DEVELOPING A COMPREHENSIVE LEVEL-OF-SERVICE FRAMEWORK OF BUS SYSTEMS CASE STUDY: DELHI

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by

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CERTIFICATE

This is to certify that the thesis entitled "**Developing a comprehensive level-of-service framework of bus systems— Case study: Delhi**" being submitted by **Ms. Sneha Lakhotia** to the Indian Institute of Technology Delhi, India, for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of original bona fide research work carried out by her. Sneha has worked under my guidance and supervision.

To the best of my knowledge, the thesis has reached the requisite standard. The material contained in this thesis has not been submitted, in part or in full to any other university or institute for the award of any degree or diploma.

Dated:

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ABSTRACT

Public transport (PT) forms the foundation of sustainable transport, as it aims to maximise accessibility and mobility options, and minimise externalities of transport sector (such as, pollution, energy, and congestion), with an emphasis on providing social equity. However, PT systems have to maintain a balance between providing a reasonably good level-of-service (LoS) to the public, and doing so at affordable costs. The challenge also lies in providing a high LoS so as to encourage passengers who use PT out of choice, but also in striving to be affordable to the low-income population, who use PT primarily as captive users.

In current practice, LoS of PT systems is primarily measured by traditional operational indicators, such as frequency of service (or headway), reliability, speeds, and fares. Three major research gaps have been identified in this current research— a) lack of focus on safe access to PT stops, b) lack of focus on perceived comfort measures (derived from passenger demand), and c) lack of focus on perceptions of existing and potential users. This thesis aims at developing a framework to determine a comprehensive LoS of urban bus systems.

In the context of this, LoS can be understood to be comprised of primarily two components— a) current performance of the bus system, and b) perceptions of the existing and potential users regarding the bus system. Delhi was selected as the case study. In order to assess the current performance of the bus system, traditional operational indicators, such as headway, reliability, and speeds, were measured. Reliability was measured in terms of travel time variability (TTV) and headway variability (HV). For measuring speeds, link speeds were estimated. Further, since perceived comfort measures are predominantly derived from passenger demand, indicators pertaining to demand were also measured.

In order to include access-related indicators, quality of pedestrian access to bus stops, and safety of pedestrians around bus stops were assessed. Quality of pedestrian access was assessed by conducting pedestrian accessibility audits around a representative sample of 360 bus stops, determined by multi-criteria stratified random sampling. The Public Transport Accessibility (PTA) toolkit was used, which has objective and measurable definitions for rating the access indicators. For assessing safety of pedestrians around bus stops, scores from the PTA toolkit were used, and secondary data regarding pedestrian fatalities in Delhi were

collected. Two Poisson regression models (with their geographically-weighted counterparts) were developed to assess how pedestrian fatalities are associated with access to bus stops—a) considering the fatalities where the impacting vehicle was known, and b) considering the fatalities where the impacting vehicle was unknown (hit-and-run cases).

Perceptions of existing and potential users regarding the relative importance and current satisfaction level perceived to be derived from the bus service in Delhi were assessed by conducting stated-preference interviews at sampled locations. Multivariate ordered probit models were developed for all the different user groups to assess the LoS perceived by them, and also its determinants.

PTA scores for pedestrian accessibility were predominantly low across Delhi. There was significant spatial clustering of the scores, indicating spatial disparity in the quality of pedestrian infrastructure, which was found to be in tandem with the spatial disparity of income levels. For the two safety models developed, geographically-weighted Poisson regression performed better than their global Poisson counterparts. Overall improved access was seen to be positively associated with fewer pedestrian fatalities.

On assessing reliability, it was found that majority of the links experience low TTV throughout the day. HV was found to be critically high at more than 70% of the stops. As majority of the stops were observed to experience low TTV, but critically high HV, it indicates that congestion or other traffic conditions are not primarily responsible for high unreliability of headways. Less than 15% of the links were found to suffer from congestion conditions in the morning (average link speed less than 10 km/h), which increases to ~20% in the off-peak and evening peak periods. High-speed conditions (over 40 km/h) were observed for ~2% of the links only.

The indicators of average passenger volume, coefficient of flow variation, and coefficient of passenger exchange represent the comfort conditions for the passengers along the entirety of the route. It was found that longer routes were associated with higher passenger volumes and lower coefficient of passenger exchange. High frequency routes were also associated with higher passenger volumes, and had lower coefficient of flow variation. Thus, longer routes and high frequency routes perform more efficiently in Delhi.

Significant differences were observed in the perceptions of the respondents who were existing bus users and those who were potential users. To improve bus service for existing bus users, it is imperative to improve reliability and travel times, as these attributes were most critical for them. On the other hand, to induce mode-shift by potential users, it is imperative to improve lighting around bus stops, which was interestingly the least critical attribute for the existing users.

Finally, based on the estimation of the current performance of the various indicators developed to assess the LoS, and the perceptions of the user groups, a two-pronged strategy for bus system reforms was recommended— a) a framework to identify the indicators which need to be improved on priority, and b) scenario development to recommend how to improve each indicator. To determine which indicator needed to be prioritised for improvement, robust criteria for determining the stops with the poorest performance for each indicator was recommended. This was assessed in combination with the users' perceptions regarding the indicator, to determine its priority. Finally, multiple scenarios were developed to suggest how to improve each indicator, and the most practical scenario to implement for improving each indicator was identified.

Reliability was found to be the most critical indicator, which needed improvements on a priority. This was followed by the access-related indicators, and finally, travel time. For improving reliability, it was recommended to make interventions based on high-demand and low-performance routes, and for improving travel times, it was recommended to make improvements by identifying corridors of congested links. The access-related indicators were recommended to be improved on a case-by-case basis.

The framework developed and the results were discussed through a workshop with bus operators belonging to various Indian cities. They found majority of the indicators developed in this thesis to be important, and that these should be included to assess the performances of their own operations. This reinforced the applicability and robustness of the framework. It is advocated that the framework presented in this thesis can be applied for assessing the LoS of bus systems in other cities, and also for assessing the LoS of metro systems.

सारांश

सार्वजनिक परिवहन नीव होती है सतत परिवहन की। सार्वजनिक परिवहन को सेवा का स्तर (एल-ओ-एस) अच्छा बनाने में और किफायती लागत में नाज़ुक संतुलन बनाना पड़ता है। कठिनाई आती है एक ऊंचा सेवा का स्तर देने में, जो कम आमदनी वाले लोगों के लिए किफायती हो, ख़ास तौर पर बंदी उपयोगकर्ताओं के लिए।

वर्तमान प्रथा में, सार्वजनिक परिवहन का एल-ओ-एस मुख्य रूप से पारम्परिक परिचालन संकेतक द्वारा नापा जाता है, जैसे सेवा की आवृत्ति, विश्वसनीयता, गति, और किराए। तीन प्रमुख खामियां की पहचान की गयी हैं– १) स्टॉप पर सुरक्षित पहुँचने पर कम ध्यान देना, २) यात्रियों की खपत पर कम ध्यान देना, और ३) मौजूदा और शक्य यात्रियों की धारणाओं पर कम ध्यान देना। इन शोध अंतराल को ठीक करने की आवश्यकता है, और एक समावेशी ढाँचे की ज़रुरत है सार्वजनिक परिवहन के एल-ओ-एस के आकलन के लिए। इस शोध का उद्देश है ऐसे ढाँचे को विकसित करना जो सार्वजनिक परिवहन के समावेशी एल-ओ-एस का आकलन करे। इस लक्ष्य को प्राप्त करने के लिए, प्रासंगिक संकेतक को पहचानने और विकसित करने की ज़रुरत है, और ऐसे ढाँचे को विकसित करने की ज़रुरत है जो विभिन संकेतक की सापेक्ष महत्व का आकलन कर सके।

इस सन्दर्भ में, एल-ओ-एस में मुख्य रूप से दो घटक शामिल हैं– १) बस व्यवस्था का वर्तमान निष्पादन, और २) बस व्यवस्था के विषय में मौजूदा और शक्य यात्रियों की धारणाएं। दिल्ली चयनित हुआ केस अध्ययन के लिए। वर्तमान निष्पाद का आकलन करने के लिए, पारम्परिक परिचालन संकेतक, जैसे आवृत्ति, विश्वसनीयता, और गति, मापे गए थे। इसके अतिरिक्त, यात्री खपत भी मापे

गए थे। विश्वसनीयता का आकलन करने के लिए, यात्रा के समय में परिवर्तनशीलता (टी-टी-वी) और आवृत्ति में परिवर्तनशीलता (एच-वी) मापे गए थे। गति की माप करने के लिए, लिंक गति का अनुमान लगाया गया था, बजाये तत्काल गति का।

पहुंच से संबंधित संकेतकों को शामिल करने के लिए, पैदल यात्री की आधारिक संरचना की गुणवत्ता, और पैदल यात्रियों की बस स्टॉप के पास सुरक्षा का आकलन किया गया था। पैदल यात्री की आधारिक संरचना की गुणवत्ता का आकलन ३६० बस स्टॉप पर लेखापरीक्षा आयोजित करके किया गया। इसके लिए, पब्लिक ट्रांसपोर्ट एक्सेसिबिलिटी (पी-टी-ए) टूलकिट का उपयोग किया गया था, क्यूंकि उसमे आकलन के लिए मापनीय परिभाषाएं हैं। पैदल यात्रियों की सुरक्षा का आकलन करने के लिए, पी-टी-ए टूलकिट के स्कोर्स का उपयोग हुआ था, और दिल्ली में हुई पैदल यात्रियों की मौतों का सहायक डेटा एकत्र किया गया था। दो पोइसो रिग्रेशन मॉडल (उनके भौगोलिक दृष्टि से भारित समकक्षों के साथ) विकसित किये गए थे– १) उन मौतों के लिए जिनके मारने वाले वाहनों की जानकारी थी, और २) उन मौतों के लिए जिनके मारने वाले वाहनों की जानकारी नहीं थी।

मौजूदा और शक्य उपयोगकर्ताओं की बस सेवा के विषय में धारणाओं का आकलन कहा-वरीयता साक्षात्कार के द्वारा किया गया था। मौजूदा उपयोगकर्ताओं के साक्षात्कार ३६० बस स्टॉप के सैंपल पर लिए थे। शक्य उपयोगकर्ताओं, जैसे टू-व्हीलर, ऑटोरिक्षा, मेट्रो, और मिनीबस) के साक्षात्कार के लिए स्तरीकृत प्रतिचयन किया गया था। मल्टीवेरीएट ऑर्डरद प्रोबिट मॉडल विकसित किया गया था आकलन के लिए।

आखिरकार, इन विभिन्न संकेतकों के वर्तमान निष्पादों, और उपयोगकर्ताओं की धारणाओं के आकलन पर आधारित, एक दो-आयामी दृष्टिकोण कार्यनीति की अनुशंसा की गयी है– १) कौनसे संकेतों को

सबसे पहले सुधारना है, और २) प्रत्येक संकेतक को कैसे सुधारना है। मानदंड की अनुशंसा की गयी है सबसे खराब निष्पादन वाले संकेत की पहचान करने के लिए, जिसे सबसे पहले सुधारने की आवश्यकता है। अनेक परिदृश्य विकसित किये गए हैं संकेतों को सुधारने के लिए, और सबसे ज़्यादा उपयोगी परिदृश्य का सुझाव दिया गया है।

पी-टी-ए स्कोर दिल्ली में मुख्या रूप से कम थे। स्कोर में महत्वपूर्ण स्थानिक क्लस्टरिंग अवलोकित किया गया, जो दर्शाता है कि स्कोर असमानता और आय असमानता में मेल था। दोनों पोइसो रिग्रेशन मॉडल में, भौगोलिक दृष्टि से भारित समकक्षों के निष्पादों बेहतर थे। समग्र में, पैदल यात्री के बेहतर आधारिक संरचना के पास काम पैदल यात्रियों की मौतें देखी गयी।

विश्वसनीयता के आकलन में पाया गया की ज़्यादातर लिंक पर कम टी-टी-वी का अनुभव होता है। एच-वी ज़्यादातर स्टॉप्स पर गंभीर रूप से उच्च पाया गया। यह संकेत करता है कि यातायात संकुलन ज़्यादा आवृत्ति के अविश्वसनीयता के लिए ज़िम्मेदार नहीं है। सुबह के समय, १५% से कम लिंक्स पर यातायात संकुलन की समस्या का अनुभव होता है, जो शाम के समय में २०% लिंक्स पर अनुभव होता है। तीव्र गति के हालात केवल २% लिंक्स पर ही अनुभव होते हैं।

यात्रियों की आराम की स्थिति का प्रतिनिधित्व है यात्रियों की खपत का आकलन करने वाले संकेतक। लम्बे रूट पर ज़्यादा यात्री मात्रा पायी गयी और यात्री विनिमय का गुणक कम पाया गया। उच्च आवृत्ति के रूट पर भी ज़्यादा यात्री मात्रा पायी गयी और प्रवाह भिन्नता का गुणक कम पाया गया। इस प्रकार, लम्बे और उच्च आवृत्ति के रूट बेहतर निष्पादन प्रदर्शन करते हैं।

मौजूदा यात्रियों और शक्य यात्रियों की धारणाओं में महत्वपूर्ण अंतर पाए गए। मौजूदा यात्रियों के लिए बस सुविधा को सुधारने के लिए विश्वसनीयता और यात्रा का समय सुधारने की आवश्यकता है। दुसरे हाथ पर, शक्य यात्रियों का बस उपयोग बढ़ाने के लिए सड़क के प्रकाश प्रबंध को सुधारने की आवश्यकता है।

बस सुधारने की कार्यनीति के अनुसार, विश्वसनीयता को सबसे संकटमय संकेतक पाया गया था, जिसको प्राथमिकता सुधार की आवश्यकता है। इसके पश्चात, पहुँच से संबंधित संकेतकों को सुधारने की आवश्यकता है, और आखिरकार यात्रा के समय को। विश्वसनीयता को सुधारने के लिए, ऊँची खपत व सबसे खराब निष्पादन वाले रूट को सुधारने की अनुशंसा की गयी। यात्रा के समय को सुधारने के लिए अनुशंसा की गयी कि कम गति के गलियारों की पहचान की जाए और वहाँ सुधार किया जाए। पहुँच से संबंधित संकेतकों को विषयानुसार सुधारा जा सकता है।

यह ढांचा जो विकसित किया गया था व निष्पादन के परिणामों की चर्चा विभिन्न भारतीय शहरों के बस ऑपरेटरों के साथ कार्यशाला द्वारा की गयी। उन्हें बहुमत संकेतक उचित व ज़रूरी लगे, और उनका यह सम्मति थी कि इन संकेतकों के माप को अपनी संस्थान में शामिल किया जाना चाहिए। यह इस ढाँचे की उपयोगिता का समर्थन करता है। आखिरकार, यह सलाह दी जाती है कि इस ढाँचे का उपयोग हो सकता है दुसरे शहरों की बस सुविधा के निष्पादन का आकलन करने के लिए, एवं मेट्रो सुविधा के निष्पादन का आकलन करने के लिए।

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LIST OF ABBREVIATIONS

AICc	Akaike Information Criterion (Corrected)
AVL	Automatic Vehicle Location
BRT	Bus Rapid Transit
CI	Confidence Interval
DIMTS	Delhi Integrated Multimodal Transit Systems (Ltd.)
ETM	Electronic Ticketing Machine
FIR	First Information Report
GIS	Geographic Information Systems
GPS	Global Positioning System
GWPR	Geographically-Weighted Poisson Regression
HV	Headway Variability
IPT	Informal Public Transport / Intermediate Public Transport
ITS	Intelligent Transport Systems
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
LoS	Level-of-Service
M2W	Motorised Two-Wheeler
M3W	Motorised Three-Wheeler
MCD	Municipal Corporation of Delhi
MOP	Multivariate Ordered Probit
MoUD	Ministry of Urban Development
NDMC	New Delhi Municipal Corporation
NTDPC	National Transport Development Policy Committee
NUTP	National Urban Transport Policy
PCA	Principal Components Analysis

PT	Public Transport
PTA	Public Transport Accessibility
SD	Standard Deviation
SE	Standard Error
SLB	Service Level Benchmarks
SMS	Space Mean Speed
SP	Stated Preference
TCQSM	Transit Capacity and Quality of Service Manual
TfL	Transport for London
TT	Travel Time
TTV	Travel Time Variability