Fuzzy Multidimensional Assessment Approach of Travel Deprivation in Small Underdeveloped Cities: Case Study of Lhasa, China

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In small, underdeveloped Chinese cities, the travel needs of economically disadvantaged residents have not been satisfactorily met for a long time, and thus, the problem of travel inequality has become increasingly serious. This study developed and applied a fuzzy multidimensional assessment approach of travel deprivation to assess the travel deprivations that arise because of this travel inequity. The resulting model includes both monetary and nonmonetary indicators, and involves multiple measurement items, dimensions, and related weights. Then, this fuzzy multidimensional assessment approach of travel deprivation is used to measure the travel deprivation in the underdeveloped, small city of Lhasa, China. The results identified both differences and similarities between different parts of the city. Among all measured dimensions, the following four dimensions cause strong travel deprivation: disposable income, travel service quality, travel time, and available transportation. Differences in the travel deprivation were identified between different parts of Lhasa, indicating multidimensional travel deprivation. Furthermore, an early warning analysis on travel deprivation and an assessment of different levels of residents’ travel deprivation in underdeveloped cities are presented. These findings provide an effective evaluation of the current situation of travel inequity in underdeveloped small cities.

1. Introduction

During the process of urbanization, the problem of uneven and inadequate development among different countries, regions, and cities has become a common challenge that residents face across the world. Affected by multiple factors, such as governmental policies, macroeconomic factors, regional resource endowments, and factor mobility, the differences in development levels between different regions of China have become increasingly apparent. The result is the formation of developed and undeveloped regions. In China, the eastern region is the main developed region, while both the western region and the northeast region are the main underdeveloped regions.

Underdeveloped and developed regions are a relative concept. A certain gap still exists between the economic development levels and scientific and technological development levels of these underdeveloped areas compared with developed areas. As an important part of China’s urban system, small cities (with a permanent population of 200,000 to 500,000) are widely distributed. Of these, more small cities are situated in underdeveloped areas than in developed areas. In a number of small cities in western and northeastern China, an insufficiency of public facilities is widespread. For example, in the underdeveloped small cities of the Tibet Autonomous Region and the Qinghai Province, factors such as harsh climate, poor living conditions, and difficulty associated with population settlement restrict further development.

In underdeveloped and small cities, economically disadvantaged residential groups are common, and their number far exceeds that of economically advantaged groups. Huang pointed out that economically disadvantaged groups, to some
extent, represent the economic characteristics of residents of underdeveloped small cities [1]. Mallett reported that economically disadvantaged groups generally take part in life-sustaining behaviors, while the demand for travel to participate in communicative and recreational activities is often suppressed [2]. Blumenberg and Agrawal pointed out that for low-income groups, which form a specific subgroup of economically disadvantaged groups, communicative and recreational travel increases their travel budget and thereby their burden of living. Therefore, low-income groups generally utilize the main type of travel behavior, while the demand for other types of travel is often suppressed [3].

In many developing countries, the travel demand of economically disadvantaged groups is easily ignored. Chikaraishi et al. pointed out that the phenomenon of restrained travel demand is severe in India. Specific economically disadvantaged groups have low mobility, and spatial distance still remains the main obstacle that restricts their travel needs. Except for the travel needs caused by school attendance and work, other travel needs of economically disadvantaged groups cannot be effectively met [4]. Salon and Gulyani compared economically disadvantaged groups in the slums of India with economically advanced groups and found that economically advanced groups can choose between more travel methods. Furthermore, economically disadvantaged groups can only rely on nonmotorized transportation [5]. The studies of Srinivasan and Rogers, as well as that of Li, showed that the cost of using private cars in relatively underdeveloped small cities is relatively high for most residents; consequently, public transportation has become a dependent mode of transportation for residents [6, 7].

The current level of prioritization of public transport development policies in less-developed small cities is not ideal. Giuliano identified the low level of public transportation provided (e.g., low service quality and low accessibility) as the main factor affecting the transportation-related decision-making of economically disadvantaged groups [8]. The study of Nuworsoo et al. showed that low-income groups experience strong dissatisfaction with inadequate public transportation facilities and with the low frequency of bus departures. In underdeveloped small cities, public transportation does not manage well to regulate travel equity. This results in the common situation, where the travel rights of economically disadvantaged groups cannot be effectively guaranteed [9]. Grengs as well as Blumenberg and Thomas pointed out that the social exclusion of economically disadvantaged groups participating in urban transportation will exert a deeper impact on the economic and social relationship network, thus causing a series of social problems, such as social group events and riots [10, 11]. The urgent need to solve the travel inequity problems underdeveloped small cities are facing has prompted scholars to conduct relevant travel equity assessments of such cities.

2. Literature Review

Equity, which originates from the concept of justice within the context of Western political philosophy, has received extensive attention from various fields. Related research on residents’ travel equity stems from the developmental strategy of the USA that promoted private cars during the "Post World War II" (1946–1960) period.

Rosenbloom and Altshuler studied the urbanization and motorization of the USA from 1950 to 1972. They found that the US urban population and urban land grew rapidly, at growth rates of 71% and 176%, respectively. Moreover, during this time of growth, the corresponding household car ownership ratio increased from 52% to 79%, and the ownership ratio of more than two private cars increased from 7% to 30%, respectively [12]. Sanchez demonstrated that the rapid economic development of the USA has induced a series of social problems, including that black people not only had to face pressures of racial discrimination and high unemployment rates, but their travel needs had also been severely neglected, which triggered the civil rights movement. At this point, many studies began to focus on the travel needs of ethnic minorities and low-income groups, and the travel equity of urban residents has become the subject of transportation engineering and related disciplines [13].

Deboosere and El-Geneidy, from the Victoria Transportation Policy Research Institute, have extensively studied the issue of travel equity and continuously conducted research for many years. Deboosere and El-Geneidy divided travel equity into three types, according to horizontal and vertical dimensions: (1) Horizontal equity, which involves equity and egalitarianism; (2) vertical equity, which involves social justice, environmental justice, and social inclusion; and (3) vertical equity regarding mobility needs and ability. In the process toward achieving travel equity, these three different types of travel equity often overlap and diverge with regard to the specific traveler’s interest balance. This is a dynamic process requiring constant balance and coordination [14]. Hay showed that horizontal travel equity is suitable for balancing and coordinating the travel needs of different urban residents in a large area or region, while research on vertical travel equity usually uses a specific city as research object and studies the interior of travel equity [15]. From the perspectives of income level, social class, as well as ethnic or racial differences, studies on the distribution of benefits of a specific mode of urban travel belong to the category of vertical travel equity [16–21].

Travel equity assessment, from the perspective of subjective perception, has become a research hotspot, including travel well-being and travel deprivation. These two conflicting subjective perceptions form the psychological feedback of the public with regard to travel equity. This feedback not only includes the cognition and demand for the overall travel supply or a certain aspect but also the emotions and feelings that emerge during the travel process. Consequently, many aspects are involved such as travel interests and travel opportunities.

Bell showed that the goal of transportation policies is to improve travel well-being, including satisfaction, mobility, and accessibility [22]. Stanley and Vella-Brodrick found that using travel well-being to evaluate travel equity is more meaningful than assessments based on mobility. The reason is that the simple improvement of mobility will cause a series of problems such as traffic congestion and
environmental pollution [23]. Lucas et al. investigated elderly and disabled groups with weak mobility, and showed that these two groups benefited very little from an expansion of the road infrastructure or an expanded and shortened travel time; therefore, it is more valuable to evaluate travel equity from the perspective of psychological perception [24]. Steg and Gifford, as well as De Groot and Steg, identified objective indicators and subjective attitude indicators as equally important to measure travel equity from the perspective of well-being [25, 26]. Jones et al. used a number of indicators, such as reliability, speed, and traffic volume, to assess travel well-being [27]. Busari et al., as well as Delbosc and Currie, showed that improving the mobility of residents will increase their sense of freedom of travel and their sense of happiness, especially when responding to emergencies. The positive psychological effect is more obvious [28, 29]. According to Delbosc, accessibility, mobility, and transportation infrastructure are key factors that affect residents’ travel well-being [30]. Watson et al. and Bergstad et al. used objective indicators, such as mobility, trip times, and trip frequency, to assess travel well-being. The Satisfaction with Travel Scale (STS) and the Swedish Core Affect Scale (SCAS) they proposed have played a positive role in promoting travel well-being related research [31, 32]. Currie and Delbosc used travel satisfaction and travel cost acceptability to assess travel well-being [33]. Later, Delbosc and Currie studied the travel well-being in Melbourne, Australia, and found that the four variables of transport disadvantage, public transport disadvantage, traffic-disadvantaged groups, and relying on others to travel, exert significant effects on travel well-being [34].

Scholars’ concerns about travel deprivation mainly focus on residents’ inequity during travel; however, few studies measured the value of travel deprivation. Duvvuri and Mizokami assumed that the travel needs of traffic-vulnerable groups were all met, and on this basis, they further assessed travel equity among different groups, and proposed corresponding travel guidance strategies to reduce travel deprivation [35]. Lucas studied the phenomenon of travel deprivation in developing countries of Southern Africa. The results identified weak infrastructure and poor traffic management as the main reasons for the social exclusion of vulnerable groups in society. Lucas proposed a travel guidance strategy to alleviate travel deprivation [36]. Ferguson et al. found that the phenomenon of travel deprivation should be reduced in detail. For example, travel equity should inform the setting of bus departure intervals, to provide more travel opportunities for low-income groups and increase their employment, shopping, and medical service opportunities [37].

To the best of the author’s knowledge, so far, travel equity in small and underdeveloped cities has not been studied. Despite the increasing attention devoted to the assessment of travel equity, the current literature suffers from a number of research gaps that have motivated this research.

The contributions of this paper are threefold: Much of the previous work on the travels of economically disadvantaged residents suffers from large differences in the study background. These include differences between countries, and between the cities of the same country. Residents’ income and travel costs vary greatly between cities with different economic development levels. Similar to cities with different population sizes, residents’ travel patterns and lifestyles also differ significantly. Studies on residents’ travel behavior found significant regional and city size differences, but these results are insufficient to guide the economically disadvantaged groups of China’s underdeveloped small cities to solve the travel problems they face. Therefore, this study investigated the travel conditions of residents in China’s underdeveloped small cities and proposed an effective travel deprivation assessment method. Empirical analysis of a specific investigated city provides a reference for solving travel inequity problems of similar cities.

In addition, when studying travel equity from the perspective of subjective perception, most previous studies focused on travel well-being and travel deprivation, which refer to negative feelings that arise because of perceived travel inequity. This paper presents a survey to measure the value of travel deprivation, which enriches research on travel equity assessment.

Finally, with few exceptions, most previous studies on travel deprivation have only considered a specific link or a specific set of factors associated with the travel process. However, research that comprehensively considers the causes of travel deprivation is insufficient. This study analyzed causes of the travel deprivation in the underdeveloped small cities from both monetary and nonmonetary indicators. This makes the assessment of travel deprivation more broadly meaningful and can better reflect the inequity associated with travel. Following previous studies, the developed approach proposes a fuzzy multidimensional assessment approach of travel deprivation, and provides the possibility for residents in underdeveloped small cities to implement traffic demand management strategies to alleviate the travel inequity problem.

3. Methodology

Walker and Mann defined the concept of relative deprivation. This concept implies that someone expects to own certain things, without currently owning these things (because of, e.g., income, housing conditions, transportation, and personal physical condition [38]. De la Sablonnière et al. studied the adaptability of both horizontal relative deprivation and vertical relative deprivation in applications. They pointed out that the field of sociology is more concerned with horizontal relative deprivation, while the field of political science is more concerned with vertical relative deprivation [39]. Smith et al. standardized the process of relative deprivation, and divided the generation of relative deprivation into three steps: (1) comparative motivation; (2) personal cognitive assessment, where an individual realizes that he or the group is at a disadvantage; and (3) negative emotional identification, where the perceiver believes that the current disadvantage he or his group faces is unfair, which triggers negative emotions. When the relative deprivation level of a group reaches a certain threshold, it is easy
to induce group events, such as protests, demonstrations, processions, and strikes [40]. Tiraboschi and Maass verified this conclusion through situational experiments [41]. Combined with the integrated fuzzy and relative (IFR) deprivation measurement model, this paper proposes a measurement model for travel deprivation, which can reflect the travel inequity problem in underdeveloped small cities. The IFR deprivation measurement model considers two factors: the share of the number of individuals whose index value exceeds the research target in the sample set, and the share of the total index of the total index value of other individuals whose index value exceeds that of the individual. Based on considering both monetary and nonmonetary indicators, the IFR method is used to identify the size of the deprivation sensing value, and to assess the deprivation of both monetary and nonmonetary dimensions in underdeveloped small cities. The method this study utilized to measure residents’ sense of deprivation is summarized in the following: based on the individual attributes and measurement items in different dimensions, the individual’s travel deprivation index values are calculated in different dimensions; then, they are weighed to ensure that the individual belongs to the same group. Dimensional total travel deprivation and the average individual travel deprivation of individual groups in different dimensions are finally calculated.

3.1. Model Hypothesis

Hypothesis 1. In the study of the relationship between income and travel ability, Blumenberg and Agrawal, Chikaraishi et al., as well as Salon and Gulyani found that income and travel ability are closely related. This is one of the important reasons why the travel demand of economically vulnerable groups cannot be effectively met [3–5]. Income is an important factor for testing the individual’s comprehensive ability, and it has been extensively applied in the social deprivation perception as an effective tool. To a large extent, income represents the consumption or purchasing power of commodities, and includes personal income, family income, disposable income, and hidden income (e.g., social welfare). Therefore, it is assumed that the income factor (monetary index, \( M \)) is the same as other important factors that lead to travel deprivation for residents in small, underdeveloped cities (nonmonetary index, \( S \)).

Hypothesis 2. Monetary indicators and nonmonetary indicators have significant differences in travel deprivation, and the inherent correlation between both is not considered.

Hypothesis 3. If the travel needs of residents in underdeveloped small cities cannot be met (or cannot be met sufficiently), this will cause deep-seated social exclusion issues (spatial exclusion, temporal exclusion, and economic exclusion). These, in turn, will impose adverse effects on residents’ employment, education, entertainment, and social aspects [35]. Particularly in underdeveloped small cities, traffic-disadvantaged groups face more difficulties to obtain effective protection for their travel rights compared with other groups. The insufficiency of barrier-free transportation facilities is the main reason that restrains the travel demand of physically disadvantaged groups. At the same time, this group is also vulnerable to restrictions in terms of travel distance, travel mode, and travel cost. The social exclusion of such economically disadvantaged groups is mainly manifested in three aspects: spatial exclusion, temporal exclusion, and economic exclusion. Spatial exclusion mainly manifests as poor travel accessibility, time exclusion mainly manifests as an inability to choose efficient travel modes, and economic exclusion has a significant impact on employment, consumption, and entertainment in addition to the impact caused by the need to pay for travel expenses.

Hypothesis 4. Travel deprivation not only originates from the relative comparison of residents during the process of travel but also from the comparison of the travel status of residents with their past and future (or their desired situation). Therefore, travel events (e.g., traffic accidents, traffic congestion, and travel disputes) and the desire for a certain means of transportation will increase the probability of residents’ travel deprivation.

Hypothesis 5. The factors that affect the travel deprivation of residents in small and underdeveloped cities are discrete random variables. The factors that cause residents to experience travel deprivation are discrete random variables, \( \tilde{X} = \{ \tilde{X}_1, \tilde{X}_2, \ldots, \tilde{X}_n \} \), where \( n \) represents the number of influencing factors. Among these, one or more influencing factors with the same attribute can form a dimension that creates travel deprivation, \( \tilde{d}, \tilde{d} \in \{ 1, 2, \ldots, \delta, \ldots, \tilde{h} \} \). Each dimension causes travel deprivation, and the combination of multiple dimensions causes comprehensive travel deprivation.

Hypothesis 6. All dimensions of travel deprivation are positive indicators, i.e., a larger index value indicates a higher level of travel deprivation. In contrast, a smaller index value indicates a weaker travel deprivation perceived by residents.

Hypothesis 7. The deprivation values produced by residents in different indicators and different dimensions are comparable and additive.

3.2. Index Value. The dichotomy method has good applicability for assessments of travel deprivation when nonmonetary indicators are used [42]. The distribution function offers a good assessment of individual deprivation of nonmonetary indicators. When the nonmonetary index deprivation value \( (\mu_i) \) is 1, the travel demand is not satisfied, and travel deprivation emerges. In contrast, when the value of \( \mu_i \) is 0, the travel request is satisfied, and there is no travel deprivation.

For nonmonetary indicators that involve more than two ordered categories, Cerioli and Zani proposed a calculation method that uses equally spaced and ordered categories to reflect the different degrees of deprivation experienced by individuals \( (\tilde{d}_{ki}) \), and it can be written as follows [4]:

\[
\tilde{d}_{ki} = \frac{\text{Index value}}{\text{Maximum index value}} \times 10
\]

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\tilde{d}_{ki} = \frac{\text{Index value}}{\text{Maximum index value}} \times 10
\]
\[ \tilde{d}_{k,i} = \frac{\bar{C} - \bar{c}_i}{\bar{C} - 1}, \quad 1 \leq \bar{c}_i \leq \bar{C}. \] (1)

In equation (1), the value of the deprivation assessment item \((k)\) represents the ordered category of \([1, \bar{C}]\) and \(\bar{c}_i\) represents the value of the ordered category of the individual \((i)\) in the assessment item \(k\). The value of deprivation is 1 to indicate the highest deprivation, and the value \(\bar{C}\) represents the minimum deprivation.

Belhadj proposed the use of the distribution function \((\bar{F}(\bar{c}_i))\) to replace the relatively simple ordered category ranking in equation (1) to assess the deprivation of individual nonmonetary indicators, as shown in (43)

\[ \tilde{d}_{k,i} = \frac{1 - \bar{F}(\bar{c}_i)}{1 - \bar{F}(1)}, \] (2)

when \(\bar{C} = 2\), equation (2) presents a dichotomy, \(\tilde{d}_{k,i} = 1\) represents deprived, and \(\tilde{d}_{k,i} = 0\) represents not deprived.

In the deprivation assessment, income is a typical monetary indicator. The threshold of monetary indicators \((\bar{z})\) is set as the basis for dividing deprivation and non-deprivation. When the value of a certain type of currency is higher than \(\bar{z}\), the individual is not deprived, and the sense of deprivation is 0. The monetary indicator travel deprivation function \((m.f.)\), based on binary classification, is calculated by

\[ m.f. = \left\{ \begin{array}{ll}
\mu_i = 1, & y'_i < \bar{z}, \\
\mu_i = 0, & y'_i \geq \bar{z}.
\end{array} \right. \] (3)

Based on the dichotomy, Cerioli and Zani used interval forms to represent monetary indicators, and defined the individual deprivation value as a linear value of \([0, 1]\) within the income interval \((z_1 - \bar{z}_2)\). This is represented by (42)

\[ m.f. = \left\{ \begin{array}{ll}
\mu_i = 1, & y'_i < \bar{z}_1; \\
\mu_i = \frac{z_2 - y'_i}{\bar{z}_2 - \bar{z}_1}, & \bar{z}_1 \leq y'_i \leq \bar{z}_2; \\
\mu_i = 0, & y'_i \geq \bar{z}_2.
\end{array} \right. \] (4)

3.3. Model Development. By combining monetary and nonmonetary indicators, the developed approach proposes a fuzzy multidimensional assessment approach to assess travel deprivation from multiple dimensions. This approach uses the above framework with a number of important refinements as outlined in the following:

Step 1: the influencing factors of the deprivation of residents in small cities is first analyzed and screened for; then, items of travel deprivation sensitivity are set based on the determined influencing factors; finally, the factor analysis method is used to divide the items into different dimensions according to nonmonetary indicators and monetary indicators \(\delta\).

Step 2: the weight and deprivation value of the items are determined in the same assessment dimension. Combined with the analytic hierarchy process, the weight of different items in the same latitude dimension is determined, and the weight set is established as follows (44):

\[ W_\delta = (\omega_{\delta_1}, \omega_{\delta_2}, \ldots, \omega_{\delta_k}, \ldots, \omega_{\delta_h}), \] (5)

where \(\omega_{\delta_k}\) represents the weight of item \(k\) in dimension \(\delta\), and \(\omega_{\delta_k} \geq 0, \sum_{k=1}^{h} \omega_{\delta_k} = 1\).

Furthermore, based on the deprivation index value method, the travel deprivation value obtained corresponds to each item in different assessment dimensions. Finally, the travel deprivation value of different assessment dimensions \((SM_{\delta_i})\) is calculated with

\[ SM_{\delta_i} = \frac{\sum_{k=1}^{h} \omega_{\delta_k} (1 - d_{\delta,k,i})}{\sum_{k=1}^{h} \omega_{\delta_k}}, \quad \delta \in (1, 2, 3, \ldots, \bar{h}), \] (6)

where \(d_{\delta,k,i}\) represents the travel deprivation value obtained from item \(k\) in dimension \(\delta\).

Step 3: based on the totally fuzzy and relative (TFR) method, combined with the deprivation of the travel function in different assessment dimensions, and the Lorentz curve of the deprivation of travel \((i)\), the individual’s travel deprivation \((\bar{t})\) is determined. The travel deprivation of any individual can be expressed in three forms.

Step 3.1: using the TFR method, the distribution function \(F^{(1)}_i\) of the travel deprivation \((SM)\) of the individual \(i\) in the dimension \(\delta\) can be obtained. \(F^{(1)}_i\) is expressed as follows:

\[ F^{(1)}_i = 1 - \left( \frac{\sum_{h=1}^{\bar{h}} \omega_{\delta_h} |SM_{\delta_h} - SM_i|}{\sum_{h=1}^{\bar{h}} \omega_{\delta_h} |SM_{\delta_h} - SM_{\delta_1}|} \right), \] (7)

Furthermore, the proportion of samples with a sense of travel deprivation lower than that of individual \(i\) in the total sample can be obtained, i.e., the fuzzy index of the sense of travel deprivation \(\zeta_i\), which can be expressed as:

\[ \zeta_i = FSM^{\delta}_i = (1 - F^{(1)}_i), \quad i \in (1, 2, 3, \ldots, n). \] (8)

Step 3.2: based on the fuzzy index of travel deprivation, as determined in Step 3.1, the fuzzy index is optimized using the deprivation curve. The optimized fuzzy index of travel deprivation \((\zeta'_i)\) can be calculated using

\[ \zeta'_i = FSM^{\delta}_i = (1 - L^{(1)}_i), \quad i \in (1, 2, 3, \ldots, n), \] (9)

where \(L^{(1)}_i\) represents the value of the deprivation curve of individual \(i\) in the first dimension \(\delta\). \(L^{(1)}_i\) can be calculated by

\[ L^{(1)}_i = 1 - \left( \frac{\sum_{h=1}^{\bar{h}} \omega_{\delta_h} |SM_{\delta_h} - SM_i|}{\sum_{h=1}^{\bar{h}} \omega_{\delta_h} |SM_{\delta_h} - SM_{\delta_1}|} \right). \] (10)
Step 4: using the IFR method, combined with equations (8) and (9), an individual’s travel deprivation measurement model in individual dimensions can be obtained according to equation (11) [45–47]. The model considers the index weights in different assessment dimensions.

\[
\mu = \sum_{\delta=1}^{n} \alpha^{(\delta)} \left( 1 - F_i^{(\delta)} \right) \left( 1 - L_i^{(\delta)} \right) / n,
\]

\[i \in (1, 2, 3, \ldots, n),\]

where \(\alpha^{(\delta)}\) represents the weight of different dimensions of monetary and nonmonetary indicators, and \(0 < \alpha^{(\delta)} < 1\), \(\sum_\delta \alpha^{(\delta)} = 1\). This model considers the index weights in different measurement dimensions. A Bayesian network is used to measure the degree of difference between travel deprivation measurement dimensions, i.e., to determine the index weights within different measurement dimensions.

4. Study Area Details and Data

According to the 2018 Statistical Yearbook of the Tibet Autonomous Region, Lhasa had a registered population of 540,000 at the end of 2018 and a population of 300,000 in the municipal district. This is typical for an underdeveloped small city in the plateau region. Therefore, this paper selected Lhasa as a case city to assess the travel deprivation value, and conduct an empirical analysis of the constructed travel deprivation measurement model.

The investigation team randomly selected 15 residential districts from the four districts under the jurisdiction of Lhasa (i.e., areas of Zhucheng, Duilong, Liuwu-Cijuelin, and Baidian-Dazi) from a total of 60 districts. A questionnaire survey on residents’ deprivation of travel was carried out. In the investigation, adults over 18 years of age were selected as family representatives to complete the questionnaire on travel deprivation.

In reference to relevant questionnaires of the social deprivation survey and the residents’ travel behavior survey, the questionnaire items for the travel deprivation sensitivity survey in the underdeveloped small cities were prescreened and evaluated. Finally, seven assessment dimensions were formed, including both monetary indicators and nonmonetary indicators, totaling 27 items, as shown in Tables 1 and 2 [48]. In the questionnaire, nonmonetary indicators allow two alternative answers: “Yes” and “No”. “Yes” is represented by a value of 0, indicating that there is no deprivation; “No” is represented by a value of 1, indicating that there is deprivation; the items involved in monetary indicators mainly investigate the residents’ monthly disposable income, and the respondents’ needs to provide a specific income. The final number of valid questionnaires was 52 in the areas of Zhucheng, 39 in Duilong, 43 in Liuwu-Cijuelin, and 49 in Baidian-Dazi. Finally, 30 sets of effective data were extracted from each area to assess the deprivation of the residents of Lhasa. Descriptive statistics differences between cities are the result of sampling and are representative of the descriptive statistics of the city, overall. In order to balance the population differences between cities, our analysis does not focus on the differences between cities but rather on their similarities.

5. Empirical Results and Discussion

5.1. Case Study of Lhasa. According to the travel deprivation evaluation model proposed in Section 3, the average values of travel deprivation for the seven assessment dimensions that correspond to the four investigated areas of Lhasa are shown in Table 3 (for the travel deprivation examples of Zhucheng area, see Tables A1 and B1 in Supplementary Materials). FSM1 is the travel deprivation perceived for the income dimension (i.e., the currency indicator). FSM2, FSM3, FSM4, FSM5, FSM6, and FSM7 are the deprivation of travel produced by \(S_1, S_2, S_3, S_4, S_5,\) and \(S_6\) dimensions under nonmonetary indicators, respectively.

Table 3 shows that all the seven assessment dimensions play an important role in the assessment of travel deprivation. The average value of travel deprivation corresponding to the dimensions of income, travel conditions, service quality, transportation, travel values, travel efficiency, and travel costs can explain residents’ perceived travel deprivation. The nonmonetary indicator dimensions (FSM2, FSM3, FSM4, FSM5, FSM6, and FSM7), as well as the monetary indicator dimension as a whole, are negatively correlated. In other words, the higher the per capita disposable income, the lower the probability of travel deprivation generated by the nonmonetary indicator dimension. In contrast, the lower the income, the higher the probability of travel deprivation generated by the nonmonetary indicator dimension.

These results confirm that the sense of deprivation caused by different dimensions is different and uniform in different areas, and the intensity of the sense of travel deprivation caused by different dimensions is also inconsistent. The specific conditions are summarized in the following:

The same dimension leads to different travel deprivations in different areas. Among these, the three dimensions of FSM2 (travel condition), FSM3 (service quality), and FSM6 (travel efficiency) showed the most significant differences in deprivation in different areas. The differences between the maximum and minimum travel deprivation values were 0.1235, 0.1202, and 0.0834, respectively. The travel deprivation generated by the dimension of travel conditions is related to the location of the residence. A large difference was found in the transportation resources available for residents in noncommercial areas and commercial areas (i.e., the administrative center). This leads to a large difference in the sense of travel deprivation perceived by residents in different areas. For example, the Zhucheng area has an abundance of transportation infrastructure; therefore, the deprivation value of the travel condition dimension is smallest in this area. The service quality dimension focused on the travel safety, travel experience, and mobility of travel involved in the travel process of residents. The service quality problems are most typical in the Liuwu-Cijuelin area. The
Princess Wencheng live performance venue is located in this area; the phenomenon of scattered residents is quite common, and service quality cannot be guaranteed continuously. At the same time, because the transportation planning in this area has entered the adjustment stage, the residents’ demands for service quality have been ignored by both the government and transportation planning departments. Travel time is the main reason why the travel efficiency dimension leads to residents’ perceived travel deprivation. Underdeveloped, small cities face a higher probability of traffic congestion in densely populated areas. When congestion is not managed in a timely manner, the likelihood of travel deprivation caused by travel efficiency increases, which is the case in the Duilong area.

Table 1: Distribution of travel deprivation questionnaire.

| Types of indicators | Dimensions | Purpose of assessment |
|---------------------|------------|----------------------|
| Comprehensive indicators (SM) | Travel conditions $S_1$ | Advantages and disadvantages of residents’ travel conditions |
| Nonmonetary indicators ($S$) | Service quality $S_2$ | Level of service quality |
| | Transportation $S_3$ | Travel demands for missing means of transportation |
| | Travel values $S_4$ | Regional travel culture cognition |
| | Travel efficiency $S_5$ | Travel time consumption tolerance |
| | Travel cost $S_6$ | Acceptability of travel cost |
| Monetary indicator ($M$) | Income $M_1$ | Economic status of respondents (related to travel capacity) |

Table 2: Content of travel deprivation items.

| Dimensions | Items | No. |
|------------|-------|-----|
| Income $M_1$ | Monthly disposable income (disnic) | $M_{11}$ |
| | Good public transportation conditions | $S_{11}$ |
| | Existence of conditions for private car travel | $S_{12}$ |
| | Existence of conditions that facilitate transportation | $S_{13}$ |
| | Existence of conditions for travel by taxi | $S_{14}$ |
| | Good walking conditions | $S_{15}$ |
| | Existence of other travel conditions, such as commuter shuttle | $S_{16}$ |
| | Existence of good travel security | $S_{17}$ |
| Service quality $S_2$ | Existence of a more satisfactory travel experience | $S_{21}$ |
| | Existence of a smooth travel environment | $S_{22}$ |
| | No appeal for private cars | $S_{23}$ |
| | No appeal for electric vehicles | $S_{24}$ |
| | Has good consistency with the surrounding people in the choice of travel mode | $S_{25}$ |
| | Frequently used travel methods are not easily affected by other travel modes | $S_{26}$ |
| Transportation $S_3$ | Assuming that the chosen way of travel is guaranteed | $S_{31}$ |
| | Satisfaction with current travel mode | $S_{32}$ |
| | The time from the departure point to the boarding point is within an acceptable range | $S_{33}$ |
| | The waiting time is within an acceptable range | $S_{34}$ |
| Travel values $S_4$ | The travel time of the vehicle is within an acceptable range | $S_{41}$ |
| | The time from the drop-off point to destination is within an acceptable range | $S_{42}$ |
| | Transfer time, and other time consumptions, are within an acceptable range | $S_{43}$ |
| | Travel costs are totally unacceptable for an extended time | $S_{44}$ |
| | Travel costs are high but can be accepted for an extended time | $S_{45}$ |
| Travel efficiency $S_5$ | Travel costs are reasonable and can be accepted for an extended time | $S_{51}$ |
| | Travel costs can be accepted for an extended time, but lower costs would be better | $S_{52}$ |
| Travel cost $S_6$ | Note. According to the raw data of these four areas, the per capita disposable incomes of the residents of Lhasa and the four assessed areas (i.e., areas of Zhucheng, Duilong, Baidian-Dazi, and Liuwu-Cijuelin) are 1974, 2040, 1921, 1981, and 1953, respectively. |
specific means of transportation. The traffic congestion in Lhasa is becoming increasingly severe; therefore, residents in the four districts have a strong desire for large-capacity transportation such as rail transit. In different areas, the travel deprivation produced by the vehicle dimension is relatively uniform, and the difference between the maximum and minimum value of travel deprivation is only 0.0076. The travel value dimension (FSM) mainly reflects the residents’ cognition and assessment of the currently existing travel status, which involves travel mode recognition, road rights allocation, and other relevant aspects. The caused deprivation is relatively consistent across all four areas, and the difference between the maximum and minimum deprivation values is 0.0095, indicating strong uniformity. Traffic jams are common in Lhasa. Therefore, the residents of the four areas have a unified desire for increased transportation capacity (in the form of, e.g., rail transit). The sense of deprivation caused by the vehicle dimensions is more uniform, and the difference between the maximum and minimum deprivation is 0.0076.

The degree of travel deprivation caused by different dimensions differs. The four assessment dimensions of service quality, travel efficiency, income, and travel conditions are associated with the highest levels of travel deprivation. The average values of travel deprivation in Lhasa are 0.4846, 0.4579, 0.4372, and 0.4118, respectively. The level of travel supply in underdeveloped, small cities was evaluated through the quality of travel conditions, the level of travel service quality, and the efficiency of travel. The income dimension mainly assesses the economic status of residents. In underdeveloped, small cities, where economically disadvantaged groups form the main body of residents, the income level of residents is relatively low compared with other cities. Therefore, income has a close relationship with the ability of residents to travel, and their sense of travel deprivation indicates their satisfaction with their current income. Weak traffic infrastructure and backward traffic management are important factors that restrict the level of travel supply. The three dimensions of travel quality, travel efficiency, and travel conditions cause higher travel deprivation, which represents the comparatively low level of travel supply in underdeveloped, small cities. Among the seven assessment dimensions, the travel cost dimension causes a relatively small travel deprivation, with an average value of 0.3519. This indicates that compared with other dimensions, such as travel quality and travel efficiency, the residents’ acceptability of travel costs is relatively high. This further indicates that residents pay more attention to travel quality, travel efficiency, and travel conditions during travel.

Based on the values of travel deprivation in different dimensions, the comprehensive travel deprivation generated by residents of Lhasa in multiple dimensions, as well as both monetary and nonmonetary indicators, are assessed. The deprivation assessment results are shown in Table 4.

Table 4 shows that residents in different areas of Lhasa have different perceptions of the comprehensive travel deprivation they face. Of the investigated areas, the Baidian-Dazi area has the largest comprehensive travel deprivation value, while the Zhucheng area has the smallest value. The difference in travel deprivation between these two areas was 0.056. The reason for the observed differences in the comprehensive travel deprivation among different areas of Lhasa is related to the degree of urbanization and motorization in this area. Since it is the location of the Potala Palace, the Zhucheng area forms the political and economic center of Lhasa. The government and transportation-related management departments attach relatively high importance to this area, which manifests as an increased allocation of transportation resources and improved transportation management. At the same time, residents living in the Zhucheng area have relatively higher incomes compared with those living in other areas. The Baidian-Dazi area is far from the city center, and factors such as weak transportation infrastructure and low-income levels of residents have led to a low degree of satisfaction of residents’ travel needs. Therefore, residents in the areas of Zhucheng and Baidian-Dazi present stronger differences in travel deprivation, which means that the degree of travel deprivation in different areas is inconsistent.

### Table 4: Comprehensive deprivation of residents in Lhasa.

| Macro-region            | µ    |
|------------------------|------|
| Lhasa                  | 0.4194|
| Zhucheng area          | 0.3883|
| Duilong area           | 0.4190|
| Baidian-Dazi area      | 0.4443|
| Liuwu-Cijuelin area    | 0.4174|

5.2. Early Warning Analysis of Travel Deprivation. If a certain degree of travel deprivation accumulates, as a result of negative psychological and emotional feedback caused by perceived travel injustice, it will not be conducive to maintaining the normal travel order of residents in small and underdeveloped cities. Based on previous studies on the Gini coefficient of social equity and by combining the relationship between the deprivation function and the Gini coefficient in the travel deprivation measurement model, this paper calibrates the critical threshold of the comprehensive travel deprivation of residents in small and underdeveloped cities to 0.4–0.45. If the comprehensive travel deprivation value exceeds 0.45, this indicates a severe urban travel deprivation problem that can easily induce discontent in other social groups.

Based on the results of the mean deprivation of single-dimensional travel, Figure 1 shows a comparison of deprivation in different dimensions. The color distribution in Figure 1 depicts the size of the single-dimensional travel deprivation in different areas.

Based on the results of comprehensive travel deprivation, the comprehensive travel deprivation value of Lhasa is 0.4194. The range of the critical value classifies this as a warning state; the comprehensive travel deprivation value of the main city area is 0.3883, which is classified as a non-warnning state; the comprehensive travel deprivation values of the areas of Duilong, Baidian-Dazi, and Liuwu-Cijuelin are all in an early warning state; the comprehensive travel deprivation value of Baidian-Dazi area is 0.4443, which
represents a high early warning state. The warning status of Lhasa’s comprehensive travel deprivation is shown in Figure 2. The color-coded areas in the figure show the warning areas of Lhasa, and the red area indicates areas with a high warning state.

Figure 2 shows that the comprehensive travel deprivation in Lhasa city center (i.e., Zhucheng area) is in a non-warning state, while other (non-Zhucheng) areas are in an early warning state. This is consistent with previous studies on travel equity in other types of cities [34]. In China, many economically disadvantaged groups live in nonurban centers, and the urban marginalization of such places of residence increases the vulnerability of economically disadvantaged groups. Compared with the residents in the urban centers, the economically disadvantaged groups live in nonurban centers. Participation in urban transportation neither manifests in the fact that their travel needs are not well met in space and time nor in the economic and social networks. Grengs, as well as Blumenberg and Thomas, found that low-income groups that live on the edge of cities are prone to miss job opportunities throughout the city. Therefore, they generally choose a job nearby, and their probability to receive comparatively low salaries and remuneration is high, which is not conducive to the reduction of residents’ perceived travel deprivation [10, 11].

The assessment of comprehensive travel deprivation is, in fact, an assessment of the relationship between travel supply and travel demand. The value of travel deprivation can better
represent the satisfaction of the travel needs of residents in small and underdeveloped cities, i.e., travel deprivation reflects the contradiction between travel-related supply and demand. The more the comprehensive travel deprivation value exceeds a critical threshold, the more severe the travel deprivation in the city will be. Based on the results of the early warning status of urban comprehensive travel deprivation, the large difference of comprehensive travel deprivation values in different areas indicates that Lhasa not only faces a travel inequity problem but also that it suffers from a deep-seated problem of perceived internal travel inequity. Therefore, the implementation of traffic demand management policies or other measures that alleviate the contradiction between travel demand and supply is very important toward realizing travel equity in underdeveloped, small cities.

6. Conclusions

This study investigated the travel inequity problem in small and underdeveloped cities of China and identified the impacts of both monetary and nonmonetary indicators on travel deprivation. The authors have conducted long-term, intermittent observations and research on the travel behavior of local residents to promote travel equity in underdeveloped small cities in China. This paper proposes a fuzzy multidimensional assessment approach of travel deprivation to assess residents’ negative feelings that arise because of a sense of travel inequity based on relative deprivation theory, combined with the IFR deprivation measurement model. This model involves both monetary and nonmonetary indicators, multiple measurement items, dimensions, and related weights. Then, the travel deprivation measurement model is used to assess the travel deprivation in underdeveloped, small cities. This assessment yielded several interesting conclusions.

The first conclusion is that both monetary and nonmonetary factors are important reasons for the deprivation of residents in small and underdeveloped cities. The dimensions of income, travel conditions, service quality, transportation, travel values, travel efficiency, and travel costs significantly impact the value of travel deprivation.

The three factors of travel conditions, service quality, and travel efficiency lead to obvious differences in travel deprivation in different areas of the city. The difference in the available transportation resources in different areas is an important reason for the inconsistence of travel deprivation between different areas in the same measurement dimension of small and underdeveloped cities.

The two measurement dimensions of transportation demand and travel values are uniform in the travel deprivation of different areas of the city; therefore, the difference in the value of travel deprivation between the investigated areas is small. In underdeveloped, small cities, traffic congestion is becoming increasingly severe and, therefore, urban residents have a relatively strong demand for large-capacity transportation. Residents in different regions of Lhasa have a better understanding of the overall travel status, such as travel mode recognition and road rights allocation. The fact that these two measurement dimensions have unified travel deprivation in different areas of Lhasa forms a unique regional travel culture.

The measurement dimensions of service quality, travel efficiency, income, and travel conditions have high levels of travel deprivation, while the travel cost measurement dimension has a lower level of travel deprivation. This also indicates that residents of underdeveloped, small cities are more prone to perceive travel deprivation because of travel efficiency and travel conditions.

Since comprehensive travel deprivation is at an early warning state, the governments and transportation management departments of underdeveloped, small cities urgently need to implement transportation demand management policies and measures to alleviate the ongoing contradiction between travel supply and travel demand. In the process of improving the travel inequality situation, it is necessary to focus on the differences in the values of travel deprivation in different areas of the same city, i.e., the deeper level of travel inequality issues.

Data Availability

In this study, the data of travel deprivation scores for monetary and nonmonetary indicators are presented in the supplemental files. All other data used are contained within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supplementary Materials

Table A1: travel deprivation scores for monetary and nonmonetary indicators are presented in the supplemental files. Table B1: average values of travel deprivation in the case of Lhasa forms a unique regional travel culture.

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