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Evaluating Social Equity of Transit Accessibility: A Case of Salt Lake County, U.S.

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Abstract
Addressing social equity in public transportation remains a key challenge for many cities and planning organizations. In this study, we examined social equity dimensions of accessibility to light rail transit (LRT) stations in Salt Lake County, U.S., by employing two novel methods. First, we used the Two-Step Floating Catchment Area (2SFCA) method to examine the interactions between the demand and supply of the public transit service. Second, we developed geospatial models to account for spatial bias in transit equity analysis. Results showed little evidence of inequitable access to LRT stations in Salt Lake County. The accessibility to LRT stations appeared to be generally higher in the downtown and transit catchment areas with a higher concentration of low-income and ethnic minority populations. Furthermore, we found statistically significant associations between higher transit accessibility and households without a home or private motor vehicle. Our findings suggest that transit investments in Salt Lake County could leverage substantial transportation accessibility opportunities to achieve an equitable and sustainable future.

Keywords
Accessibility, Equity, Light Rail Transit, 2SFCA

Accessibility is an important measure that captures people's ability to connect with desired services and destinations. These desired services and activities mainly include but are not limited to education, health, housing, and employment opportunities. Therefore, improving accessibility is an important goal for most transportation planning agencies, and policies (*1*). Recently, there has been growing interest in public transit accessibility, which led to the development of accessibility-based performance measures for public transit agencies (*1*–*3*). However, there remains a challenge to assessing both the allocation of transportation resources and socio-demographic factors – the supply and demand of public transportation infrastructure (*4*). From a social equity perspective, understanding the disparities in the demand and supply of public transit services is a crucial first step to addressing the equity gap in public infrastructure.

The most commonly used accessibility measures include frequency-based indicators, opportunity-based metrics, or gravity-based measures (*5*). A major theoretical limitation of these approaches is that they lack consideration of the demand side of accessibility. In some studies utilizing cumulative opportunity measures, the demand side has been somewhat considered (*6, 7*). The two-step floating catchment area (2SFCA) analysis is a good alternative method that considers both the demand and supply sides of accessibility. This approach has been widely used in public health and geography (*8*). Despite its popularity, the application of 2SFCA within transportation planning literature has been somewhat limited. This study leverages the relative novelty of the 2SFCA method in transportation planning to evaluate both the demand and supply of transit services for equity analysis.

An equally important question in transit accessibility analysis is how transit facilities are distributed across space and by socioeconomic status. This is the question of equitable distribution of public transportation infrastructure. Over the past several years, a growing body of research has examined the equity dimension of transit accessibility (*5*–*7, 9, 10*). These studies have shown that any systemic or unintentional obstacles to accessibility for underserved populations, including low-income and racial minority groups, can lead to significant social exclusion, resulting in increased social, economic, and transportation inequities. Focusing on the issues of social exclusion, previous research has largely examined the distributional aspect of transportation burden and benefits (*11, 12*). Relatively straightforward

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methods, such as Gini Coefficients, descriptive statistics, and regression models (5, 7), have been used for analyzing the distributional aspect.

Although Light Rail Transit (LRT) systems have been studied extensively from a cost-benefit angle (13), their social equity dimensions have been understudied. Given that LRT investments consist of a large share of taxpayers' money, it is imperative to examine whether these investments have been distributed equitably. To fill the gaps in the current literature, this study adopts the widely used spatial accessibility technique (2SFCA) and spatial regression to evaluate social equity dimensions of accessibility to LRT in Salt Lake County, U.S. The subsequent sections of this research are organized as follows. First, we reviewed the existing literature on accessibility measurement and transit equity assessment methods. Second, we briefly illustrated the study area context along with the data and methods. Third, we presented our analysis and statistical test results. In the fourth and final sections, we provide an in-depth discussion of our results and analysis along with a summary of our findings, recommendations, and future research directions.

Literature Review

Transit Accessibility

According to Hansen (2), accessibility is defined as "... a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation." In general, accessibility can be understood as the ease of reaching the desired destination from a specified location (7) and can be operationalized in terms of the number of available opportunities given some spatial friction, or impedance (14). Commonly, the desired destinations are tied to economic opportunities, whereas the impedance is measured in terms of distance or travel time to the destination from the origin.

Building on this conceptual definition of accessibility, there have been numerous efforts to develop an accessibility measure using quantitative methods. Most of these research boil down to the following categories: (i) infrastructure-based models, (ii) graph theory and spatial separation (distance) measures, (iii) cumulative opportunities models, (iv) gravity measures, (v) utility measure, and (vi) time-space measure (15–18). These accessibility measures have been developed to understand the characteristics of a given location based on transportation options, land use distribution, time, and individual choices, which are known as the components of accessibility (15). Previous research has used these features to understand the interactive nature of land use and transportation, analyze the impacts of proposed transportation projects, find suitable land use interventions, and even highlight the differences in the impacts between various population groups in order to analyze social equity dimensions of accessibility (16, 17).

Recent studies have focused on public transit accessibility because it has the potential to contribute to a more equitable distribution of public investments across different population groups (19). Improvements in public transit service could lead to addressing existing socioeconomic inequalities by increasing access to various social and economic opportunities. There are two approaches to quantifying transit accessibility: accessibility to transit and accessibility by transit (20). Accessibility to transit captures one's potential to utilize public transit services from their place of residence, typically being measured as access to public transit stations. On the other hand, accessibility by transit focuses on the access to opportunities enabled by public transit across a given geographic boundary. In this research, we are primarily interested in understanding accessibility to public transit and its equitable distribution within Salt Lake County. This helps us analyze the distributional aspect of transit service across different demographic groups within the metropolitan region.

Social Equity

Equity research entails examining metrics for accessibility that can be quickly assessed for specific demographics, such as people from low-income households or members of racial or ethnic minorities (21). In transportation research, social equity has been largely understood as having two components: horizontal equity and vertical equity (5, 22, 23). In horizontal equity, each individual/group is treated equally in resource and cost distribution. As horizontal transit equity ensures the uniform spatial distribution of transit facilities, it disregards the population densities and regional/urban characteristics to access the need for public transit (23). On the contrary, vertical transit equity, also referred to as transit justice, advocates for the distribution of transit resources among individuals or groups with different abilities and needs, thus favoring groups depending on social class or specific requirements to offset societal disparities (22).

Limited research has been conducted on transit equity for Utah and Salt Lake City. Previous studies examined transit equity in terms of home-to-workplace accessibility during the pandemic, but accessibility to public transit stations was not analyzed (24). Another study assessed the walking accessibility to transit stops; however, its geographic scope was limited to a small neighborhood in Salt Lake City (25). As transit accessibility has a direct impact on disadvantaged groups' livelihood, which can result in social exclusion (26), this study aims to access the vertical equity in the distribution of Utah light rail stations using Salt Lake County as the study area.

Data and Method

Study Context

Figure 1 shows our study area and the light rail systems in Salt Lake County. Utah Transit Authority (UTA) introduced light rail services branded as UTA TRAX to enhance transit ridership and connectivity to shared community destinations throughout the Salt Lake valley (27). Currently, 12% of renter households and 2% of owner-occupied households in Salt Lake County have no car, so they are solely dependent on public transit (28). The race-wise distribution of car ownership further demonstrates that 15% of black, 8% of Asian or Pacific Islanders, and 5% of White/Latino households depend on public transit to access jobs and basic amenities as they do not have any car (29). So, the question remains whether the TRAX is effectively supporting the mobility demand of these diverse groups.

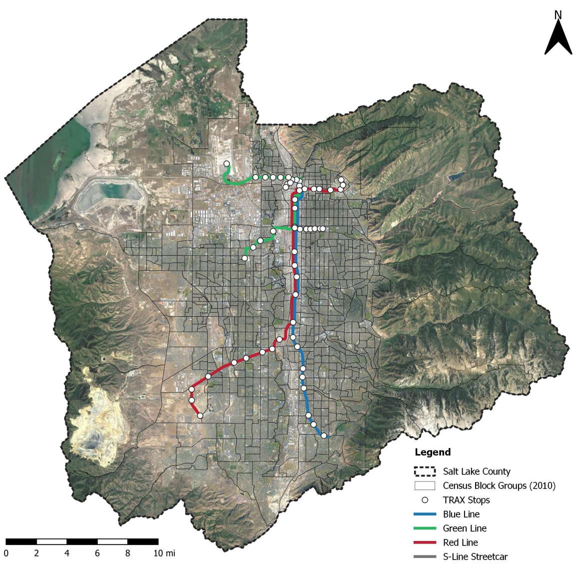

Figure 1. Study Area in Salt Lake County, Utah, United States

Spatial Accessibility Using the 2SFCA Method

To quantify the supply and demand sides of transit accessibility, we used the two-step floating catchment area (2SFCA) method. Over the past decades, the 2SFCA has emerged as a key measure for spatial accessibility, with current enhancements leveraging the shortfall of distance-decaying effects (30–33). For instance, recent applications of 2SFCA have measured the differentials in spatial accessibility at the micro-scale to reflect the balance between supply and demand of public facilities, such as healthcare and education (34, 35). There are three steps to calculate spatial accessibility using the 2SFCA method. The first step comprises extracting census block group and TRAX station data for spatial joins. We calculated the supply ratio of TRAX stations for each station area by deriving the transit frequency and ridership capacity. We calculated the TRAX ridership capacity from GTFS by following sequential steps of importing the transit dataset for Utah, identifying the weekday schedule of service, calculating headways, and mapping headways by route. In the second step, we defined a 15-minute walk shed by calculating a network buffer around every transit station area at the census block group level and joined the resultant catchment area with the already computed supply ratio. Lastly, a supply-demand ratio is computed by finding the population to transit supply per capita for each transit station area – to derive a spatial accessibility measure.

Indicators of Social Equity

We compiled various indicators of social equity based on previous literature. While the concept of social equity has been around for years, previous studies have produced mixed results due to their variations in adopted methodologies (36). Despite these variations, some research still provides a useful framework for operationalizing social equity in transportation. For example, Dill and Haggerty (37) used a combination of demographic variables, such as racial and ethnic minorities, families living below the poverty line, children under the age of 18, seniors over the age of 65, and people who speak little English, to examine historically underserved populations in their analysis. Building on these previous studies, we adopted eight commonly used social equity indicators. These indicators were household income, race, ethnicity, age, employment, education, vehicle ownership, and house ownership. A full list of social equity indicators and their descriptive statistics is shown in Table 1.

For all our data, we relied on publicly available secondary data sources, such as the U.S. Census. The demographic dataset of the socioeconomic indicators was adopted from the 2019 5-year American Community Survey at the block-group level. The geospatial dataset of the UTA-TRAX services, routes, and stops was obtained from Utah Geospatial Research Center. The service frequency of the UTA TRAX service was derived from the UTA General Transit Feed Specification (GTFS) feed, which is a commonly adopted form of transit data that provides predetermined information on transit routes, stop timings, fares, and more. The isochron buffers of the service area around the TRAX stations were created using the OpenRouteServices API key.

Analytical Approach

We used spatial regression models to account for spatial bias in our data. Spatial bias can occur when there is a systematic clustering or dispersion of observed variables (i.e., spatial autocorrelation), violating the independent and identically distributed (i.i.d.) assumptions of random variables. As a rule of thumb, the presence of autocorrelation in an observation violates the statistical assumption of independence within and between groups of observations (38–40). Technically, the presence of spatial autocorrelation can be expressed by:

$$Cov(y_i, y_j) = E(y_i, y_j) - E(y_i)E(y_j), i \neq j \qquad (1)$$

Where, (y_i) and (y_j) are observations on a random variable at locations (i) and (j) in space, and (i), (j) can be points (i.e., measured as latitude and longitude or areal units). In this regard, the value of a variable of interest in each region (i) is associated with the value of the same variable in the neighboring regions (j). We first used Moran's I to check for spatial autocorrelation (*41, 42*). Then we developed both ordinary least square and spatial regression models to assess the equity impact of transit accessibility. The process is finalized by empirically selecting the best spatial model to interpret the resultant impact of transit accessibility on the social equity indicators.

All our analyses were conducted using open-source software, R (v4.2.1) and QGIS (3.22.2).

Results

Descriptive Summary

Table 1 shows the descriptive statistics of the social equity indicators. The mean percentage of dependent groups (children and older adults) was about 37%, which is comparable to the general US population. About 39% of households in Salt Lake County are considered low-income families according to the area median income level. The ratio of the non-white population and Hispanic population is about 20% and 18%, respectively, which are lower than those of the U.S. population. The unemployment rate is about 3.7%, which is higher than that of the U.S. population.

Transit Accessibility

The 2SFCA analysis of transit accessibility shows that the accessibility to the TRAX stations in Salt Lake County is generally higher in the block groups that are within walking distance from the transit stations. Particularly, the block groups near downtown Salt Lake, central Salt Lake City, around the center of West Valley City, and near the Murray-Draper areas have comparatively higher accessibility than other block groups adjacent to the TRAX lines. These block groups have high population density and multiple transit stations in close proximity to each other, thus effectively increasing the accessibility to the TRAX stations. Additionally, amongst the areas with high transit accessibility, downtown Salt Lake and Sugarhouse areas demonstrated the highest 2SFCA values - partly because of the larger number of TRAX stations in these areas.

Ordinary Least Square Regression Model

In order to examine the relationship between the social equity variables and transit accessibility, we first used the Ordinary Least Square (OLS) model. Our model specification followed the details described in the method section, which includes eight key variables, such as a percentage of dependent age groups (below 15 and above 65), a percentage of renter households, and a percentage of households without a car. However, the goodness-of-fit was relatively low (0.239), indicating that further improvements can be made. Upon further analysis, the residual histogram and the Q-Q plot demonstrated that the data were not normally distributed and violated the assumption of the independent and identically distributed (i.i.d) random variables. The Moran's I test further illustrated a spatial correlation using the Queen's Contiguity matrix. The Lagrange Multiplier (L.M.) diagnostic test, a widely used test to check for spatial dependence, also demonstrated significant L.M. and Robust L.M. (RLM) statistics for both the spatial error and spatial lag models, indicating the need for using spatial models for further analysis.

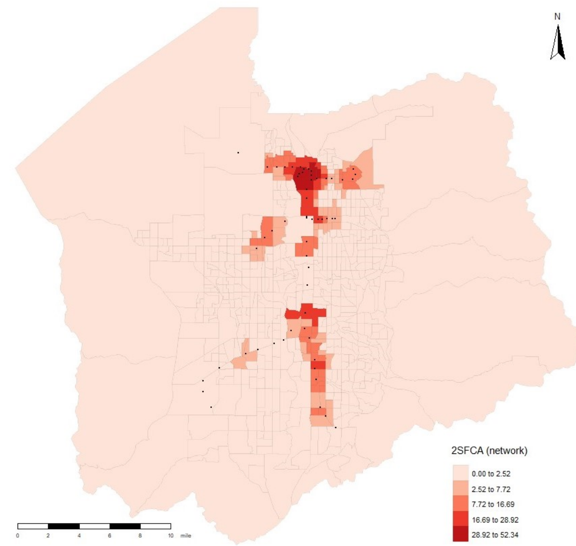

Figure 2. Light Rail Transit Accessibility in Salt Lake County

Spatial Regression Models

To address the spatial autocorrelation issues in our data, we used two spatial regression models, Spatial Lag Model and Spatial Error Model. The Spatial Lag Model addresses spatial dependency in a spatial unit's dependent variable and its surrounding units, whereas the Spatial Error Model considers geographic dependence in a spatial unit's error term and its neighboring units (*43*). The Spatial Lag Model showed that only the percentage of households with no vehicle significantly impacted transit accessibility. In contrast, the Spatial Error Model produced no significant impact of the explanatory variables on accessibility other than the intercept. Although the performance of these models does not vary significantly, the Spatial Lag model was selected as the best-fitted model based on the Akaike information criterion (AIC) values.

Table 1. Summary of Variables by Block groups

Variable	Description	Min	Median	Mean	Max	SD	IQR	NA's
% Dependent Population	Percentage of dependent groups (i.e., less than 18 and over 65 years)	3.981	38.347	37.107	61.345	8.939	10.586	1
% Household < 80% AMHI	Percentage of households with income less than 80 percent of the Area Median Income (74,865 USD)	0	37.559	39.41	89.024	19.052	30.175	2
% Non-White	Percentage of non-White population	0	14.828	20.13	86.616	16.64	22.925	1
% Hispanic	Percentage of the Hispanic population	0	11.876	17.835	81.726	16.789	22.34	1
% Unemployed	Percentage of the unemployed civil population	0	2.895	3.66	21.165	3.357	3.64	2
% < High School	Percentage of the population over 25 years with less than a High School Diploma	0	4.208	6.009	38.211	5.866	7.679	1
% No Vehicles	Percentage of Households who do not own Vehicles	0	2.51	4.885	50.224	6.937	6.625	2
% Renters	Percentage of renter-occupied house-holds	0	24.485	31.187	100	25.393	37.5	2

Table 2. Model Results of Transit Accessibility in Relation to Social Equity Indicators

Variable	Ordinary Least Square		Spatial Lag Model		Spatial Error Model	
	Estimate	*p*-Value	Estimate	*p*-Value	Estimate	*p*-Value
Intercept	3.769**	0.005	0.585	0.457	3.861	0.025
% Dependent Population	-0.115***	0.000	-0.022	0.217	-0.032	0.107
% Household < 80% AMHI	0.016	0.454	-0.002	0.876	-0.01	0.459
% Non-White	-0.028	0.242	-0.009	0.545	-0.015	0.331
% Hispanic	0.005	0.857	-0.007	0.671	-0.013	0.371
% Unemployed	0.122	0.088	0.069	0.097	0.044	0.265
% < High School	-0.009	0.893	-0.009	0.810	-0.01	0.794
% No Vehicles	0.240***	0.000	0.071**	0.003	0.047	0.060
% Renters	0.044**	0.005	0.011	0.224	0.013	0.156
Model Performance						
	$Adjusted R^2 : 0.2424$		$Rho : 0.8764$		$Lambda : 0.9120$	
Log-likelihood			-1,641.953		-1,650.228	
AIC	3836.40		3,305.905		3,322.456	
LM (Robust LM) Statistic			624.1029 (91.1694)		535.6696 (2.7361)	

*Statistical Significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Discussion

In this study, we found that transit accessibility is generally higher within the 15-minute walking shed of the transit station along the TRAX lines. This observation is largely consistent with previous literature on transit accessibility. Studies conducted in Auckland, Brisbane, Perth, and Vancouver (7) have shown that transit accessibility is relatively higher for households in close proximity to transit services. However, our study also found several instances of spatial clustering of accessibility around Salt Lake City Downtown, towards the University of Utah, and southbound towards Murray and Sandy. This result implies that transit accessibility is concentrated in certain neighborhoods, and further improvements in transit connectivity would be needed to address this imbalance in transit access while optimizing the network coverage within the Salt Lake Valley for more equitable outcomes.

Our results showed statistically insignificant relationships between transit accessibility and characteristics of under-served populations in our study area. This suggests that transit accessibility in Salt Lake County appears to have little or no association with characteristics of traditionally underserved populations, such as dependent groups (children and older adults), renter households, non-white families, households with low educational backgrounds and income, and families without a private motor vehicle. In other studies (for example, (6)), transit accessibility to desired destinations in Chicago was not ubiquitous for all social minority groups.

Our spatial model indicated a significant positive correlation between accessibility and the percentage of households without a car. This suggests that an increase in accessibility to transit has the potential to provide more opportunities for underserved populations, which has substantial equity implications, especially for households without a car who are more dependent on public transit. Other equity variables, such as the percentage of the unemployed population and renter households within the census block group, were positively correlated with access to transit, although their statistical significance disappeared after accounting for spatial autocorrelation.

In short, we found little evidence to support the significant influence of other equity indicators on transit accessibility, such as race, ethnicity, income, age, education, employment, and homeownership. This result can be contextualized by understanding the history of public transit investment in Salt Lake County (*44*). The Salt Lake streetcar lines existed long before the LRT line, and even the modern UTA TRAX lines have been in service for more than 20 years now. Therefore, it seems plausible to think that the transit investments in the existing streetcar network might have played a role in improving the accessibility of inner-city residents. Our findings suggest that the people who are most dependent on transit for their commute (i.e., households without a car) appear to have relatively higher transit accessibility. In this regard, the UTA-TRAX, in contrast to other counterarguments (*45–47*), seems to provide somewhat robust and inclusive opportunities for households more dependent on public transit.

In comparison to similar transit accessibility studies conducted in other cities (Chicago, Auckland, Brisbane, Perth, and Vancouver), our study found that the accessibility to the light rail service within Salt Lake County is relatively equitable to the socially marginalized groups based on their socioeconomic position. The public transit system in Chicago, Brisbane, Perth, and Auckland appeared to provide relatively lower accessibility in areas with a higher percentage of the socioeconomically disadvantaged population (*6, 7*), whereas transit accessibility was higher for populations residing near the economic centers. Existing population distribution in those cities might explain such results as previous transit lines predating newer transit systems were responsible for shaping the land use patterns and the emergence of more affluent suburban neighborhoods during the streetcar era (*48*). However, the Vancouver study has shown that Metro Vancouver's public transit system provides a better service for low-income families (*7*). Our analysis also found better accessibility in areas with a higher concentration of social minority groups, suggesting an equitable distribution of light rail lines within Salt Lake County. Such equitable distribution of public transit might have been achieved thanks to the long history of coordination and partnership among various government agencies (e.g., Salt Lake County, Wasatch Front Regional Council, Utah Department of Transportation, and Utah Transit Authority), which might have contributed to increasing the overall access to opportunities in the Salt Lake valley (*49*).

Furthermore, there are methodological differences between existing studies, which might have resulted in disparate findings. For example, the Chicago study used a statistical technique to group census tracts into the upper, middle, and lower categories based on equity variables. On the other hand, the Auckland, Brisbane, Perth, and Vancouver studies only considered income and population density as equity variables. While these studies provide a solid basis for measuring transit equity, their selection of equity-related variables and the methods used to analyze the equity impact is somewhat limited. The 2SFCA method and the spatial regression models employed in our study not only capture the spatial component of accessibility but also integrates various components of social vulnerability into the equation, thereby providing a more comprehensive and robust measure of transit equity.

Still, our study is limited in that we only focused on public transit. It would be critical for future studies to empirically examine other modes of transportation as well as other equity variables not examined in this study. Given that this study employed a robust method of accessibility measurement and its spatial relationship with the equity variables, applying the same methods to other cities would be useful and necessary to advance methodological rigor in future studies.

Conclusion

While transit accessibility and equity remain a buzzword in the transportation field across the globe, the distribution of public transit infrastructure and services has remained largely unchanged. Against this backdrop, this study examined transit accessibility for traditionally underserved populations within a fast-growing region. Our study demonstrated that although the spatial clustering seems to be prominently contributing to the distribution of access to transit stations across Salt Lake County, the UTA-TRAX moderates transit equity and does not appear to have any disparate impact on socially marginalized groups in terms of transit accessibility within Salt Lake County. The spatial clusters identified were diffused within the census block groups with a higher percentage of socially marginalized groups and low-income households, demonstrating an equitable distribution of these transit services. This finding is further supported by the result of our spatial regression model, which demonstrated higher transit accessibility for families without a car. This indicates that the availability of transit stations has the potential to increase ridership for households with no vehicles, further reducing dependence on private vehicles in areas well-served by the transit lines. While the overarching findings are uniquely pertinent to the socioeconomic and spatial distribution of transit service in Salt Lake County, this study provides useful insights to inform decision-making on public transit investments and service provisions in order to achieve an equitable and sustainable future.

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Author Contributions

The authors confirm the contributions to the paper as follows: **Faria Afrin Zinia:** conceptualization, study design, formal analysis and interpretation of results, writing - original draft manuscript preparation, validation, and review; **Pukar Bhandari:** conceptualization, study design, formal analysis and interpretation of results, writing-original draft, manuscript preparation, validation, writing - review and formatting; **Justice Prosper Tuffour:** conceptualization, data preparation, data interpretation, writing - original draft, preparation and formal analysis, writing - review and editing; **Andy Hong:** validation, review, supervision, and editing.

Declaration of conflicting interests

The authors, to the best of their knowledge, declare that they have no conflict of interest.

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