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Adaptation of economic intervention effect on mobility model in Far East environment

Mate ZOLDY
mate.zoldy@gtk.bme.hu
Budapest University of Technology and Economics
Hungary, Budapest

Li Aijuan
liajuan@sdjtu.edu.cn

Abstract

Mobility is a key pillar of the 21st century, connecting people and information while presenting sustainability challenges. This paper aims to evaluate the impact of economic interventions on urban mobility, specifically through the introduction of parking fees in Jinan, China. The study employs a refined mobility model that categorises road usage into downtown, city, rural, and motorway environments and adapts European baseline data to the Far Eastern context. Data and methods include the development of a model measuring individual utility by average speed and social utility by CO_2 emissions per passenger kilometre. The model is adapted to reflect Far Eastern cities' unique urbanisation and energy mix. Results indicate that the introduction of parking fees in Jinan has significantly reduced traffic congestion, increased public transportation usage by 20%, and decreased CO_2 emissions by 8%. The tiered pricing system has improved urban space utilisation and economic efficiency. In conclusion, the study highlights the effectiveness of economic tools in promoting sustainable urban mobility and underscores the need for region-specific adaptations. Future research should explore additional economic interventions and expand the model's applicability to other regions.

Keywords

Sustainable Mobility, Economic Interventions, Urbanisation, CO_2 Emissions, Public Transportation

1. Introduction

Mobility is a key pillar of the third millennium. It connects and helps to be informed but also has several externalities (Buzási and Csete, 2015). One of the most challenging tasks is influencing or changing mobility to serve society and be sustainable (Zoldy et al., 2022; Kocziszky, 2023). Several researchers are trying to find engineering solutions to improve the sustainability dimension of mobility (Buzási and Jäger, 2020). Research today focuses on more sustainable energy sources (Torok et al., 2014; Orynycz et al., 2025), alternative solutions in the automotive drivetrain, new tendencies regarding modal split (Zamprogno and Esztergár-Kiss, 2024), improvements in vehicle dynamics, a new solution in safety and cyber security, more secure connection between the vehicle and the infrastructure, applications on the internet of the things (Nguyen et al., 2025) smart infrastructure, and cognitive traffic management (Zöldy et al, 2024). Although these and several other studies have tangible outcomes; it is more and more clear that without involving the governmental toolkit to force the changes (Szalmáné Csete et al., 2024; Wengritzky et al., 2024)), not all of these opportunities will be part of the future mobility system. Governmental subsidies and tax effectiveness depend at least on the internal structure of mobility (Zöldy and Kolozsi, 2025) the share of performances. A new model describes the urban mobility modal split and mobility forms to clearly show the governmental action's effects (Gaal et al., 2015; M. Zöldy, 2024).

While investigating the parking fee introduction in Jinan, China, it was clear that Chinese metropolises have a different modal split from the European cities. This research presents the framework of the developed modelling space and analyses the Chinese metropolises to include them into the model. In the last part of this study, an economic tool, namely the parking fee introduction effect, is shown with the help of the updated model.

2. The method

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A model was developed to show the effects of different economic interventions on individual and social utility in the context of mobility. In this model, average speed, measured in meters per secundum, is used as an indicator of individual utility within mobility. If the average speed increases, the individual utility increases as well, as it implies that mobility goals can be reached faster. Meanwhile, social utility is measured by emissions, specifically the CO_2 emitted in grams over passenger kilometres [gCO_2/pkm]. If the amount of emitted CO_2 over passenger kilometres increases, it lowers the model's social utility.

The model uses a space model for mobility: it divides mobility into four layers: downtown, city, rural and highway. These four levels better characterise the mobility of the cognitive era, which is influenced heavily by more and more urbanisation. Previous research introduced a refined classification of road mobility (Zöldy, 2024) by expanding the traditional three categories – urban, rural, and motorway – with a fourth: downtown. This new category reflects the evolving nature of mobility in highly urbanised environments.

The downtown category represents the innermost parts of large cities, often historic centres or traffic-calmed zones. These areas are characterised by very low speeds, typically around 10 km/h, and a high level of interaction with pedestrians and micromobility devices like scooters and bicycles. There are usually no lane separations, and the infrastructure is not designed for high vehicle throughput. Instead, the focus is on sustainability, with very low emissions and energy consumption per participant. Vehicle dynamics are limited, and the environment is optimised for walking, cycling, and public transport.

In contrast, the urban category covers general city traffic in densely populated areas. Here, vehicles move at slightly higher speeds – under 30 km/h – but still face frequent stops, turns, and interactions with diverse road users. The traffic is complex and turbulent, with high emissions and energy use. This category reflects traditional city driving, where private cars, buses, and delivery vehicles share the road.

The rural category includes roads in less populated areas like small towns and the countryside. These roads typically support moderate speeds of around 75 km/h and have fewer intersections and interactions than urban roads. The traffic mix, including agricultural vehicles and bicycles, is diverse, but the dynamics are more stable. Emissions and energy use are moderate, and the infrastructure is simpler than in urban areas.

Finally, the motorway category refers to high-speed roads like highways and expressways. These roads are designed for efficient, long-distance travel, with average speeds around 110 km/h. They feature physically separated lanes, no level crossings, and minimal vehicle interaction. The traffic is homogeneous, mostly cars and trucks, and vehicle dynamics are stable. However, this efficiency comes at the cost of high emissions and energy consumption.

Additionally, our model uses four passenger mobility categories. It is easy to associate them with mobility forms. The four modes are: walking, micromobility (roller, bike, e-bike, scooter, e-scooter), public transport (bus, tram, metro), and passenger cars. These four categories describe mostly the mobility modes of the 21st century.

Visualisation of the model is shown in Figure 1. It represents the average European mobility patterns.

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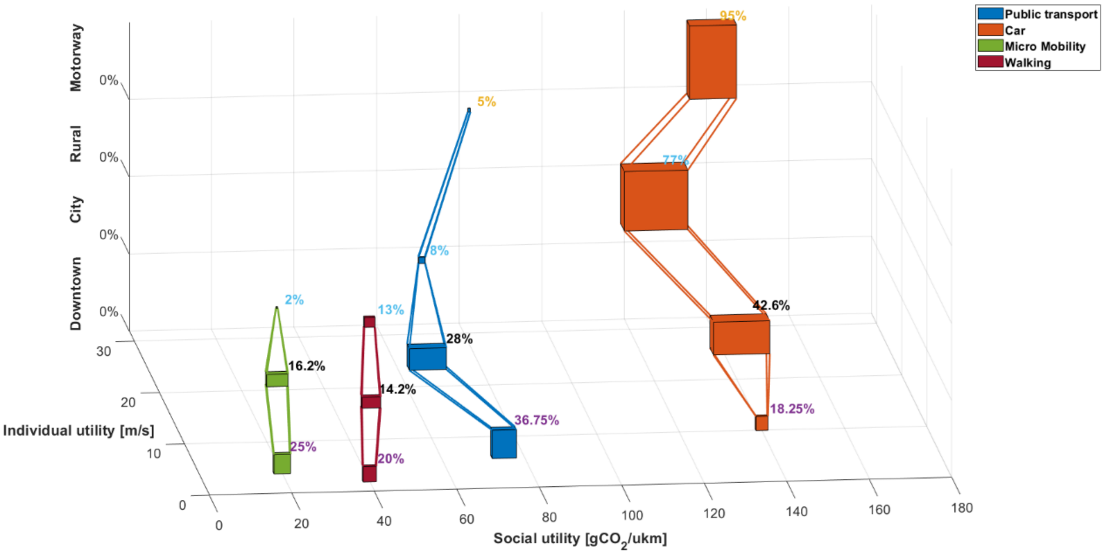

Figure 1. Model visualisation for a European mobility scenario

One key element of the model is the modal split between transport modes.

3. Far East context

During the investigation of the model's adaptability, all dimensions were checked and validated. The first assumption was that European average data could be good for evaluating governmental economic intervention's effect on sustainable mobility. It was recognised that all aspects should be rechecked and corrected if needed. The following aspects were investigated:

Table 1. Model adaptation from European context to far-east context

aspect of the model	adaptation need	remark
social utility [gCO$_2$/ukm]*	to keep	common measure worldwide
measure of social utility by mobility categories	to review	In the Far East, micro-mobility is based on electric vehicles with a lower CO_2 impact.
personal utility [m/s]	to keep	common measure worldwide
measure of social utility by mobility categories	to keep	traffic flow is similar around the globe
space use categories [downtown, city, rural, motorway]	to keep	common measure worldwide
mobility categories	to keep	common measure worldwide
mobility modal split %	to review	different urbanisation in the far-east resulted in different modal split
economical interventions	to keep	similar toolkit worldwide

*please note CO$_2$/ukm: ukm is the Hungarian abbreviation of passenger kilometre performance indicator

Based on the reviewed literature, the following adaptations were carried out according to the Far East cities' specialities, presented in Table 2. The adaptation is based on two main pillars. First, the Chinese energy mix differs from the European one, as it has a higher carbon footprint. It appears to have higher CO_2 emissions in the model (Bieker (2021), IEA (2020) and Transport & Environment (2020). This adaptation will help improve the baseline model's punctuality, new data used to refine the CO_2 footprint of European micro-mobility across different space utilisations.

Table 2. Adaptation of social utility baseline values

measure of social utility [gCO$_2$/ukm]	European baseline [gCO$_2$/ukm]	Far-east baseline [gCO$_2$/ukm]
Micro-mobility/downtown	20	40
Micro-mobility/city	20	35
Micro-mobility/rural	20	45

The mobility split ratios have to be adopted as well. Based on the overviewed literature, the main difference between the mobility split of the two regions is based on the urbanisation differences (He et al. 2011, Yang et al. 2017). Based on a synthesis of academic literature, government reports, and World Bank studies, we can outline the estimated modal split

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across different urban zones in the largest far east cities (World Bank, 2018; Pengjun and Shengxiao, 2018). Downtown areas like Beijing and Shanghai are heavily transit-oriented due to dense metro networks and car restrictions (e.g., license plate lotteries and congestion pricing). Micromobility (especially e-bikes) is widely used for first/last-mile connections and short trips, particularly in suburban and peri-urban zones. Motorways are almost exclusively used by private vehicles and freight, with minimal public transport presence except intercity buses. Walking remains significant in historic cores and older residential districts, where urban form supports pedestrian activity. Table 3 shows the new baseline values for Far-East cities (PT: public transport, MM: micromobility).

Table 3. Adaptation of Far East modal split ratios

BASELINE		European ratio %	Far-east ratio
down-town	PT	34	56
	Car	25	12
	MM	23	12
	walking	18	20
City	PT	23	45
	Car	48	25
	MM	16	12
	walking	14	17
rural	PT	7,65	26
	Car	77,5	46
	MM	2,1	16
	walking	13,1	12
motor-way	PT	5	5
	Car	95	95
	MM	0	0
	walking	0	0

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4. Factors that influence mobility - Evaluation of parking fee: case study in Jinan

The introduction of parking fees in Jinan, which began in early 2023, was a pivotal measure in addressing the city's chronic traffic congestion and promoting sustainable urban mobility. The local government implemented a tiered pricing system, where parking fees vary based on the location and duration of parking. In high-demand areas, such as the central business district, fees are higher to discourage long-term parking and encourage vehicle turnover. This approach has significantly reduced traffic congestion, as fewer drivers are circling to find free or cheap parking spots. Additionally, the revenue generated from these fees is reinvested into public transportation infrastructure, further enhancing the city's mobility options (Gao, 2025).

The impact of these changes has been multifaceted. Firstly, there has been a noticeable decrease in vehicles on the road during peak hours, contributing to a reduction in average commute times by approximately 10–12% (Zhang et al., 2021). Secondly, public transportation usage has increased by around 20%, with more residents opting for buses and the metro instead of driving. This shift has also reduced CO_2 emissions by about 8% in urban areas, improving air quality (Chen, 2017).

Moreover, the turnover rate for parking spaces has improved, with spaces being used more efficiently and frequently. This has eased congestion and enhanced the economic efficiency of urban space utilisation (Pengjun and Shengxiao, 2018). The introduction of parking fees has thus played a crucial role in transforming Jinan's transportation system, making it more efficient and environmentally friendly. The data after the introduction of parking fees in Jinan is presented in Table 4.

Table 4. Changes in personal and social utility after the introduction of parking fee in Jinan

Jinan, parking fee		ratio %	individual utility (m/s^2)	social utility (gCO_2/km)
downtown	PT	56	8.3	73.6
	Car	12	10	147.2
	MM	12	6	50
	walking	20	1,42	40
City	PT	45	8.3	60
	Car	25	10	140
	MM	12	6	40
	walking	17	1.42	40
rural	PT	26	13.9	60
	Car	46	19.4	115
	MM	16	5.5	60
	walking	12	0	0
motorway	PT	5	7.7	76
	Car	95	30,5	140
	MM	0	0	0
	walking	0	0	0

5. Conclusion

This paper presents a comprehensive model to evaluate the impact of economic interventions on mobility in urban environments, specifically focusing on the introduction of parking fees in Jinan, China. The study highlights the significant differences in modal split and mobility patterns between European and Far Eastern cities, emphasising the need for region-specific adaptations in sustainability models. The crucial results of this research demonstrate that the introduction of parking fees in Jinan has led to a notable reduction in traffic congestion, increased public transportation usage, and improved air quality. The tiered pricing system has effectively discouraged long-term parking in high-demand areas, contributing to more efficient urban space utilisation and reduced CO_2 emissions.

Overall, this paper contributes to the body of knowledge by offering a refined model for evaluating economic interventions in urban mobility, highlighting the importance of region-specific adaptations, and suggesting new directions for further research.

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References

Bieker, G. (2021). A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars. ICCT White Paper. URL: https://theicct.org/sites/default/files/publications/Global-LCA-passenger-cars-jul2021_0.pdf

Buzási, A., Csete, M. (2015). Sustainability indicators in assessing urban transport systems. *Periodica Polytechnica Transportation Engineering*. 43(3), 138–145. DOI: 10.3311/PPtr.7825

Buzási, A., Jäger, B. S. (2020). District-scale assessment of urban sustainability. *Sustainable Cities and Society*. 62, 102388. DOI: 10.1016/j.scs.2020.102388

Chen, C. (2017). At 20km/h you are moving only slightly faster than a donkey in Jinan, China's most gridlocked city. *South China Morning Post*, 2017, November 28. URL: https://www.scmp.com/business/china-business/article/2121979/20km/h-you-are-moving-only-slightly-faster-donkey-jinan

Gaal, G., Horváth, E., Török, Á., Csete, M. (2015). Analysis of Public Transport Performance in Budapest, Hungary. *Periodica Polytechnica Social and Management Sciences*. 23(1), pp. 68–72. DOI: 10.3311/PPso.7724

Gao, J. (2025). Research on improving traffic planning control in Jinan City, Shandong Province based on big data urban planning. *Advances in Economics Management and Political Sciences*. 148(1), 60–66. DOI: 10.54254/2754-1169/2024.LD19168

He, D., Meng, F., Wang, M. Q., He, K. (2011). Impacts of urban transportation mode split on CO_2 emissions in Jinan, China. *Energies*. 4(4), 685–699. DOI: 10.3390/en4040685

IEA (2020). GHG intensity of passenger transport modes, 2019. URL: https://www.iea.org/data-and-statistics/charts/ghg-intensity-of-passenger-transport-modes-2019

Koczиszky, Gy. 2023. Quo Vadis, Market Economy? Challenges of Sustainability and Values, Possible Answers. *Public Finance Quarterly*. 69(1), 9–28. DOI: 10.35551/PFQ_2023_1_1

Nguyen, H. P., Le, P. Q. H., Pham, V. V., Nguyen, X. P., Balasubramaniam, D., Hoang, A. T. (2025). Application of the Internet of Things in 3E (efficiency, economy, and environment) factor-based energy management as smart and sustainable strategy. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 47(1), 9586–9608. DOI: 10.1080/15567036.2021.1954110

Orynycz, O., Rodrigues, G. S., Mendes dos Reis, J. G., Kulesza, E., Matijošius, J., Teixeira Machado, S. (2025). Energy and environmental benefits of in-motion charging trolleybuses: A case study of Vilnius. *Energies*, 18(12), 3015. DOI: 10.3390/en18123015

Pengjun, Z., Shengxiao, L. (2018). Suburbanisation, land use of TOD and lifestyle mobility in the suburbs. Journal of Transport and Land Use, 11(1), 195-215. DOI: 10.5198/jtlu.2018.1099

Szalmáné Csete M., Zöldy M., Török Á. (2024). Új mobilitási megoldások: technikai lehetőségek és pénzügyi aspektusok a fenntarthatóság tükrében [New mobility solutions: technical possibilities and financial aspects in the light of sustainability]. In: Kolozsi P. P. (szerk.): *A pénz jövője, a jövő pénze I: Pénzügyek történelmi perspektívában, zöld pénzügyi fordulat* [The Future of Money, the Money of the Future: Finance in Historical Perspective: the Green Financial Turn]. METU–MNB, Budapest. 183–199.

Torok, A., Torok, A., Heinitz, F. (2014). Usage of production functions in the comparative analysis of transport related fuel consumption. *Transport and Telecommunication*. 15(4), 292. DOI: https://doi.org/10.2478/ttj-2014-0025

Transport & Environment (2020). How clean are electric cars? T&E's analysis of electric car lifecycle CO2 emissions. *Briefing by Transport &* Environment. URL: https://www.transportenvironment.org/uploads/files/TEs-EV-life-cycle-analysis-LCA.pdf

Wengritzky, Z., Szabó, T. P., Dézsi-Benyovszky, A. (2024). Spatial effects of economical and infrastructural factors on BEV adoption: Evidence from an emerging market. *Review of Economic Studies & Research Virgil Madgearu*. 17(1). DOI: 10.24193/RVM.2024.17.113

World Bank. (2018). Reducing Traffic Congestion and Emission in Chinese Cities. *World Bank.* URL: https://www.worldbank.org/en/news/feature/2018/11/16/reducing-traffic-congestion-and-emission-in-chinese-cities

Yang, Z., Jia, P., Liu, W., Yin, H. (2017). Car ownership and urban development in Chinese cities: A panel data analysis. *Journal of Transport Geography*. 58, 127–134. DOI: 10.1016/j.jtrangeo.2016.11.015

Zamprogno M. M., Esztergár-Kiss D. (2024). Applying Cluster Analysis for the Investigation of Travel Behavior and User Profiles. *Periodica Polytechnica: Transportation Engineering*. 52(4), 362–371. DOI: 10.3311/PPtr.25663

Zhang, Y., Zhao, L., Zhao, H., Gao, X. (2021). Urban development trend analysis and spatial simulation based on time series remote sensing data: A case study of Jinan, China. *PLoS ONE*. 16(10), e0257776. DOI: 10.1371/journal.pone.0257776

Zöldy, M. (2024). Changes at mobility space use in the cognitive mobility era. *Acta Technica Jaurinensis*. 17(4), 163–168. DOI: 10.14513/actatechjaur.00750

Zöldy M., Kolozsi P. P. (2025). Analysis Of Economic Policy Instruments To Promote Sustainable Mobility. *Acta Universitatis Sapientiae – Economics and Business*. Online first. URL: https://acta.sapientia.ro/content/docs/ACTA-Economics-2025-13--2.pdf

Zoldy, M., Csete, M. S., Kolozsi, P. P., Bordas, P., Torok, A. (2022). Cognitive sustainability. *Cognitive Sustainability*. 1(1). DOI: 10.55343/cogsust.7

Zöldy, M., Baranyi, P., Török, Á. (2024). Trends in Cognitive Mobility in 2022. *Acta Polytechnica Hungarica*. 21(7), 189–202. DOI: 10.12700/APH.21.7.2024.7.11