also appeared in multiple models. "Miles of bicycle facilities" and "other score" co-appear in three models, while "Pedestrian shed" and "Miles of bicycle facilities" and "Pedestrian shed" and "other score" appear as pairs in two models. The fact that these three variables 'hang' together in the models implies possible utility in grouping them as part of a future "level of integration" composite variable.

Variables that appear in the models seldom or not at all are also noteworthy. Intersection density, presence of station within or adjacent to highway right-of-way, transit score and access to grocery amenities appear not to be important in explaining travel outcomes, as none appear in any of the four models. The lack of explanatory power for intersection density and grocery amenities is particularly surprising, since previous research suggests that both are important predictors of non-motorized travel. Both "intersection density" and "highway ROW" were subject to concerns about multi-collinearity, which could have affected their inclusion in final models. The number of parking spaces at park and ride stations, walkability index, access to schools, and access to food and entertainment amenities also appear to hold little explanatory power, with each only appearing in one final model. These variables need to be revisited in order to understand whether they are measuring the phenomena of interest. In particular, it may be important to account for additional parking factors including the presence of on-street parking, parking costs, and parking occupancy rates.

For the most part, integration variables followed our a priori expectations with variables related to increased walk- and bike-ability and access to amenities associated with travel outcomes thought to be beneficial – decreased car ownership, decreased weekly VMT, and higher likelihoods of LRT and alternative mode use. However, there are some notable instances in which the relationships between integration variables and travel outcomes do not follow expectations. Curiously, an increase in the supply of bicycle spaces at park and ride stations is associated with higher levels of car ownership. However, this finding has limited implications since the variable contributes little to an understanding of how integrated a station area is. Results also indicate that several of the amenity scores are related to travel outcomes in ways that defy expectations. The "other" (shopping, banks, parks, and books) amenity score is particularly difficult to account for with results suggesting that higher levels of access to "other" amenities are associated with higher VMT, and lower likelihoods of using LRT and alternative modes regularly. Similarly, higher scores for food and entertainment and school amenities are associated with higher VMT. These relationships suggest that more nuanced methods of measuring access to amenities should be developed and assessed. It should be noted that although the direction of the above relationships do not follow expectations, the inclusion of the variables in the final best-fit model suggest that they merit further inquiry as possible measures of "level of integration."

Key Socio-demographic Factors

All the socio-demographic factors tested appear to be important in explaining travel behavior outcomes, with all but two (“employed” and “high income”) appearing in at least two of the four models. “Low income” (annual household income less than $25,000) and “non-white” appear to be most important with presence in three models, while “age,” “student,” and “presence of children” all appear in two models. Socio-demographic variables are particularly important in explaining regular LRT use, with seven of the eight factors included in the final best-fit model. Results of our analysis clearly indicate that socio-demographic variables must be accounted for in future investigations of the effects of level of integration.

Self-Selection and Proximity to Transit

Possible effects of self-selection were tested in the models through inclusion of the dummy variable “moved after transit.” This variable is important in explaining only one outcome variable – regular use of LRT – with results suggesting that residents who moved to station areas after implementation of transit are more likely to use LRT. This finding makes sense, since it is understandable that in-moving residents may have selected their residential location based on its proximity to transit and thus are likely to use LRT. Therefore, it is apparent that self-selection should be accounted for in future efforts that seek to measure and assess level of integration. Failure to do so may over-estimate the impact of integration on travel behavior outcomes, particularly if future research aims to precisely estimate the impact of policies encouraging integration between transit and the built environment.

The variable “within one-mile” was included in the analysis with the assumption that residents living within one-mile of transit stations may exhibit different travel outcomes than those living between one and two miles from stations. This variable is only included in one final model (assessing “weekly VMT”) suggesting that it is of limited utility in future integration analysis. Interestingly, residents living within one-mile of stations are associated with higher VMT, which runs counter to a priori expectations.

CONCLUSIONS

While countless studies evaluate travel behavior associated with various elements of TOD, most assess built environment factors in isolation, preventing a comprehensive understanding of the interrelated nature of the fabric of transit-oriented communities. We take a different approach by aiming to understand the elements that contribute to the integration of rail transit and the built environment, and how varying levels of integration may affect travel outcomes and quality of life more broadly. In the present research, we identified the key integration factors that will contribute to the development of measures accounting for “level of integration.” The variables used in the present analysis were developed based on readily-available data in order to explore the viability of a “level of integration” measure. Although they do not represent perfect measures, they help us in moving towards a deeper understanding of the factors contributing to integration. Future work will develop more nuanced measures for integration factors, particularly in those cases in which unexpected and counterintuitive effects on travel outcomes in the present analysis. In particular, the measurement of access to amenities should be reconsidered. While the measures derived from Street Smart Walk Score provide a good starting point, and appear in several of the models, results are inconsistent. Further work should also account for regional accessibility. Future research will also aim to develop composite measures of level of integration, and will test the effects of these measures on travel behavior using more sophisticated modeling techniques. In sum, this research expands knowledge around the factors that contribute to the integration of transit and the community fabric, particularly in cities characterized by auto-dependence with second-generation LRT systems, such as Denver. The present analysis begins to shed light on the ways in which positive travel and quality of life outcomes might be realized and optimized in communities investing in rail transit, and provides a foundation upon which future research will continue this important work.

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