Research Article

Benchmarking Intelligent Transportation Systems Performance of Urban Public Transportation Operations

Tugay Çelik[1*], Soner Haldenbilen[2], Halim Ceylan[3]
[1,2,3] Department of Civil Engineering, Faculty of Engineering, Pamukkale University, Denizli, Türkiye
*Correspondence: tcelik@pau.edu.tr
DOI: 10.51513/jitsa.1572364

Abstract: Urban transportation problems have been increasing in developing and developed countries around the world and traditional planning approaches have started to be obsolete in regards to come forward with the solutions to these problems. Planning paradigm shifted from infrastructure development and expansion to look for innovative, sustainable and urban life focused solutions. With this paradigm shift, Intelligent Transportation Systems (ITS) have emerged as a growing and developing phenomenon in means of reaching sustainable urban mobility goals. Many ITS technologies have been integrated with public transportation systems in urban areas which are used for purposes such as monitoring, data collection and informing. Although implementation of the technologies into the urban transportation systems are beneficial for the quality of urban transportation, monitoring and evaluation is essential for ensuring the continuous improvement of these systems and their positive impacts. With this purpose a benchmarking framework is developed in this study, subjecting transit agencies to comparative analyses amongst its peers. 7 transit agencies from metropolitan areas of the United States have been chosen for the study, to be benchmarked in the base of 24 performance indicators in 5 performance categories. A performance index is calculated using these indicator values and several sensitivity analyses are carried out to determine the strengths and weaknesses of transit agencies compared to each other. It is aimed by the study to provide a benchmarking tool for ITS performance assessment.

Keywords: Benchmarking, Intelligent Transportation Systems, Public Transportation

Toplu Taşıma Organizasyonlarında Akıllı Ulaşım Sistemlerinin Karşılaştırmalı Değerlendirme Yöntemi ile Performans Analizi

Özet: Gelişmiş ve gelişmekte olan ülkelerde kentsel ulaşım problemleri artış göstermekte, geleneksel planlama yöntemleri bu problemlere çözüm üretme konusunda yetersiz kalmaktadır. Planlama yaklaşımları ulaşım altyapılarının geliştirilmesi ve kapasitesinin arttırılması gibi geleneksel çözümlerden yenilikçi, sürdürülebilir ve kentsel yaşam odaklı çözümlerin tercih edildiği çözümlere doğru değişim göstermiştir. Planlama yaklaşımlarındaki bu değişim ile birlikte Akıllı Ulaşım Sistemleri (AUS), sürdürülebilir kentsel hareketlilik hedeflerine ulaşmada büyüyen ve gelişen bir olgu olarak ortaya çıkmıştır. Gözlemleme, veri toplama ve etkili yönetim amaçları ile kullanılan bir çok AUS teknolojisi kentsel toplu taşıma sistemlerine entegre edilmiştir. Bu teknolojilerin kentsel ulaşım sistemlerinde uygulanması kentsel ulaşımın kalitesi açısından her ne kadar fayda sağlasa da, bu sistemlerin sürekli gelişiminin ve olumlu etkilerinin devamlılığının sağlanması açısından izleme ve değerlendirme çalışmaları gereklidir. Çalışmanın amacı AUS uygulamaları üzerinden sistem performansı ölçümü için "karşılaştırmalı değerlendirme aracı" üretmek ve toplu taşıma organizasyonlarının performansları analiz etmektir. Çalışma için Amerika Birleşik Devletleri'nin metropolitan bölgelerinden 7 toplu taşıma işletmesi, 5 performans kategorisi altında 24 performans göstergesi üzerinden değerlendirilmek üzere seçilmiştir. Toplu taşıma işletmelerinin birbirlerine göre güçlü ve zayıf özelliklerinin belirlenmesi amacıyla bu göstergelerin değerleri ile toplu taşıma işletmelerinin performans endeksleri hesaplanmış ve çeşitli duyarlılık analizleri gerçekleştirilmiştir.

Anahtar Kelimeler: Karşılaştırmalı Değerlendirme, Akıllı Ulaşım Sistemleri, Toplu Taşıma

ORCID: 0000-0003-2282-7327, 0000-0002-6548-6481, 0000-0002-4616-5439 (in hierarchical order)
Received 23.10.2024; Received in revised form 27.02.2025; Accepted 07.03.2025

1. Introduction

Accelerated growth of population and urbanization, increase in the number of vehicles, expansion of urban economic activities and transition of needs and demands of urban citizens are the main causes of urban transportation problems of today's world. Traditionally, developed and developing countries have been focused on infrastructure investments which mostly favor private transportation in their transportation planning processes to overcome the emerging transportation problems in urban areas. Observing that traditional planning approaches seem not to be the solution to solving the problems and mitigating the outcomes of the problems, it instigated the authorities to take a paradigm shift in transportation planning concept. With the emergence of Sustainable Urban Mobility Plans (SUMP) in the last 20 years, the focus of local authorities switched from expanding the infrastructure to improving the quality of urban life, ensuring economic and environmental efficiency, and resorting to innovative solutions. Although first appearance of ITS, in global scale, date back to 1970s (Wootton et al., 1995), use of ITS in urban traffic and integration of ITS in urban transportation planning have gained a great deal of importance with this paradigm shift. ITS are useful tools in monitoring and managing the urban traffic flow, mitigating the congestion, route planning of the urban citizens, improving transportation safety and overall betterment of the urban transportation system management (Singh & Gupta, 2015).

Though it's plausible to categorize in reviewing and evaluating the ITS; such as the technologies used in certain systems (communication technologies, sensing technologies etc.), objective of the usage of certain systems (data collection, monitoring, informing etc.); one way of assessing ITS is to focus on transportation modes affected by and are integrated with the systems. Implementation and integration of ITS in public transportation operations have been an essential component in reaching the sustainable mobility goals in urban transportation planning, furthermore is a still improving planning factor with the emerging technologies. Automated Vehicle Location (AVL), Computer Aided Dispatch and Scheduling (CADS), Mobile Data Computers (MDCs), Automatic Passenger Counters (APC), Maintenance Management Systems (MMS) , Transit Signal Priority (TSP) are some of the ITS equipments used to better manage the public transportation operations. Although the implementation of such equipments to the urban transit systems improves the efficiency of the system management; as it is in all transportation planning processes aligned with sustainable development, post-implementation monitoring and evaluation of the implemented systems is essential to ensure the continuing efficiency and improvement of the whole transportation system and to assess the current situations considering the strategic goals. Turkey prepared its first Intelligent Transportation Action Plan in 2014, covering the 2014-2016 period. The action plan consisted of 5 strategic goals, 21 objectives and 38 actions. Completing the period, in 2020 a new and updated action plan was developed covering 2020-2023 period. In 2020-2023 ITS Strategic Action Plan, defined 5 strategic goals have been aimed to be achieved by monitoring and evaluating the implemented systems through SEPSIS (Strategy and Action Plan Monitoring and Evaluation System) (National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan, 2020). Explained monitoring and evaluation system in the action plan is seen in Figure 1.

Assessment of the sustainability of transportation systems and operations have been the objective of governmental bodies, NGOs and academics. In United States, ITS Joint Program Office (ITS JPO) have been conducting deployment tracking surveys since 1999 every 2 to 3 years to monitor and evaluate the intelligent transportation system deployments. The assessment of ITS deployment is investigated in 3 main areas that are transit management, arterial management and highway management. The deployment tracking surveys are conducted in 108 metropolitan areas in the United States (Intelligent Transportation Systems Joint Program Office, n.d.-b). In 1994, in order to evaluate the performance of metro systems of the metropolitan cities by benchmarking; by cooperation of Hong Kong, London, Paris, New York and Berlin metro operations, Community of Metros Benchmarking Group (CoMET) have been founded. Currently, CoMET have 45 member metro systems from 41 cities worldwide (Community of Metros (CoMET), n.d.). Benchmarking European Service of Public Transport (BEST) have been founded in 1999 in order to promote the usage of public transportation in European cities. Led by Scandinavian countries, currently BEST have 11 member cities (Benchmarking European

Service of Public Transport (BEST), n.d.). Benchmarking European Sustainable Transport project have been established by European Commision in 2000. With this project, it has been aimed to improve

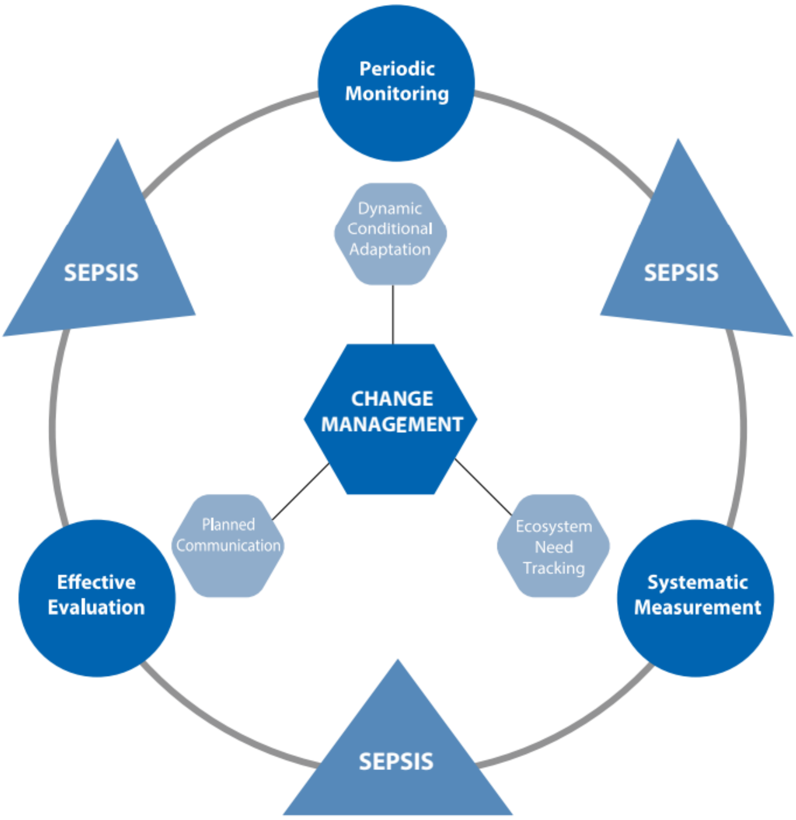

Figure 1. Monitoring and Evaluation System in 2020-2023 Action Plan of Turkey (National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan, 2020)

benchmarking strategies and bring awareness to importance of benchmarking in assessment of sustainability transportation systems (Benchmarking European Sustainable Transport, n.d.). The Urban Transport Benchmarking Initiative has been started in 2003 as a European Union Project. Benchmarking framework have been structured with 25 indicators under 5 themes. 39 cities have been selected for the case study of the project (The Urban Transport Benchmarking Initiative, n.d.).

In addition to evaluation strategies of authorities, aiming to assess the sustainability of transportations systems and efficiency and performance of ITS also academic literature presents studies as well. Choosakun and Yeom (Choosakun & Yeom, 2021) developed an evaluation framework for assessment of ITS in public transport. They used Fuzzy AHP method in their study to rank the priority level of indicators that are representing the ITS projects in order to enlist a decision making mechanism. Pindarwati and Wijayanto (Pindarwati & Wijayanto, 2015) measured the performance of ITS in 5 metropolitan cities in Indonesia and produced smartness indicators for the cities in the base of 60 indicators. Cheng et al. (Cheng et al., 2020) investigated the role of ITS in mitigating the traffic congestion in their study. They have used the data between 1994 and 2014 for 101 metropolitan areas in United States and developed models that explains the mitigation of traffic congestion taking pre-implementation congestion rates into account.

Many studies in the literature present evaluation strategies for assessing the sustainability of urban transportation systems, which studies enlist a broader point of view rather than solely focusing on ITS (Miranda & Rodrigues da Silva, 2012), (Perra et al., 2017), (da Silva et al., 2008), (Henning et al., 2011).

Zope et al. (Zope et al., 2019) selected 8 performance indicators to evaluate the sustainability of urban transportation systems of 7 metropolitan areas in India. Assessing the sustainability of the study areas, indicators have been gathered under economic, social and environmental dimensions. By selecting the upper and lower threshold values for the indicators, sustainability indexes of the areas have been calculated. Debnath et. al. (Debnath et al., 2014) developed a methodology to assess the sustainability of smart transport cities. 26 cities worldwide have been selected for the case study and smart city indexes of the cities have been calculated. Stone et. al. (Stone et al., 2012) evaluated the efficiency of public transportation operations in the cities of New Zealand by benchmarking. 14 quantitative performance indicators have been selected for the study including modal share of certain modes, public transport service-km, subsidy per boarding, car travel cost index. (Alkharabsheh et al., 2021) evaluated the quality of public transportation services in Amman, Jordan on the base of several indicators which are related to service quality, transport quality, tractability and faring. In the study the areas which need improvement are detected. (Moslem, 2024) evaluated the supply quality of bus transportation in Dublin Ireland with fuzzy AHP method, using a set of criterias which are gathered under transport quality, service quality and tractability categories. In the study features of the bus transportation such as approachability, directness, speed, comfort, information services are evaluated. (Kakati et al., 2024) developed a model for estimating the sustainable urban transportation solutions for Mersin City, Turkey by detecting the possible issues of the public transportation system. In their study they have found that reducing the fares is the most feasible option for public transportation system sustainability. Additionally, academic literature presents studies which focuses on integration of benchmarking methodologies in transportation planning and strategy development (Awasthi et al., 2018; Kiba-Janiak & Witkowski, 2019; Luque-Martínez & Muñoz-Leiva, 2005).

Although there are many performance and sustainability assessment studies in the literature, there are very few studies which encompass ITS and public transportation system assessment collectively, in the last years. The objective of this study is to develop a benchmarking framework to assess the performance of ITS in public transportation of the cities, transit agencies or metropolitan areas. With this purpose a set of performance indicators have been selected and performance indexes of the transit agencies have been calculated. It is aimed to produce a beneficial tool for decision making processes in monitoring and evaluation phases of ITS implementations by putting forward the strengths and weaknesses of ITS amongst peer transit agencies, operations or study areas.

2. Manuscript Content

The method used in this paper consists of determining the performance indicators for evaluating the performance of ITS implementations and applications in public transportation, determining the study areas and calculating the performance indexes of the study areas in order to prepare a benchmarking framework. 24 performance indicators are used in the study to benchmark 7 metropolitan area transit agencies in the United States. Sensitivity analyses are carried out to understand the strengths and weaknesses of the systems in different conditions.

2.1. Performance Indicators and Available Data

To assess the performance level of public transportation operations in study areas, 24 indicators in the performance categories of Transit Vehicle ITS Technology Adoption, Traveler Information Technology Adoption in Vehicles, Traveler Information Technology Adoption in Transit Stations, Travel Demand and Real Time Data Collection were determined. The data were collected from 2020 Deployment Tracking Survey of ITS JPO of the Department of Transportation in United States (Intelligent Transportation Systems Joint Program Office, n.d.-a). Reviewing the survey of 36 questions, data is examined and processed into indicators of this study. The survey was conducted for 136 transit agencies in metropolitan areas of United States. The performance indicators can be seen in Table 1. Determining the performance indicators two main criterias have been considered. These criterias are: data must be quantitative and the survey must have been answered by all or majority of transit agencies. Another criteria that is considered is that the indicators must have the worth and benefit of comparison. To set an example; while having a larger transit vehicle fleet might not define superiority of one transit agency to another, percentage of transit vehicles in the fleet which are equipped with several ITS technologies is a more meaningful comparison.

Transit Vehicle ITS Technology Adoption category covers the equipment rates of different ITS technologies in public transport fleets. Since transit Signal Priority is not an equipable technology for all public transport modes, calculating the rate only the number of fixed route bus, light rail and streetcar vehicles have been taken into consideration. Traveler Information Technology Adoption in Vehicles category covers the equipment rates of number of vehicles which are equipped with the traveler information technologies to the number of all transit vehicles of the agency. Traveler Information Technology Adoption in Stations category indicators covers the rate of public transport stations which are equipped with these technologies to all public transport stations of the agency. Since electronic signage and displays are not expected to be common for fixed route bus stations, this variable was calculated neglecting the fixed route bus stations in order to prevent a unnecessary low scoring of the performance index. A set of multiple choice questions from the survey which covers the category of travel demand performance indicators was selected for the travel demand category In this category, it is investigated if transit agencies provide several services to better manage the travel demand in their operation areas. For real time data collection 8 indicators were determined from the survey, in which category it is analyzed what kind of real time data are collected by the agencies.

2.2. Study Areas

Evaluating and examining the data, investigating the lack of responses to the survey questions for some of the transit agencies and taking availability of data into consideration from the survey for all the study areas, considering the transit mode diversity (considering some transit agencies only operate single type of transit modes) 7 transit agencies which have the largest transit fleet numbers have been selected for the case study of this paper. The selected transit agencies are Metropolitan Atlanta Rapid Transit Authority (MARTA) from the metropolitan area of Atlanta-Sandy Springs-Marietta, GA; Massachusetts Bay Transportation Authority (MBTA) from the metropolitan area of Boston-Cambridge-Quincy, MA-NH; Regional Transportation District (RTD) from the metropolitan area of Denver-Aurora, CO; Phoenix

Table 1. Performance Indicators

Performance Category	*Performance Indicator*	*Description*
1. Transit Vehicle ITS Technology adoption	1.1 Automated Vehicle Location (AVL)	Rate of number of AVL adopted transit vehicles to all transit vehicles of the system (%)
	1.2 Computer Aided Dispatch and Scheduling (CADS)	Rate of number of CDS adopted transit vehicles to all transit vehicles of the system (%)
	1.3 Mobile Data Computers (MDCs)	Rate of number of MDCs adopted transit vehicles to all transit vehicles of the system (%)
	1.4 Automatic Passenger Counters (APC)	Rate of number of APC adopted transit vehicles to all transit vehicles of the system (%)
	1.5 Maintenance Management Systems (MMS)	Rate of number of MMS adopted transit vehicles to all transit vehicles of the system (%)
	1.6 Transit Signal Priority (TSP)	Rate of number of TSP adopted transit vehicles to all transit vehicles which are equipable with TSP (%)
2. Traveler Information Technology Adoption in Vehicles (%)	2.1 Automatic Voice Announcement (AVA)	Rate of number of AVA adopted transit vehicles to all transit vehicles of the system (%)
	2.2 Dynamically Updating Passenger Information Displays	Rate of number of transit vehicles which are equipped with Dynamically Updating Passenger Information Displays to all transit vehicles of the system (%)
	2.3 Dynamically Triggered Automated Announcements	Rate of number of transit vehicles which are equipped with Dynamically Triggered Automated Announcements to all transit vehicles of the system (%)

Table 1. (Continued)

Performance Category	***Performance Indicator***	***Description***
3. Traveler Information Technology Adoption in Stations	*3.1 Electronic Signage or Displays*	Rate of number of rail and multi-modal stations in which Electronic Signage or Displays are provided to all rail and multi-modal stations (%)
	3.2 Mobile Application	Rate of number of public transport stations in which information through mobile application is provided to all public transport stations (%)
4. Travel Demand	4.1 Travel Management Coordination Center (TMCC)	Does the agency operate a Travel Management Coordination Center (TMCC) which works for the coordination of mobility needs of transportation disadvantaged? (Yes = 1, No = 0)
	4.2 Integrated Corridor Management (ICM)	Has the agency deployed Integrated Corridor Management (ICM) to actively manage travel demand and capacity? (Yes = 1, in planning process = 0.5, No = 0
	4.3 Route and service planning	Does the agency currently use ITS data for route and service planning? (Yes = 1, Only in certain modes = 0.5, No = 0)
	4.4 Passenger transfers	Does the agency employ vehicle monitoring and communication technologies to facilitate the coordination of passenger transfers between vehicles or between transit systems? (Yes = 1, no =0)
	4.5 Dynamic assignment of assets	Does the agency dynamically assign the vehicles based on real-time demand to cover the most overcrowded sections of the network? (yes =1, No = 0)
5. Real Time Data Collection	5.1 Vehicle time and location	Vehicle time and location data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.2 Vehicle monitoring status (i.e., vehicle diagnostics and health)	Vehicle monitoring status data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.3 Passenger count	Passenger count data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.4 Trip itinerary planning records	Trip itinerary planning records data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.5 Passenger information (e.g., fare transactions, trip origin/destination location)	Passenger information data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.6 Emergency vehicle signal preemption events	Emergency vehicle signal preemption events data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.7 Transit vehicle signal priority events	Transit vehicle signal priority events data collection in real time by the agency (Is collected = 1, Is not collected =0)
	5.8 Incidents	Incident data collection in real time by the agency (Is collected = 1, Is not collected =0)

Transit System (PTS) from the metropolitan area of Phoenix-Mesa-Scottsdale, AZ; TriMet Transit Agency from the metropolitan area of Portland-Vancouver-Beaverton, OR-WA; San Francisco Municipal Transportation Agency (SFMTA) from the metropolitan area of San Francisco-Oakland-Fremont, CA; Dallas Area Rapid Transit (DART) from the metropolitan area of Dallas-Fort Worth-Arlington, TX.

2.3. Method

The survey data is used by the ITS JPO to internally benchmark the ITS with the agency's numbers from the surveys. In this study it is aimed to develop a peer comparison benchmarking method which compares the ITS performance indexes of several transportation operations on the base of their score in 24 performance indicators from 5 performance categories. After enlisting the data and determining the study areas, performance indexes of the transit agencies are calculated. Since all the values for indicators vary between 0 and 1, normalization of the indicator values is not needed. All the indicators are in direct proportion with the performance of the ITS, also consideration of the negatively affecting indicators are not needed. Intelligent Transportation System Performance Index ITSPI is calculated by the formula given in Equation (1);

$$ITSPI = \frac{\sum_{j=1}^{J}\sum_{i=1}^{I} x_{ij}}{\sum_{j=1}^{J} I_j} \tag{1}$$

where j = number of a certain category from 5 categories
i = number of a certain indicator in any category j
x_{ij} = the value of indicator i of the jth category,
I_j = the amount of indicators in the category j.

To evaluate the performance of ITS according to different conditions and point of views, sensitivity analyses will be performed. Sensitivity analyses will be carried out by assigning different weights to performance categories as seen in Equation (2):

$$ITSPI_{S_k} = \sum_{j=1}^{J}\sum_{i=1}^{I} \frac{w_j * x_{ij}}{I_{s\,j}} \tag{2}$$

where k = sensitivity analysis number k
wj = the weight of the jth category.
Isj = the amount of indicators in only the considered and weighted (0 weight appointed categories excluded) categories for the analyses.

An example calculation is provided below to make the method more descriptive. For the example calculation, ITS Performance Index of PTS will be calculated. Performance Indicator Scores of PTS for 5 categories are given in Table 2.

ITS performance index of PTS is calculated as follows;

$$ITSPI_{PTS} = \frac{\begin{array}{c}(1.00 + 1.00 + 1.00 + 0.8429 + 1.00 + 0.0605) + (1.00 + 1.00 + 1.00) + (0.00 + 1.00) \\ (1.00 + 0.00 + 0.50 + 0.00 + 0.00) + \\ (1.00 + 1.00 + 0.00 + 1.00 + 1.00 + 0.00 + 0.00 + 1.00)\end{array}}{6 + 3 + 2 + 5 + 8}$$

$$= 64.18\%$$

Table 2. Performance Indicator Scores of Example Transit Agencies

Transit Agency	*Performance Category*	*Performance Indicator*	*Scores*
PTS	1. Transit Vehicle ITS Technology adoption	1.1 Automated Vehicle Location (AVL)	100.00%
		1.2 Computer Aided Dispatch and Scheduling (CADS)	100.00%
		1.3 Mobile Data Computers (MDCs)	100.00%
		1.4 Automatic Passenger Counters (APC)	84.29%
		1.5 Maintenance Management Systems (MMS)	100.00%
		1.6 Transit Signal Priority (TSP)	6.05%
	2. Traveler Information Technology Adoption in Vehicles (%)	2.1 Automatic Voice Announcement (AVA)	100.00%
		2.2 Dynamically Updating Passenger Information Displays	100.00%
		2.3 Dynamically Triggered Automated Announcements	100.00%
	3. Traveler Information Technology Adoption in Stations	3.1 Electronic Signage or Displays	0.00%
		3.2 Mobile Application	100.00%
	4. Travel Demand	4.1 Travel Management Coordination Center (TMCC)	100.00%
		4.2 Integrated Corridor Management (ICM)	0.00%
		4.3 Route and service planning	50.00%
		4.4 Passenger transfers	0.00%
		4.5 Dynamic assignment of assets	0.00%
	5. Real Time Data Collection	5.1 Vehicle time and location	100.00%
		5.2 Vehicle monitoring status (i.e., vehicle diagnostics and health)	100.00%
		5.3 Passenger count	0.00%
		5.4 Trip itinerary planning records	100.00%
		5.5 Passenger information (e.g., fare transactions, trip origin/destination location)	100.00%
		5.6 Emergency vehicle signal preemption events	0.00%
		5.7 Transit vehicle signal priority events	0.00%
		5.8 Incidents	100.00%

In the case of each category considered to have the same impact for sensitivity analysis, 0.2 weight is appointed to each category, since there are 5 categories. In this case, the performance index of PTS is calculated as follows;

$$ITSPI_{PTS_{S_1}} = 0.2 * \frac{(1.00 + 1.00 + 1.00 + 0.8429 + 1.00 + 0.0605)}{6} + 0.2 * \frac{(1.00 + 1.00 + 1.00)}{3} + 0.2 * \frac{(0.00 + 1.00)}{2} 0.2 * \frac{(1.00 + 0.00 + 0.50 + 0.00 + 0.00)}{5} + 0.2 * \frac{(1.00 + 1.00 + 0.00 + 1.00 + 1.00 + 0.00 + 0.00 + 1.00)}{8} = 64.84\%$$

In the case of only 1st category is considered for sensitivity analysis, the performance index of PTS is calculated as follows;

$$ITSPI_{PTS_{S_2}} = \frac{(1.00 + 1.00 + 1.00 + 0.8429 + 1.00 + 0.0605)}{6} = 81.72\%$$

3. Results And Discussion

Calculated performance indicators of the 7 transit agencies can be seen in Figure 2. DART comes forward as the best performing transit agency in ITS integration in its operations. Lowest performing transit agency is MARTA. While second lowest performing transit agency is MBTA with the performance index of 54.98%, MARTA has a performance index of 32.95% which is significantly lower.

DART outranks its peers due to its strength in traveler information technology adoption in stations and travel demand category indicators. MARTA's weaknesses stem from the lack of ITS technology adoption in transit vehicles compared to its peers, insufficient real time data collection and lack of the usage of ITS technologies in travel demand supply.

Performance indexes are calculated assuming all the indicators regardless of the performance category have the same level of importance and same effect on the system, in this case each of the indicators have the weight of 1/24 since there are 24 performance indicators. To better understand the effectiveness of the intelligent transportation system operations of the agencies, sensitivity analyses must be conducted. 6 sensitivity analyses have been conducted. For the first sensitivity analysis, same importance is considered to be given to each category; therefore since there are 5 categories, 1/5 weight is appointed to each category. In remaining sensitivity analyses; each category is considered individually, meaning considered category is weighted 1 and remaining categories are weighted 0. The calculated performance indexes according to the weights assigned to the categories by sensitivity analyses is given in Table 2.

DART comes forward in the first sensitivity analysis with 85.32% in which same importance is given to all categories. The strongest performances shown by DART is observed in the fourth and fifth sensitivity analyses with the indexes of 100%, which takes into consideration only "Traveler Information Technology Adoption in Stations" category and only "Travel Demand" category, respectively. Lowest performance shown by DART is in the 6th sensitivity analysis, which takes only real time data collection into consideration.

TriMet has the second highest performance index amongst all transit agencies in the "equal weight for each category" sensitivity analysis with the performance index of 76.66% . TriMet's strengths mostly stem from its success in traveler information technology adoption in stations in which it ranks the 2nd and real time data collection in which it ranks the 1st amongst all agencies. TriMet performs the lowest considering only traveler information adoption technologies in the vehicles with the score of 59.53% behind PTS and DART which have the performance indexes of 100% and 85.59% respectively.

SFMTA ranks the third in the first sensitivity analysis which weighs each category equally with performance index of 69.04% . SFMTA performs the best amongst all agencies considering only ITS technology adoptions in transit vehicles, which 2nd sensitivity analysis shows it has the 96.85%. All other performance indicators of SFMTA varies between 60% and 70% showing a above average performance.

PTS ranks the fourth with performance index of 64.84% in the “all categories weighted equal” sensitivity analysis. It shows the strongest performance and ranks the highest amongst all in third sensitivity analysis with performance index of 100% which considers only traveler information adoption technologies in the vehicles. Lowest performance index produced by PTS is in 5th sensitivity analysis which considers only travel demand category.

RTD has the 5th strongest performance with the index of 60.58% amongst all transit operations when all categories are considered in the same importance. RTD performs the best in fourth sensitivity analysis with performance index of 100%, which takes only “Traveler Information Technology Adoption in Stations” category into consideration. Lowest performance index of RTD is observed in “consider only traveler information adoption technologies in the vehicles” category, in which RTD ranks the lowest among all.

MBTA ranks the 6th amongst all transit agencies with the performance index of 56.35%. It performs the best in the 4th sensitivity analysis, where only “Traveler Information Technology Adoption in Stations” are considered and ranks 3rd amongst all transit agencies. It performs poorly as RTD does in the fourth sensitivity analysis with 29.55% performance index.

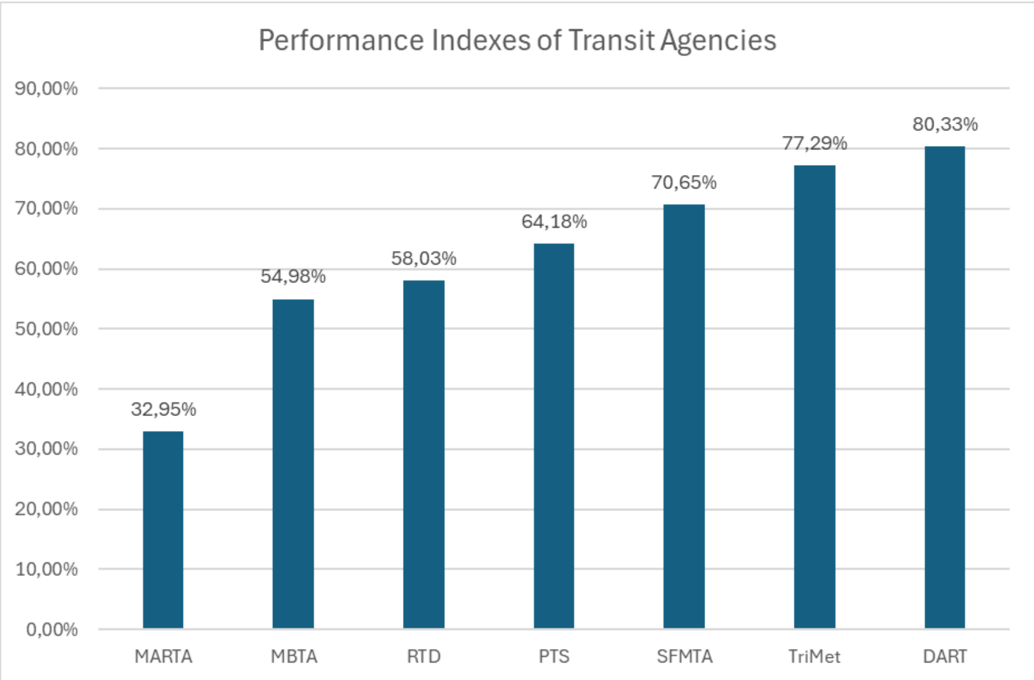

Figure 2. Performance Indexes of Transit Agencies

Table 3. Sensitivity Analysis Results

	Performance Indexes						
Sensitivity Analyses	MARTA	MBTA	RTD	PTS	TriMet	SFMTA	DART
W_j=0.2 for each category	45.33%	56.35%	60.58%	64.84%	76.66%	69.04%	85.32%
$W_1 = 1$, $W_2,W_3,W_4,W_5 = 0$	48.97%	65.40%	84.73%	81.72%	73.46%	96.85%	78.51%
$W_2 = 1$, $W_1,W_3,W_4,W_5 = 0$	66.67%	29.55%	28.15%	100.00%	59.53%	62.70%	85.59%
$W_3 = 1$, $W_1,W_2,W_4,W_5 = 0$	98.51%	94.29%	100.00%	50.00%	92.80%	63.17%	100.00%
$W_4 = 1$, $W_1,W_2,W_3,W_5 = 0$	0.00%	30.00%	40.00%	30.00%	70.00%	60.00%	100.00%
$W_5 = 1$, $W_1,W_2,W_3,W_4 = 0$	12.50%	62.50%	50.00%	62.50%	87.50%	62.50%	62.50%

MARTA has the lowest overall performance index value of 45.33%. Although it has the second highest performance index when Traveler Information Technology Adoption in Stations are considered only, MARTA has the lowest performance index values of fifth and sixth sensitivity analyses with 0.00% and 12.50% which shows important weaknesses in those areas.

4. Conclusion and Recommendations

This study provided a benchmarking framework for comparing the performance levels of intelligent transportation system operations of public transport agencies in metropolitan areas based on performance indicators. 7 transit agencies in the United States were chosen for the case study. Data were collected from the 2020 deployment tracking survey, latest of the surveys that are conducted every 2 to 3 years by the ITS JPO. After the collection of the data performance indexes of the transit agencies have been calculated and strengths and weaknesses of the agencies compared to each other came forward. In provided literature, several benchmarking studies and initiations have been referred to in order to present the practicability of benchmarking in transportation system development and improvement. One of the main goals of the study is to narrow down the focus of benchmarking strategies to ITS development. Existing monitoring and evaluation initiations which are mentioned in the study such as SEPSIS and ITS JPO Deployment Tracking Surveys deems these studies to be applicable for ITS development for local and national authorities, considering that they provide the data background. The conclusions of such studies can benefit the agencies, local and national authorities in noticing the overall situation of the development of ITS in operation areas and provide a domain for planning the future scenarios in preparation of action plans. With the conclusions of the study, it is aimed:

- For the results of the study to put light on the development needs of transit agencies,
- To produce a beneficial tool in decision-making phase in monitoring and evaluation processes of ITS,
- To develop a different benchmarking framework for ITS where peer comparison is applied instead of internal benchmarking with the systems own development in a certain period of time.

Recommendations can be listed as:

- Resorting to expert opinions in weighting the indicators to assign the importance of each indicator in contributing to overall system performance.
- Investigating the surveys from past years and measuring the growth and development of the systems in its own would provide the ability to develop models which explains the changes in congestion, emissions and traffic safety in the study area during the period between two surveys, via the measured growth of the systems.
- Need for development of benchmarking strategies and methodologies is essential in reaching the strategic goals of 2020 ITS Action Plan.

Researchers' Contribution Rate Statement

All authors contributed equally in preparation of the paper.

Conflict of Interest Statement, if any

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

5. References

Alkharabsheh, A., Moslem, S., Oubahman, L., & Duleba, S. (2021). An Integrated Approach of Multi-Criteria Decision-Making and Grey Theory for Evaluating Urban Public Transportation Systems. *Sustainability*, 13(5), 2740. https://doi.org/10.3390/su13052740

Awasthi, A., Omrani, H., & Gerber, P. (2018). Investigating ideal-solution based multicriteriadecision making techniques for sustainability evaluation of urban mobility projects. *Transportation Research Part A: Policy and Practice*, *116*, 247–259. https://doi.org/10.1016/j.tra.2018.06.007

***Benchmarking European Sustainable Transport*.** (n.d.). Retrieved June 26, 2024, from https://trimis.ec.europa.eu/project/benchmarking-european-sustainable-transport

Cheng, Z. A., Pang, M., Pavlou, P. A., Cheng, Z. A., Pang, M., & Pavlou, A. (2020). *Mitigating Traffic Congestion : The Role of Intelligent Transportation Systems Mitigating Traf fi c Congestion : The Role of Intelligent Transportation Systems*. *May*.

Choosakun, A., & Yeom, C. (2021). Developing Evaluation Framework for Intelligent Transport System on Public Transportation in Bangkok Metropolitan Regions Using Fuzzy AHP. *Infrastructures*, *6*(12), 182. https://doi.org/https://doi.org/10.3390/infrastructures6120182

da Silva, A. N. R., da Silva Costa, M., & Macedo, M. H. (2008). Multiple views of sustainable urban mobility: The case of Brazil. *Transport Policy*, *15*(6), 350–360. https://doi.org/10.1016/j.tranpol.2008.12.003

Debnath, A. K., Chin, H. C., Haque, Md. M., & Yuen, B. (2014). A methodological framework for benchmarking smart transport cities. *Cities*, *37*, 47–56. https://doi.org/10.1016/j.cities.2013.11.004

Henning, T. F. P., Muruvan, S., Feng, W. A., & Dunn, R. C. (2011). The development of a benchmarking tool for monitoring progress towards sustainable transportation in New Zealand. *Transport Policy*, *18*(2), 480–488. https://doi.org/10.1016/j.tranpol.2010.10.012

Intelligent Transportation Systems Joint Program Office. (n.d.-a). *2020 ITS Deployment Tracking Survey (DTS)*.

Intelligent Transportation Systems Joint Program Office. (n.d.-b). *ITS Deployment Tracking Survey Data Repository*. https://www.itskrs.its.dot.gov/deployment/surveys

Kakati, P., Senapati, T., Moslem, S., & Pilla, F. (2024). Fermatean fuzzy Archimedean Heronian Mean-Based Model for estimating sustainable urban transport solutions. *Engineering Applications of Artificial Intelligence*, 127, 107349. https://doi.org/10.1016/j.engappai.2023.107349

Kiba-Janiak, M., & Witkowski, J. (2019). Sustainable urban mobility plans: How do they work? *Sustainability (Switzerland)*, *11*(17). https://doi.org/10.3390/su11174605

Luque-Martínez, T., & Muñoz-Leiva, F. (2005). City benchmarking: A methodological proposal referring specifically to Granada. *Cities*, *22*(6), 411–423. https://doi.org/10.1016/j.cities.2005.07.008

Miranda, H. de F., & Rodrigues da Silva, A. N. (2012). Benchmarking sustainable urban mobility: The case of Curitiba, Brazil. *Transport Policy*, *21*, 141–151. https://doi.org/10.1016/j.tranpol.2012.03.009

Moslem, S. (2024). A Novel Parsimonious Spherical Fuzzy Analytic Hierarchy Process for Sustainable Urban Transport Solutions. *Engineering Applications of Artificial Intelligence*, 128, 107447. https://doi.org/10.1016/j.engappai.2023.107447

National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan. (2020).

Perra, V.-M., Sdoukopoulos, A., & Pitsiava-Latinopoulou, M. (2017). Evaluation of sustainable urban mobility in the city of Thessaloniki. *Transportation Research Procedia*, *24*, 329–336. https://doi.org/10.1016/j.trpro.2017.05.103

Pindarwati, A., & Wijayanto, A. W. (2015). Measuring Performance Level of Smart Transportation System in Big Cities of Indonesia. *2015 International Conference on Information Technology Systems and Innovation (ICITSI)*, 1–6. https://doi.org/10.1109/ICITSI.2015.7437716

Singh, B., & Gupta, A. (2015). Recent trends in intelligent transportation systems: a review. *Journal of Transport Literature*, *9*(2), 30–34. https://doi.org/10.1590/2238-1031.jtl.v9n2a6

Stone, J., Mees, P., & Imran, M. (2012). Benchmarking the Efficiency and Effectiveness of Public Transport in New Zealand Cities. *Urban Policy and Research*, *30*(2), 207–224. https://doi.org/10.1080/08111146.2012.666210

The Urban Transport Benchmarking Initiative. (n.d.). Retrieved June 26, 2024, from https://trimis.ec.europa.eu/project/urban-transport-benchmarking-initiative

Wootton, J. R., García-Ortiz, A., & Amin, S. M. (1995). Intelligent transportation systems: A global perspective. *Mathematical and Computer Modelling*, *22*(4–7), 259–268. https://doi.org/10.1016/0895-7177(95)00137-Q

Zope, R., Vasudevan, N., Arkatkar, S. S., & Joshi, G. (2019). Benchmarking: A tool for evaluation and monitoring sustainability of urban transport system in metropolitan cities of India. *Sustainable Cities and Society*, *45*, 48–58. https://doi.org/10.1016/j.scs.2018.11.011