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Economic and Environmental Impacts of Tag-less Framework

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Mobility as a service (MaaS) has garnered significant academic attention recently. MaaS focuses on integrating various modes of transport so that mobility can be packaged as a single complete service. The main idea of MaaS is to combine different transport modes, such as public transport, bicycles, and PM, optimize trip efficiency and provide a complete process to passengers. There are many transport modes but each mode runs separately without a system that integrates them. The current public transport pricing system requires a card to be tagged when alighting and boarding, which causes congestions and delays in the operation of public transport. With a tag-less system, the connectivity among each mode can be improved by providing a comprehensive transport service, in which the time spent on tagging the cards can be reduced. This study aims to analyze the effects of a tag-less transportation system. First, a tag-less system can form a mobility platform, which increases the convenience of the transport system. This could be the foundation of MaaS and door-to-door services. Next, it can reduce the expenditure of transport operators, and adjust headways so that more people can use public transport. Finally, the travel time can be reduced, which can be a great reason to induce more people to use public transport instead of private cars. As the travel time decreases owing to adopting a tag-less system, the mode share of cars can be decreased approximately by 8.4 %. Furthermore, due to reduced mode share of car, environmental benefits are obtained. It is found that emissions can be reduced up to 15.8%. It is expected that a tag-less system can help realize the MaaS network with various other positive effects.

1. Introduction

One of the most important issues currently addressed is reducing greenhouse gas (GHG) emissions. The revitalization of public transport has emerged as a key task in transportation as an effective method to reduce the use of passenger cars. Public transport can be an efficient mode choice in terms of energy and cost because many more people can be transported per unit vehicle compared with private cars (Jasim et al., 2021). One method to revitalize public transport is Mobility-as-a-Service (MaaS). Mulley summarized that MaaS is the core of transport services that provide customized mobility solutions according to individual needs. The core of MaaS is to integrate various modes of transportation into one digital platform so that arrival information, reservation, and payment can be made at once (ITS Australia, 2018). It is necessary to establish a mobile-based platform to integrate all the necessary processes for a trip. This study suggests a tag-less system to accomplish MaaS. In Korea, payment for public transport, taxis, or other transport modes is achieved by tagging system comprising a card and machine. Payments must be made for each transport mode individually. A tag-less system does not require a tag for payment because the payment is made through a single mobile app. In addition, it integrates all transport modes such that a user only needs to pay once per trip.

Seoul has favorable conditions for implementing a tag-less system. The key to introducing the tag-less technology is the provision of integrated information on various modes. Because Seoul collects real-time information on most transportation, it has sufficient information to provide. In terms of infrastructure, Seoul is far more advanced compared to Helsinki, where the MaaS is most actively operating. This study aims to analyze the effects of a tagless system in Seoul.

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2. Methodology

2.1 Effects of the tag-less system

2.1.1 Effect of the mobility platform

Tag-less is a mobile-based public transport payment system that does not require card tagging. Because it is a mobile-based system, not only public transport but also PM, taxis, shared bicycles, or other transport mode can be integrated into one platform and provided to users. This is an important factor in realizing MaaS, which should be able to integrate customers, transport operators, data aggregators, and trusted MaaS advisors into one platform(Cruz and Sarmento, 2020). Tag-less allows each stakeholder to be grouped into one platform, which can facilitate the introduction of MaaS.

Platforming mobility services also create added value. In the platform business, multiple participants, such as suppliers and users, share a joint platform. The value is created based on the interaction between participants, which leads to reduced transaction and operating costs per person as the number of participants increases. As the number of participants increases, the platform grows, and its attractiveness as an advertising platform improves; consequently, it can attract more companies. The platform business is a better way to adjust services. For example, as traffic behavior transformed in New York owing to the increase in telecommuting due to COVID-19, Blade created and provided a new “Computer Pass” using helicopters, which created a new mobility field (Floetgen et al., 2021). Likewise, by integrating different modes under the tag-less system, it is possible to manage usage behavior simultaneously and provide appropriate services in response to changes in demand.

2.1.2 Increased convenience through integrated information provision

Tag-less integrates each transport mode into one platform and delivers the entire information to the users at once. It combines various modes and proposes an optimal route to users to reach their destination. Users can select a route by comparing the travel cost and time of each mode, increasing the convenience. Bjorn analyzed the impact of information systems (IS) on travel in sustainable mobility. As a result, more than 80 % of survey respondents said they were willing to choose car sharing instead of private car if the convenience of the car sharing service increased owing to improved IS integration. The integration of information regarding various transport modes increases the convenience of use and, accordingly, can attract more users than before.

2.1.3 Reduced cost and headway

Currently, a card must be tagged by the reader to pay for public transport. Transport operators spend a certain percentage of their income on fare adjustment and card fees, which is estimated to be approximately 35 billion won every year. The tag-less system can reduce costs and provide room for investment in improving public-transport operations. If the saved expenses are spent on additional subway cars, then the headway can be adjusted. In Seoul Metro Line 9, the number of subways cars have been supplemented from 4 to 6. As a result, headway and congestion were reduced by approximately 6 %. Zhou et al. (2020) found that the greater the headway is, the harder it becomes to secure sufficient dwell time for passengers during peak hours, which leads to a loss of capacity. If headway is adjusted with increased subway operations, the peak time capacity can be increased as well. Accordingly, the preferred mode of transportation can be converted from private cars to public transport.

2.1.4 Mode choice change

If the payment for all transportation modes is made at once using the tag-less framework, travel time can be decreased. Zhao et al. (2021) found that at least 16 % of Maas adopters gave up car ownership when the MaaS platform was fully established. This study confirmed that MaaS has a mode-change effect. Feneri et al. (2020) analyzed the variations in users' choice of modes following the introduction of MaaS using the error component logit model. As a result, it was found that automobile users had a low tendency to continue using private cars, which proves the mode converting effect. Gkiotsalitis et al. (2022) stated that if a user purchases a ticket for all their travels at once through MaaS, they can deduce the origin and destination of door-to-door travel more accurately, which can reduce travel time. The study analyzed the effects of introducing MaaS on bus routes in Singapore and revealed that travel time was improved by 6 %. Jung (2018) studied the change in travel time and cost according to the adoption MaaS. As a result, he suggested that the subway travel time decreased by 2 % after implementation. Mode change can also cause environmental effects (Jang et al., 2021).

This study analyzes the effect of the mode transition that can quantitatively confirm the positive effects of MaaS owing to the introduction of tag-less.

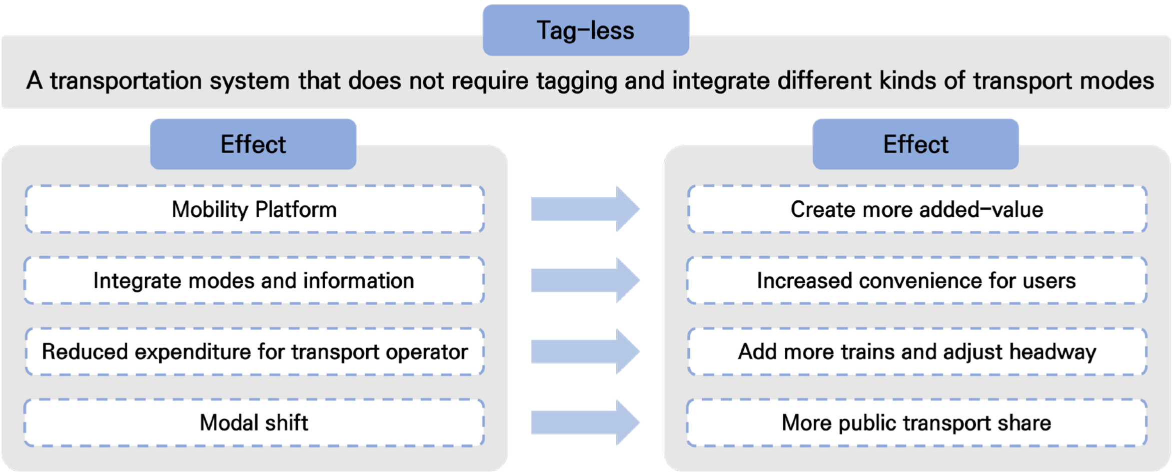

Figure 1. Framework of the study

2.2 Mode transition

To compare the change in mode shares before and after tag-less, mode share ratios before and after the introduction of tag-less were calculated. The current mode share ratio was calculated based on the O/D distribution using the Korea Transport Database (KTDB). The KTDB constructs O/D and network data for Korea and Seoul metropolitan area for traffic demand estimation. The current mode share ratio was calculated based on 2019 data without considering the influence of COVID-19 (Ku et al., 2021).

Because this study analyzes the change in mode share before and after the introduction of the tag-less system, an incremental logit model is used (Choi et al., 2021). The incremental logit model calculates the probability of selecting a mode based on the change in the mode utility measure (Mcfadden, 1974). The utility function presented by the Korea Development Institute was used in this study. The utility function and incremental logit model for each mode are shown as Eq(1) and Eq(2).

$$\begin{aligned} Car &= -0.0305128 \times \alpha - 0.0142173 \times \beta + 2.15846 \\ Bus &= -0.0305128 \times \alpha - 0.0305275 \times \beta + 0.892104 \\ Subway &= -0.0305128 \times \alpha - 0.0305275 \times \beta + 2.34424 \\ Taxi &= -0.0305128 \times \alpha - 0.0142173 \times \beta - 2.08676 \end{aligned} \tag{1}$$

where α is travel time and β is travel cost of each mode.

$$P_i^* = \frac{P_i \cdot exp\ (\Delta U_i)}{\sum_{j=1}^{J} P_j \cdot exp\ (\Delta U_j)} \tag{2}$$

where P_i^* is revised probability of choosing mode i, P_i is current mode share of mode i, U_i is utility function, and change ΔU_j is change of utility of mode j.

The incremental logit model calculates a new mode share based on the change in utility of all modes. The utility function considers the travel time and cost for each mode. Because the travel time of buses and subways decrease when the tag-less framework is introduced, the travel time in the utility function is adjusted to calculate the mode share ratio after successfully launching the framework. The travel time change was set to 94 % for buses (Gkiotsalitis et al., 2022) and 98 % for subways (Jung, 2018).

2.3 Environmental benefits

If a mode transition occurs with the tag-less framework, the traffic volume of passenger cars is expected to decrease, while that of public transport and shared mobility will increase. Ku et al. (2021) analyzed the effect of reducing traffic volume based on designating green transportation promotion areas and promoting eco-friendly transportation policies. By calculating the coefficient for each pollutant according to the changed traffic volume, it was found that the carbon dioxide reduction effect was 38.7 % before and after implementation (Kuet al., 2021). Accordingly, this study intends to calculate the benefits of reducing air pollution after successfully implementing the tag-less framework. First, the difference in vehicle kilometre travelled (VKT) before and after the introduction of the framework. The KTDB presents the emission coefficient for each pollutant by vehicle type, which is used here. The annual pollutant reduction amount can be obtained by multiplying the difference in VKT before and after the tag-less implementation by the pollution coefficient. The pollution coefficients for each vehicle type are presented in Table 1. The value of pollutant savings (PS) is derived through Equation (3). D_{lk} and D'_{lk} are vehicle-km by link l and by vehicle type k, respectively, without or with tag-less, and E^v_{lk} is air pollution factor.

$$
\begin{aligned}
&PS = PS_{without} - PS_{with} \\
&PS_{without} = \textstyle\sum_{v=1}^{V}\sum_{l=1}^{L}\sum_{k=1}^{K} D_{lk}E^v_{lk} \\
&PS_{with} = \sum_{v=1}^{V}\sum_{l=1}^{L}\sum_{k=1}^{K} D'_{lk}E^v_{lk}
\end{aligned}
\tag{3}
$$

Table 1: Car air pollution factor (g/km)

Speed	CO	NOx	VOC	PM2.5	CO_2
50	0.38	0.22	0.03	0.01	145.34

3. Results

3.1 Cost reduction

To analyze the benefits owing to reduced cost regarding transport operator charges, the number of additional trains that can be scheduled using the accumulated savings. Currently, Seoul has 10 metro lines with 325 stations, covering a total distance of 343.4 km, similar to the subways in cities such as London, New York, and Beijing. Accordingly, approximately 20 million big data points are generated per day. The total income of the operating institution is around 7 trillion KRW/y. The transportation business income of subway operators is around 2.3 trillion KRW/y, and the commission rate for transportation cards is 1.5 %, resulting in approximately 35 billion KRW/y in annual commission expenditure. According to the Seoul Metropolitan Government's Transportation Policy Division, the cost of adding one train is approximately 9.1 billion KWR. Approximately four additional trains can be arranged. Line 9, which is congested the most during peak hours, has a headway of approximately 8 min. If four more trains are arranged, the headway can be reduced to 6.3 min. Accordingly, it is possible to transport more passengers and induce a mode transition. The vehicle cost is γ and operational cost and depreciation cost of the vehicle is δ and ε.

$$
Number\ of\ Additional\ Vehicle = \frac{\text{Revenue} \times 1.5\ \%}{(\gamma + \delta + \epsilon) \times 6} \tag{4}
$$

$$
New\ headway = \frac{Peak\ Hour}{Number\ of\ Additional\ Vehicle} \tag{5}
$$

Table 2: Reduced cost and headway

Revenue(KRW)	Fee(KRW)	Cost for a train(KRW)	Additional vehicle	Headway(min)	
				Before	After
2,305,507,611,259	34,582,614,169	9,102,000,000	4	8.0	6.3

3.2 Modal shift

First, the current mode share ratio was calculated. The data used were taken from the Seoul metropolitan area network and O/D database built and distributed by the KTDB in 2019. The metropolitan area includes Seoul, Gyeonggi, and Incheon, and includes road and subway networks. The O/D in the metropolitan area is provided with respect to the modes; in this analysis, the mode share ratio of non-execution is calculated based on the sum of cars, buses, subways, and taxi O/D values. The mode share rate after introducing the tag-less framework was calculated using an incremental logit model. The utility for each mode comprises the travel time and cost. Because the travel time decreases after implementation, the changed mode share is calculated by adjusting the corresponding value. The travel times for buses and subways were applied at the previously set 94 % and 98 % levels. As a result of the modal split, the mode share rate of passenger cars decreased by 8.4 %, while that of buses and subways increased by 1.0 % and 8.1 %.

Table 3: Mode share change

Mode	Traffic volume (Trips)		Mode share (%)	
	Before	After	Before	After
Car	21,198,900	17,842,237	52.8	44.5 (-8.4)
Bus	6,995,110	7,396,375	17.4	18.4 (+1.0)
Subway	8,748,980	11,998,992	21.8	29.9 (+8.1)
Taxi	3,169,900	2,875,285	7.9	7.2 (-0.7)

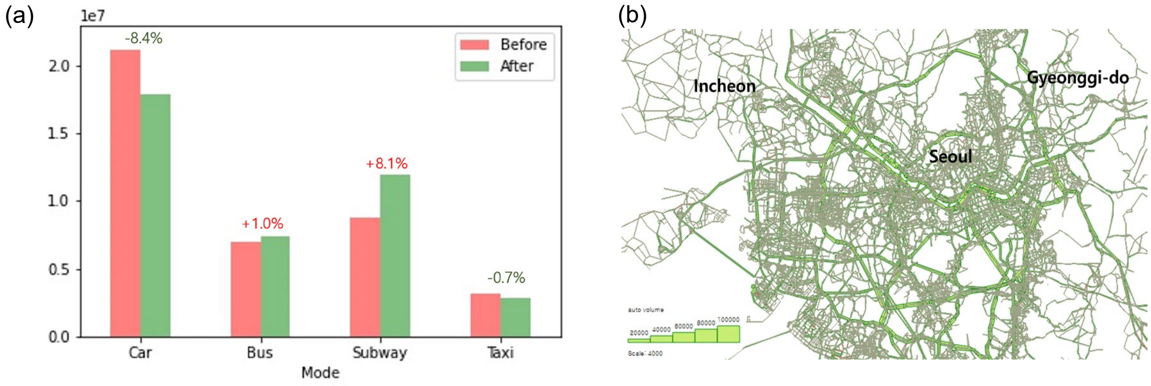

Figure 2: (a)Mode share change, (b)Decreased traffic volume after adopting the Tag-less system

3.3 Environmental benefits

From the mode transition analysis, it was shown that the traffic volume of passenger cars decreased, while that of public transport increased after tag-less implementation. Having fewer private cars in traffic results in environmental benefits; the pollutant reduction rate was calculated accordingly. Firstly, the VKT at the time of non-execution was 3,355,809,804 veh-km. The VKT at the time of implementation was 2,824,446,314 veh-km. The coefficient for each pollutant was multiplied by VKT to calculate the difference between the pollutant emissions before and after implementing the tag-less framework. Because Seoul implements a 50 km/h speed limit, the annual pollutant reduction was calculated considering 50 km/h. Consequently, after the introduction of the tag-less framework, carbon dioxide emissions decreased by 28,188,355 t (15.8 %).

Table 2: Air pollutants reduction (Unit: t)

	CO	NOx	VOC	PM2.5	CO_2
Before	465,451	269,472	36,746	12,249	178,022,690
After	391,751	226,803	30,928	10,309	149,834,335
Difference	73,700	42,668	5,818	1,939	28,188,355

4. Conclusion

In Seoul, public transport payments are made using a transportation card system. The currently used transportation card system allows transfers between public transportation modes; the modes are not integrated. By introducing the so-called tag-less framework, it is possible to establish a system where information provision and payments are made at once by integrating each transport mode into one mobile platform. If different transportation modes are integrated in this manner, effects such as the convenience of information provision and time reduction can be expected. In this study, the mode transition effect that reduces travel time, which can be quantitatively measured, was analyzed. The analysis confirmed that the traffic volume generated by passenger cars decreased while that generated by buses and subways increased. Pollutant emissions decreased as private car volume decreased as well. The annual reduction in emissions for each pollutant type was calculated. Subsequently, it was determined that 28,188,355 t of carbon dioxide emissions could be reduced in the metropolitan area.

There are other effects than mode transition. As a new mobility platform is created, convenience increases and costs decrease; it is possible to secure more users. Subsequently, more added value can be created with advertising revenue. Public transport based on a tag-less system would be a facility used by many citizens, it would be possible to create a new field of added value creation through advertisements placed at shops inside the subway and partnerships with other businesses in the private sector. To integrate transportation methods operated by different operators into one single platform, government-level support to secure data sharing and compatibility is essential. AHP analysis can be used to consider these various factors. AHP analysis is a technique for measuring the relative importance by stratifying evaluation items that is suitable for a business with many factors, such as the tag-less framework. To successfully introduce this framework, further research to discover policies, costs, and benefits is necessary.

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