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Calculating the Environmental Benefits of Trams

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The Net-Zero standard was proposed by Science Based Target (SBTi) to bring the net greenhouse gas emissions to zero as global warming intensifies, and this policy is spreading worldwide. Public transportation plays an important role in eco-friendly transportation and establishing a railway-oriented public transportation system is important. Among modes of railway traffic, trams are easy to access compared with subways (a representative modes of railway transportation) and are economical because of their low construction and operation costs. If a priority signal is given to the tram operation, the scheduled speed increases; The efficiency can be further improved. The purpose of this study was to analyse how the conversion of modes to public transportation caused by tram construction can affect the atmosphere and to study how much the increase in physical activity caused by the increase in public transportation affects the reduction of disease. Dongtan New Town in Korea, where trams are scheduled to be introduced, was set as the study area, and the effect of the conversion of modes of transportation resulting from tram construction was analysed through the modal split process of the four-stage transportation demand prediction model. The analysis shows that trams will generate a 54,700 trips/d conversion to public transportation within the affected area. The benefit from air pollution reduction is 25.13×10^8 KRW/y.

1. Introduction

Oscanoa Huaynate et al. (2015) noted that humans and various ecosystems have been affected by global warming for a long time, and that the main source of global warming is the rapid increase in carbon emissions. As the global warming problem became serious, SBTi provided a clear path for companies and governments to reduce carbon emissions by 2050. Shu and Lam (2011) argued that carbon dioxide emissions related to road traffic are particularly attracting attention, and that CO_2 emissions should be reduced through improved transportation infrastructure and development of transportation demand management systems. In order to reduce carbon emissions, Korea implements transportation demand management policies such as a day-of-the-week system for passenger cars, road space reorganization, and restrictions on the operation of class 5 vehicles in Seoul(Ku et al., 2021). This study seeks to reduce carbon emissions in the transportation sector. Song et al. (2016) said that among public transportation, rail transportation (subways, trams, monorails, etc.) is more punctual and mass transportation than other public transportation systems. The higher the accessibility of public transportation, the lower the congestion in the vehicle, and the shorter the waiting time, the higher the potentially that the passenger car user will convert the means of transportation to public transportation (Redman et al., 2013). In this paper, it is deliberated to reduce the use of passenger cars by inducing the use of public transportation from passengers. Kaewunruen et al. (2015) demonstrated that among railway modes, trams also have environmental benefits (reducing carbon emissions and reducing congestion). Zielinski et al. (2020) noted that trams have a lower capital cost per mile than light rail or subways, and trams integrate routes with existing roads. Prud'homme et al. (2011) argued that, through the integration of existing roads and routes of trams, "road diets" can inhibit the use of passenger cars, by reducing carbon emissions. The purpose of this study was to analyse how much the introduction of trams, a more economical and environmentally friendly modes of transportation, can have a positive impact on the environment. By using the logit model of Dongtan new town

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in Korea, the conversion rate of trams to public transportation was calculated. The framework of this study is shown in Figure 1.

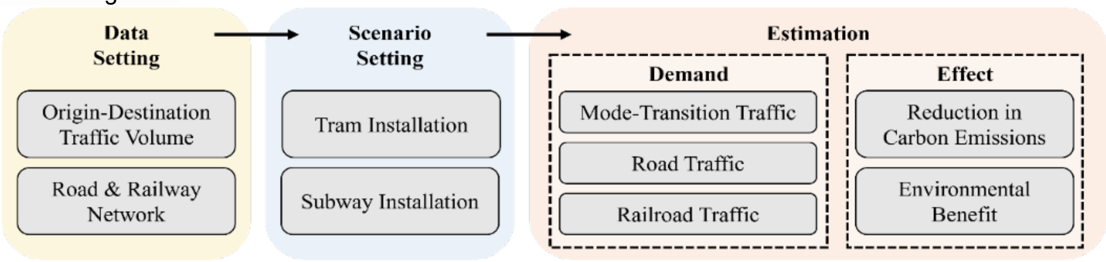

Figure 1: Framework for analysis of demand and benefit effects by introducing tram

2. Literature review

2.1 Trams as a green modes of transportations

Ku et al. (2020) noted that the reduction in passenger vehicle capacity can increase social benefits through the interpretation of the Downs–Thomson paradox in terms of traffic and that the introduction of median bus lane helps the speed of passenger cars and buses reach the user's balance and affects the increase in total social benefits. McGreevy (2021) stated that two-way laying of tram rails would reduce the number of traffic lanes available to cars and increasing the inconvenience of vehicle drivers could stimulate the conversion of private cars to public transport. Buehler and Pucher (2011) noted that the transition from passenger cars to public transport can help alleviate environmental and social problems by reducing energy consumption and CO_2 emissions. Trams have considerable advantages as a mode of transportation, such as high efficiency and flexibility, so they have merit as a new mode of public transportation. Naznin et al. (2015) examined the use of priority signals for many trams, resulting in a 16.4 % collision reduction after implementation of priority measures, as well as speed and reliability through priority signalling. Börjesson et al. (2014) noted that, unlike subways, which require many structures for construction, trams are less expensive to build and operate because they can be used only by laying rails using existing roads.

2.2 Traditional transportation demand forecasting model and modal split

Agrawal et al. (2018) extended the existing four-stage model to indicate areas requiring more highway transportation programs. In this study, the existing four-steps transportation demand prediction model was used because the demand for trams was estimated based on Dongtan New Town in Korea, where trams are scheduled to be introduced. Modi et al. (2011) argued that the traffic demand model for traffic planning consists mainly of trip generation, trip distribution, modal split, and trip assignment and that route selection in traffic planning depends on certain parameters, such as travel time, distance, cost, comfort, and safety. In this study, to consider the factors of the choice of individuals of various modes in the modal split process among the four-stage models, an attempt was made to predict the conversion method that should be used during the construction of the tram system by considering the variables of cost, distance, and time. Norm and Grady (2006) explained that the four-stage is likely to be overestimated. This four-stage demand estimation in the zone unit can be subdivided into multiple zones to predict the realistic tram demand considering the access time of passengers.

2.3 Calculate the air pollution reduction of tram

Lane and Sherman (2013) argued that the use of rail transportation could reduce water pollution from road runoff, and benefits in terms of reduced air pollution could occur as automobile and bus traffic are suppressed. The purpose of this study was to analyse how much benefit the modal split of transportation to trams and subways, calculated through the modal split process, can bring to the environment. Holnicki et al. (2021) analysed the effect of changes in air pollution caused by road traffic due to modernization of urban areas and used the Calpuff model to simulate the average annual concentrations of NO_x, CO, PM_{10}, and $PM_{2.5}$. As a result, compared with the total number of passenger cars in the city, a low-emission modal split of 0.36 % could lead to a reduction in NO_2 emissions by approximately 1.9 %. In this study, am attempt was made to calculate the air pollution reduction benefit through resulting from the use of trams, which are a low-emission form of rail transportation, rather than low-emission passenger cars. The air pollution reduction benefit was calculated by using the air pollution cost per km of the number of vehicles and the link driving speed for each vehicle type.

2.4 Calculation of health benefits from increased physical activity

Younkin et al. (2021) calculated the avoidance of death by physical activity elevation using a Health-Oriented Transportation model with an exposure-response function that estimates the relative risk of all causative deaths given physical activity levels. It was estimated that traffic-related physical activity in London's adult population in 2016 could avoid 1618 and 2720 deaths, both internally and externally. Xia et al. (2015) said that, by moving 40 % of vehicle km travelled (VKTs) by cars from a study area of an estimated population of 1.4×10^6 in 2030 to alternative transportation, the average urban $PM_{2.5}$ per year could be reduced by about 0.4 gg/m3 compared with normal, resulting in a net health benefit of 13 fewer deaths per year. The Adjustment of the number life was prevented because of improved air quality. In this study, an attempt was made to calculate the air pollution reduction benefit using trams, a low-emission railway traffic service, and to calculate the air pollution reduction benefit using the air pollution cost per km of the number of vehicles and the link driving speed of each vehicle.

3. Methodology

3.1 Overview of Dongtan new town tram

According to the basic plan of the Dongtan Urban Railway, most public transportation uses buses to access each area, and the system for transferring between different modes of public transportation is inconvenient; people often depend on passenger cars. The purpose of this project was to select the best urban railway route to solve traffic difficulties and improve public transportation convenience in Dongtan New Town, a planned large-scale development site. It consists of the Mangpo–Osan route and Byeongjeom–Dongtan 2 New Town route, and the Mangpo–Dongtan–Osan route distance is 16.4 km (see Figure 2). the scheduled speed is 20.7 km. The Byeongjeom–Dongtan 2 New Town section is 17.8 km, and the scheduled speed is 20.0 km. The tram's full capacity is 246 people. The Dongtan tram is scheduled to be built in 2027 and is adjacent to various stations, including Byeongjeom Station, Osan University Station, and Sema Station. The modal split rate of transportation was analysed according to the introduction of trams in the demonstration area of Dongtan New Town, along with the resulting environmental benefits.

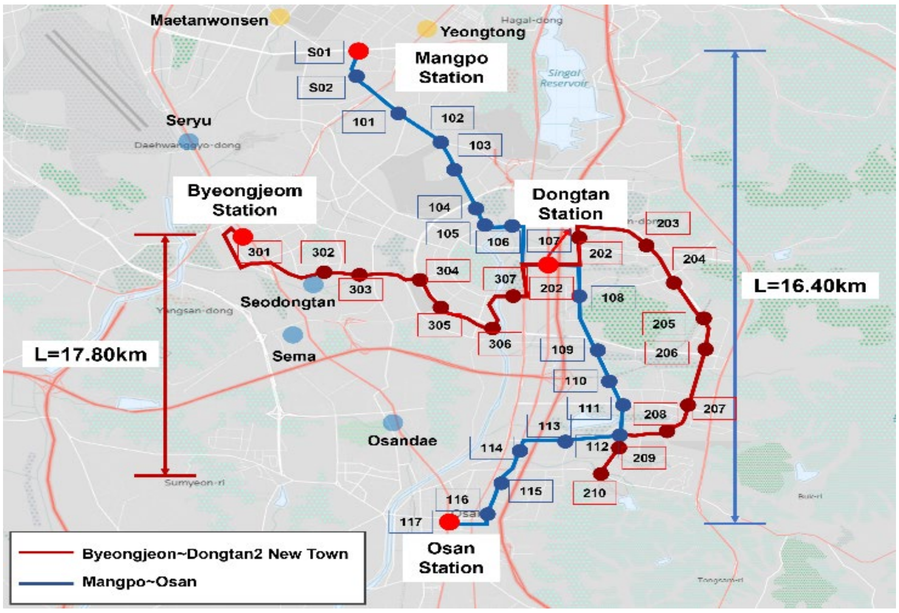

Figure 2: Basic information on the Dongtan new town tram

3.2 Calculation of modal split model

In this study, a step-by-step traffic demand prediction model at the times before and after implementation of the tram project was used to predict the extent to which the tram can produce a modal split effect. Because the Korea Transport Database, which has an Origin/Destination matrix and network, provides trip generation and trip distribution, it only uses modal split and trip assignment among the demand forecasting model processes. In the modal split process, the logit model, which is an individual traffic model, is used to predict demand by utilizing the characteristics of individual pass behaviour. In the case of utility functions, utility functions and coefficients for each modes constructed and distributed by the Gyeonggi Institute were applied (Choi et al., 2021). Reflecting the characteristics of the tram, when applying the modal split model, the length of the boarding link was shortened to 50 % of the subway boarding link. Subway stops within a radius of 300 m, based on the Dongtan tram stops, were set to be transferable and analysed. The logit model was generated using in-vehicle time, out-of-vehicle time, and waiting time as transit time variables by modes of in-vehicle and out-of-vehicle distance, and the transit cost variable was constructed by modes. For an incremental logit model, information on existing (P_k^0) and new modal split is required (P_k), and a change in utility for modes k ($-\theta_{c_k}$) is required. To modify the mode selection model using the progressive logit model, we calculate the utility at the time before the project executed and calculate a new model split that considers the utility changes, as shown in Eq(1).

$$P_k = \frac{P_k^0 \exp\left(-\theta_{c_k}\right)}{\sum_j^n P_j^0 \left(-\theta_{c_k}\right)} \quad (1)$$

3.3 Calculation of benefits

3.3.1 Calculation of air pollution reduction benefits

The environmental benefits of constructing a tram were calculated by reducing air pollution through modal division of the tram. To calculate the benefits of air pollution reduction, the emission coefficient for each pollutant generated by driving a car and the environmental damage cost per unit of pollutant were calculated. Changes caused by the construction of trams in pollutant emissions from pollutant sources were calculated, and the calculated value was converted into currency by multiplying the unit of cost of environmental damage by the pollutant. Air pollution costs by vehicle type and speed are used by the Korea Development Institute (KDI), an institution that conducts a comprehensive study on Korea's economic and social phenomena, in the "Transportation Sector Business Benefit Calculation Methodology Study (Lee, 2017)". Eq(2) compares the air pollution benefits ($VOPCS$) when a specific project is implemented and when it is not implemented to obtain the air pollution reduction costs ($VOPC$). Eq(3) is an equation for obtaining air pollution reduction benefits. D_{kl} in Eq (3) means vehicle·km by link (l) and vehicle type (k), VT_k means air pollution cost per km of the link speed by car type (k), where k means a car at 1, a bus at 2, and a truck at 3.

$$VOPCS = VOPC_{Unimplemented} - VOPC_{implemented} \quad (2)$$

$$VOPC = \sum_l \sum_{k=1}^{3} \left(D_{kl} \times VT_k \times 365\right) \quad (3)$$

3.3.2 Calculation of health benefits from increased physical activity

In this study, the health benefits estimated by the Health Economic Assessment Tool (HEAT) and the Disease Absence Reduction Tool (SART) used by the WHO were employed to calculate and compare the fundamental benefits of three health benefits (Ku, Kwak, et al., 2021). In this study, it was predicted that the construction of trams would lead to the conversion to public transportation, and physical activities, such as walking and cycling, would increase as the use of passenger cars decreased. Physical activity can be an important factor in preventing dementia and other health problems (Abbott et al., 2004). Eq(4) compares the physical activity benefits ($VMCS$). when a specific project is implemented and when it is not implemented to obtain the air pollution reduction costs (VMC). Eq(5) is an equation for obtaining physical activity reduction benefits D_w means pedestrian and bicycle total walking distance (person·km). M means mortality, and ρ_M means the original unit of mortality. P^M means the social cost of death. The number of preventive units of mortality from walking and cycling and the value of life per death is 671,810,000 KRW.

$$VMCS = VMC_{Unimplemented} - VMC_{implemented} \quad (4)$$

$$VMC = D_w \times \rho_M \times P^M \quad (5)$$

4. Results

4.1 Transition effect of tram introduction

The modal segmentation in 2028 was calculated, and the results were compared using the Eq(1) presented in the methodology, using the application of the modal segmentation model reflecting the characteristics of the trams and the configuration of the boarding link length suitable for the trams. As a result, when the tram system was implemented, the car modal split decreased by 41,800 trip/d, the bus modal division decreased by 11,390 trip/d, and the proportion of subway and bus plus subway conversions increased by 54,700 trip/d. Table 1 shows the differences between the traffic volume and split rate of the modal split at the time of project implementation and non-execution in 2028.

Table 1: The effect of the alteration of the trams in Dongtan new town (Unit: trip/d)

Division		Unimplemented		Implemented		Difference	
		Amount of traffic	Split rate	Amount of traffic	Split rate	Amount of traffic	Split rate
2028	Car	20,731,900	49.51 %	20,690,100	49.41 %	−41,800	−0.10 %
	Taxi	3,368,740	8.04 %	3,367,230	8.04 %	−1,510	0.00 %
	Bus	7,164,170	17.11 %	7,152,780	17.08 %	−11,390	−0.03 %
	Subway	7,070,390	16.88 %	7,098,870	16.95 %	28,480	0.07 %
	Bus + subway	3,542,750	8.46 %	3,568,970	8.52 %	26,220	0.06 %
	Total	41,877,950	100.00 %	41,877,950	100.00 %	0	0.00 %

4.2 Estimation of environmental and health benefits from the introduction of trams

Air pollution reduction benefits can be expected owing to reduced passenger traffic and changes in pollutant emissions by vehicle type and speed calculated based on a discount rate of 4.5 % according to the methodology. Based on the monetary value obtained by calculating changes in pollutant emissions by pollutant sources and multiplying the change in pollutant emissions by the cost of environmental damage by pollutants, 25.13 $\times 10^8$ KRW should be saved in 2028, one year after the construction of the new city. As a result of calculating the disease reduction benefit by reflecting the preventive mortality rate and the life value, 734.91$\times 10^8$ KRW/y in health benefits will accrue as of 2028. Environmental benefits from the introduction of trams are summarized in Table 2, and health benefits are summarized in Table 2.

Table 2: Environmental and health benefits of Dongtan new town tram project implemented to unimplemented

Division	VKT difference	Air pollution cost coefficient	Unit of mortality	Benefits
Environmental benefits Health benefits	607,136.82 km	11.34 KRW/km	0.000173	25.13 $\times 10^8$ KRW 734.91$\times 10^8$ KRW

5. Conclusion

As interest in carbon neutrality has increased worldwide, efforts are being made to introducing various eco-friendly modes of transportation. And interest in trams, which have high mobility and reliability, is increasing. In this study, a method to study the tram conversion effect compared with subways was developed using the tram modal split process. Subsequently, the analysed modal split rate was used to determine the environmental and health benefits caused by the decrease in air pollution caused by the conversion to public transportation, and Dongtan New Town in Gyeonggi-do, Korea, where trams are scheduled to be introduced, was set as the study area. Calculating the modal split when trams are implemented in Dongtan New Town revealed that 54,700 trip/d will convert to public transportation. Calculating the air pollution reduction benefit caused by the reduction in passenger cars through the modal split showed that 25.13 $\times 10^8$ KRW/y will be saved. Finally, the benefit of reducing diseases caused by increased physical activity owing to the use of public transportation is predicted to be 65.63.5 $\times 10^8$ KRW/y. In this study, excessive demand estimation may have occurred because zone-level demand estimation was performed to derive the modal split rate. It is necessary to add a walking-related study by conducting an analysis that can clearly reflect the access characteristics of passers-by based on an agent-based model.

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