# Exploring the impact of urban built environment on land use diversity under shared autonomous vehicles and road pricing

Yunhai Gong, Zhong Wang, Shengchuan Zhao, Shaopeng Zhong*
School of Transportation and Logistics, Dalian University of Technology, Dalian 116024, China

Shared autonomous vehicles (SAVs) will become one of the travel modes for urban residents in the next 10 to 20 years (Wadud et al., 2016; Milakis et al., 2017a; Litman, 2018). The changes in travel modes will directly affect the urban transportation system, the changes of which will affect the locations of land use to eventually cause the change of urban land use system. Most of the existing studies focus on the short-term impact of SAVs and road pricing on the urban transport system (Fagnant and Kockelman, 2014; Gong et al., 2016; Talebpour and Mahmassani, 2016; Chen et al., 2017). Some scholars have studied the impact of SAVs and road pricing on urban land use system, but most of them mainly focus on accessibility (Childress et al., 2015; Zhang et al., 2015; Zakharenko R., 2016; Zhong et al., 2019). From the above analysis, we can draw a conclusion that researches on the impact of land use diversity under SAVs and road pricing are limited. Therefore, this paper analyzes the impact of urban built environment on land use diversity under SAVs and road pricing. This paper adopts the following four steps: ① Analysis of the impact of SAVs and road pricing on land use diversity using land use and transportation integrated model; ② Using multiple regression model to explore the relationship between built environment attributes and land use diversity; ③ Using factor analysis and cluster analysis to further analyze the impact of built environment attributes on land use diversity under different policies; ④ Sensitivity analysis is used to further illustrate the robust of the method adopted in this paper.

In this paper, we choose Jiangyin City as the study area. The land use and transportation data (Jiangsu Institute of Urban Planning and Design, 2011) are obtained from relevant departments of Jiangyin City to establish the land use and transportation integrated model. We establish four regional development scenarios: business as usual scenario (Scenario A), SAVs scenario (Scenario S), road pricing scenario (Scenario C), and SAVs and road pricing joint scenario (Scenario B). Among them, the road pricing policy is implemented from 2020, and SAVs are introduced from 2025. This paper uses the cordon-based road charging scheme, which is widely used in the world (Zhang and Yang, 2004; Zhong et al., 2015; Zhong and Bushell, 2017b). The charging objects include all motor vehicles (private cars, SAVs, trucks, etc.) except public transportation. The level of toll rates is 20 Chinese Yuan (CNY).

Traffic Analysis Zones (TAZs) are selected as the fundamental analysis unit in this paper, whereby the whole study area is subdivided into 265 TAZs. 56 TAZs locate inside the road pricing region, and 209 TAZs locate outside the road pricing region. For the 56 TAZs, seven basic factors are identified through factor analysis, which are Regional Size, Industrial Job, Retail Job and Bus, Population, Government Job, Street Design, and Infrastructure Accessibility. For the 209 TAZs, seven basic factors are also identified using factor analysis, namely CBD Accessibility, Retail Job, Industrial Job, Population, Street Design and Bus, Government Job, and Infrastructure Accessibility. A total of 16 types of TAZs are classified inside and outside the road pricing region using K-means clustering analysis based on the results of factor analysis, as shown in Figure 1 and Figure 2. Among them, it should be noted that 1 to 8 represent the TAZ types within the road pricing region, and -8 to -1 represent the TAZ types outside the road pricing region. The spatial distribution of all TAZ types is shown in Figure 3.

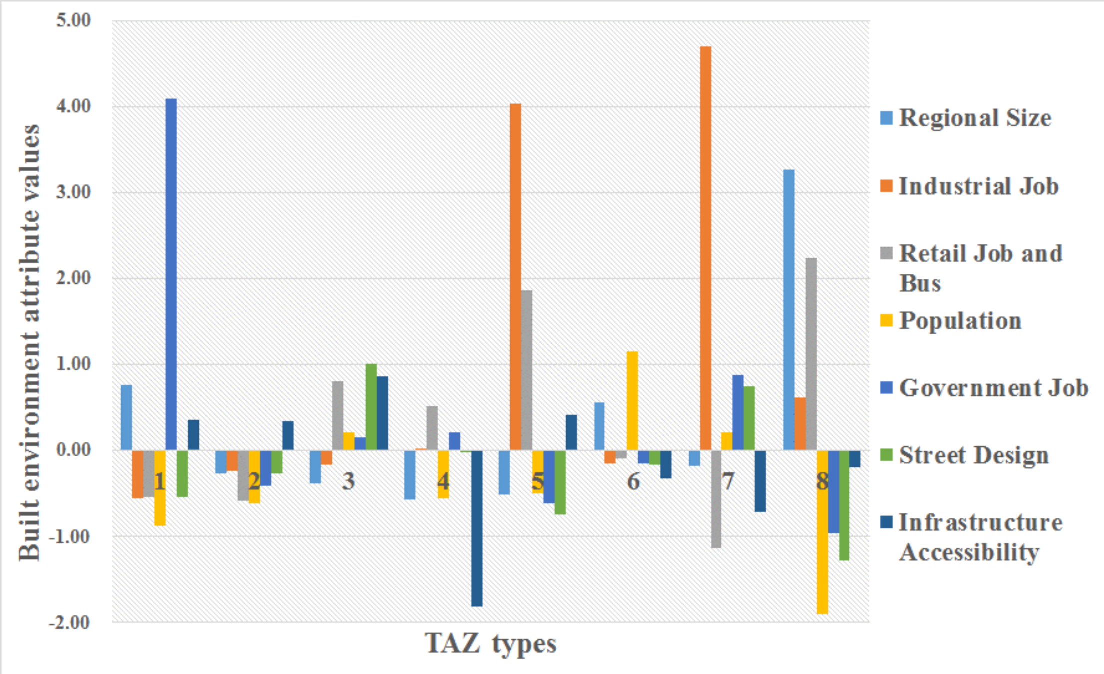


Figure 1 TAZs classification and corresponding built environment attributes within the road pricing region

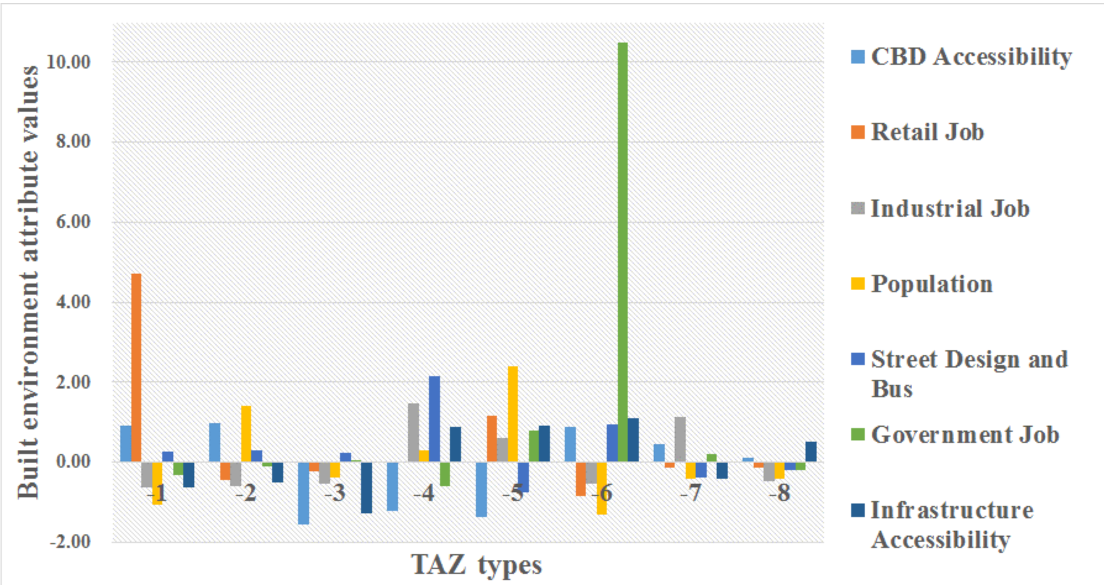


Figure 2 TAZs classification and corresponding built environment attributes outside the road pricing region

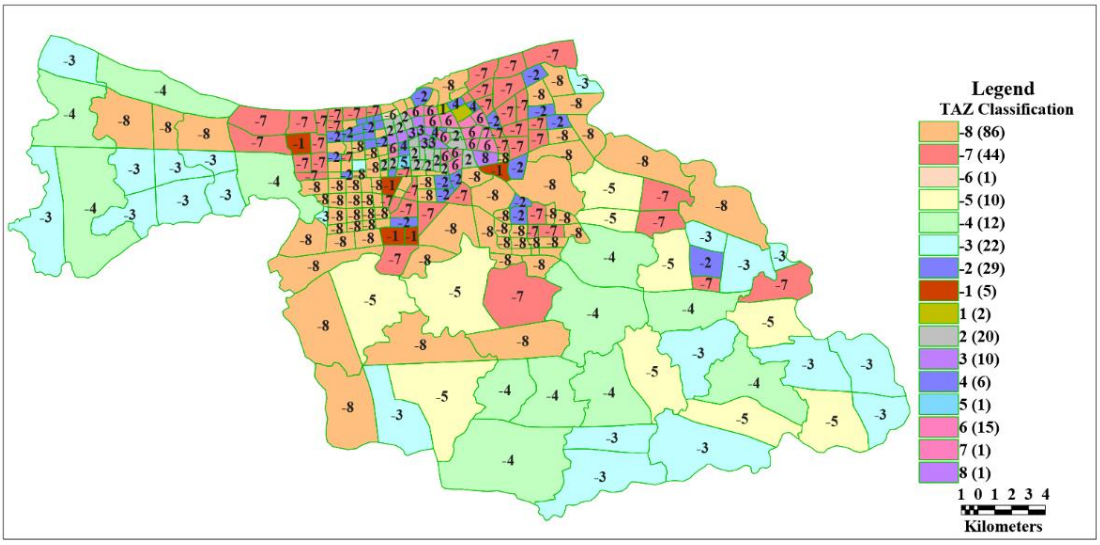


Figure 3 Classification of TAZs in the study area

The analysis results of land use diversity within the road pricing region can be obtained from Figure 4. In Figure 4, 40A means Scenario A in 2040, 40S represents Scenario S in 2040, 40C refers to Scenario C in 2040, and 40B denotes Scenario B in 2040. Generally speaking, in the road pricing region, SAVs have less impact on land use diversity; In addition, after charging 20 CNY in TAZ type 5 and TAZ type 7, it will lead to the decreasing of the land use diversity of the TAZs within the road pricing region. Along with the introduction of SAVs under this condition, land use diversity will increase. One possible reason may be that in the context of the road pricing policy, the cost of factory workers traveling to work will increase, which results in that some factories in the pricing region will move outside the cordon (Zhong and Bushell, 2017a). The introduction of SAVs will reduce the impact of road pricing to some extent. Compared with Scenario 40C, Scenario 40B will promote the development of land use diversity in these two TAZ types and make urban development more reasonable; Besides, compared with Scenario 40C, among the land use diversity of all TAZ types under Scenario 40B, TAZ type 5 is the most improved one. According to Figure 1, although TAZ type 5 locates in the center of the city, the street design is poor. After the implementation of the road pricing policy, the land use diversity will greatly reduce. However, because retail jobs, infrastructure accessibility and buses of TAZ type 5 are better, and the residential population of TAZ type 5 is small, the introduction of SAVs will increase the positive impacts of retail jobs and infrastructure accessibility and buses, and reduce the negative impacts of street design.

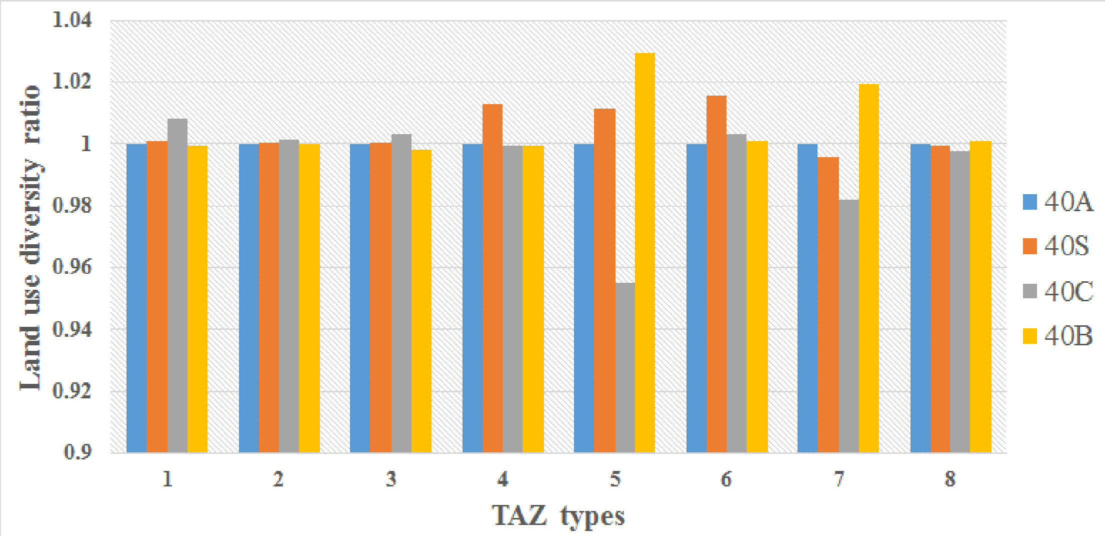


Figure 4 Land use diversity ratio in different TAZ types within the road pricing region under different scenarios

The analysis results of land use diversity outside the road pricing region can be obtained from Figure 5. First, compared with Scenario 40A, apart from TAZ type -1, TAZ type -3, and TAZ type -7, Scenario 40S will increase the land use diversity of all TAZs outside the road pricing region. Except for TAZ type -1, Scenario 40C will reduce the land use diversity of all TAZs outside the road pricing region. Second, it is easy to find that the land use diversity of TAZ type -1 will be improved after the implementation of the road pricing policy, while it will decrease after the introduction of SAVs. The one possible reason for the decline in land use diversity could be that, after the implementation of road pricing policy, some companies inside the road pricing region will move outside the cordon. At the same time, according to Figure 2, the advantages of TAZ type -1 which belongs to the commercial areas is its proximity to the CBD and road pricing region, thus TAZ type -1 will become the preferred location for companies to move into. The second possible reason for the decline in land use diversity is that TAZ type -1 has far more retail jobs than other jobs. According to the land use diversity calculation formula, land use diversity will increase when the proportion of retail land area decreases. With the introduction of SAVs and the implementation of the road pricing policy, TAZ type -1 will be convenient for residents to travel. Because TAZ Type -1 is a commercial district, it will attract a large number of residents to spend more time here, which will result in generating new types of retail jobs to increase retail land. The increase in the proportion of retail land will eventually lead to a decline in the land use diversity of TAZ type -1. Third, the impact of the use of SAVs technology on the land use diversity outside the road pricing region are closely related to CBD accessibility, retail jobs, street design and buses. Specifically, with a worse the CBD accessibility, a better the retail jobs, and a better street design (intersection numbers and street density) and buses, it will have a better effect on land use diversity, or vice versa.

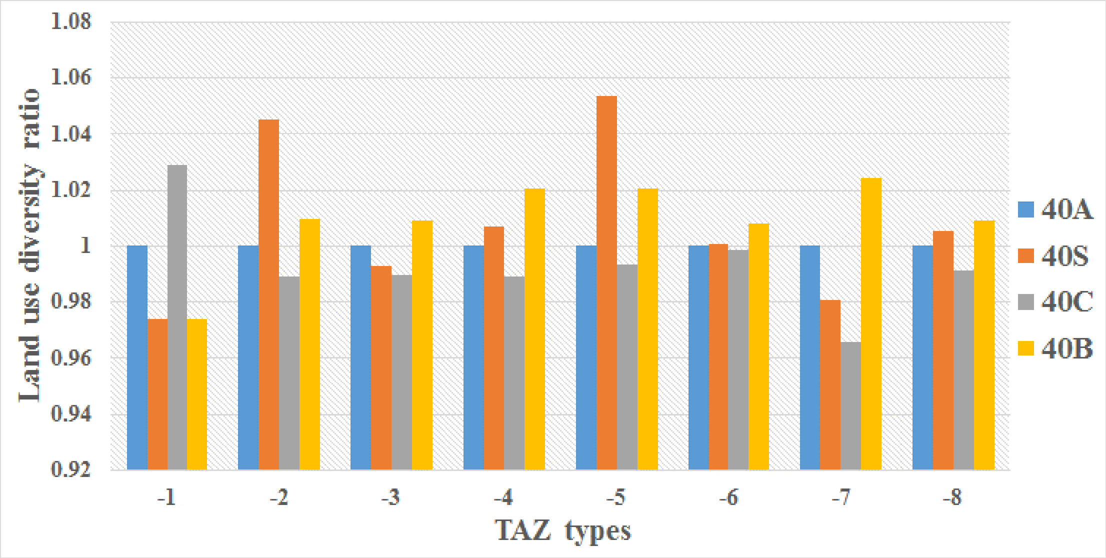


Figure 5 Land use diversity ratio in different TAZ types outside the road pricing region under different scenarios

Finally, this paper analyzes the sensitivity of land use diversity under Scenario 40S based on the SAVs market penetration. The rate of changes in the land use diversity of SAVs scenario (Scenario 40S) compared with business as usual scenario (Scenario 40A) under different SAVs market penetration are shown in Figure 6. It can be found that, whether within or outside the road pricing region, changes in the SAVs market penetration have negligible impacts on land use diversity under Scenario 40S.

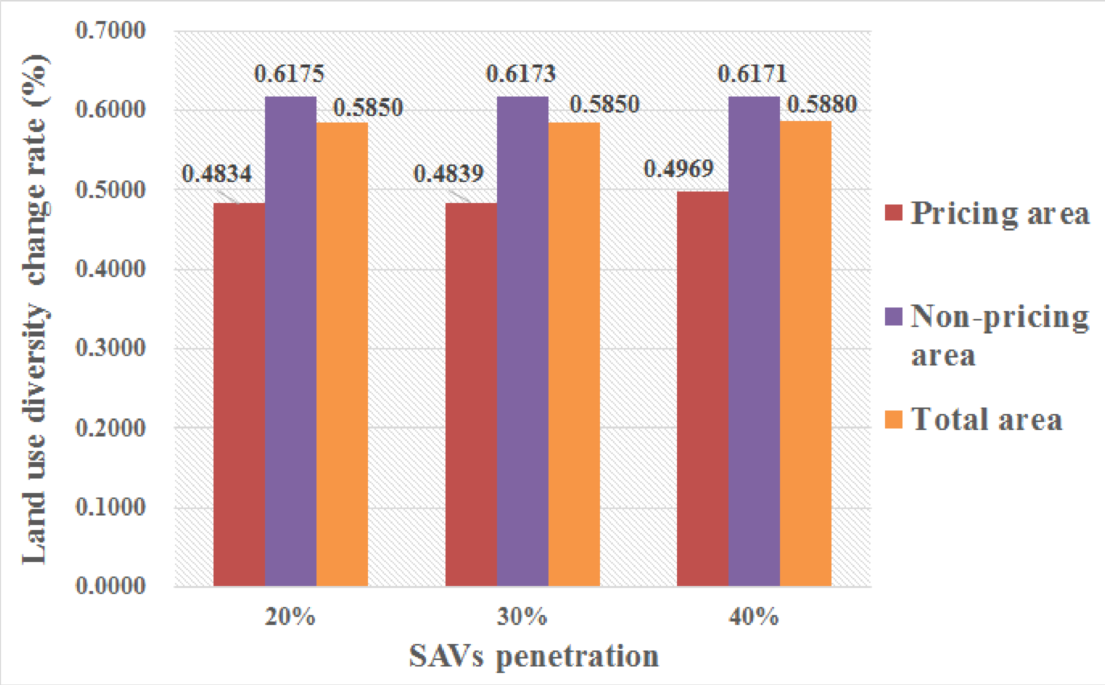


Figure 6 Variation of land use diversity under different SAVs penetration based on Scenario 40S

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