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NOVEL APPROACH TO TRANSPORT PROJECT APPRAISAL: DEMAND WEIGHTED MULTI-MODAL LEVEL OF SERVICE

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ABSTRACT

Traffic management, road network planning and appraisal are highly dependent on effectively assessing the performance of existing and future road infrastructure. In traffic engineering, performance assessment has been underpinned by a grading system known as the “Level of Service” (LoS), which identifies performance criteria that reflects the functionality of the road. This study develops a novel, consistent calculation methodology, the Demand Weighted Level of Service Estimation (DWLE) method, to estimate singular holistic multi-modal LoS metrics, which can be used to compare and contrast the performance of road segments. The generalized approach is independent of the definition and quantification of LoS indicators which offers global application potential. A demonstration of the approach provides evidence for the robustness and consistency of the approach. The value of the DWLE method is that it offers a tool for project prioritization evolving a long-held traffic engineering concept of the Level of Service.

Keywords: Road network appraisal, Level of Service, Multi-modal

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Traffic management, road network planning and appraisal are highly dependent on effectively assessing the performance of existing and future road infrastructure. In traffic engineering, performance assessment has been underpinned by a grading system known as the "Level of Service" (LoS), which identifies performance criteria that reflects the functionality of the road. This study develops a novel, consistent calculation methodology, the Demand Weighted Level of Service Estimation (DWLE) method, to estimate singular holistic multi-modal LoS metrics, which can be used to compare and contrast the performance of road segments. The generalized approach is independent of the definition and quantification of LoS indicators which offers global application potential. A demonstration of the approach provides evidence for the robustness and consistency of the approach. The value of the DWLE method is that it offers a tool for project prioritization evolving a long-held traffic engineering concept of the Level of Service.

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1. INTRODUCTION

Traffic management, road network planning and appraisal are highly dependent on effectively assessing the performance of existing and future road infrastructure. Performance measurement aims to identify the quality and efficiency of operations for a user across individual road segments and the network as a whole. In traffic engineering, performance assessment has been underpinned by a grading system known as the "Level of Service" (LoS), where the operation and functionality of a road segment is qualitatively categorized using "letter grading" between A (reflecting excellent performance) and F (failing performance). The complexity of LoS appraisal methodology lies in the quantification of quality which is inherently linked to perceptions and risk attitudes of travelers (Roess and Prassas, 2014).

LoS assessments of roads have generally focused on the movement of vehicles, with particular emphasis on using the delay of private vehicles as the primary performance metric. Research and literature has begun to incorporate multi-modal level of service (MMLOS) over the last 2 decades as means to capturing public transport, walking and cycling LoS within road corridors (Brozen et al., 2014, Zuniga-Garcia et al., 2018). Furthermore, road agencies (Transport for New South Wales, 2017a, Jones et al., 2007) are beginning to also acknowledge that roads serve not only for the purposes of 'movement' but also as a 'place' which supports activities conducted on adjacent land uses, highlighting the limitation of the current application of the LoS concept.

This paper presents the "Demand Weighted Level of Service Estimation" (DWLE) method, a potential evolution of the LoS concept. The DWLE method accounts for multiple modes, the 'place' feature of a road network and also provide singular holistic LoS metrics useful for high level appraisal and prioritization of road segments.

2. BACKGROUND

This research covers three topics concerning the development of LoS, the application of multi-modal LoS methodologies, the consideration of adjacent land use and definition of 'place' from a road network context and also the potential for aggregation of LoS indicators. The following literature review discusses all these aspects briefly to contextualize the development of the DWLE method.

2.1 Multi-modal Level of Service (MMLOS) Assessment Methodologies

Formal documentation of the MMLOS within transport planning manuals have gained momentum from the NCHRP project in 2008, "Multimodal Level of Service Analysis for Urban Streets" (Dowling et al., 2008). This report provided the primary source of information to form the Highway Capacity Manual MMLOS methodology presented in the 2016 version of the HCM. The study conducted a comprehensive set of video and field surveys across auto drivers (private vehicle users), bus riders (public transport users), bicycle rides and pedestrians to understand the factors which affected LoS for each mode and the perceptions towards quality of each of the factors. The results of the surveys were analyzed to develop four separate LoS models for each mode considered, incorporating the interactions of all user classes present on the street. The greatest feature of the MMLOS approach is that by capturing the interactions between modes, it offers an opportunity for practitioners to evaluate trade-offs between modes and test a number of design features to understand the impact of the changes on each mode independently.

In addition to the NCHRP project there have been a number of other efforts to describe multi-modal LoS. Brozen et al. (2014) and Zuniga-Garcia et al. (2018) present a summary of the metrics and approaches that have been applied in recent times. Existing methodologies are generally classified into two groups, methods which build upon the LoS approach and others which uses an independent scoring system. Some of these methods include: Transit Capacity and Quality of Service Manual (Kittelson & Associates et al., 2013), Florida Department of Transport Quality and Level of Service Handbook (State of Florida Department of Transportation, 2013), Urban Street Design Guidelines, Charlotte, NC (City of Charlotte, 2007), Bicycle Compatibility Index (Harkey et al., 1998), Pedestrian (2008) and Bicycle Environmental Quality Index (2009) and the Multimodal Analysis of Urban Road Transport Network Performance (MPI) (Rudolph and Szabo, 2016). These methods provide an effective means of capturing movement characteristics of each mode, however they are limited in defining the place aspect of a road section.

2.2 Accounting for "Place"

Effectively capturing non-movement oriented aspects of road performance was initiated by the "Link and Place" idea " (Jones et al., 2007) which described the design of urban streets based on providing connectivity for the movement of people (roads serving as links) and as place for people, where the street itself is a destination on its own right. The study developed a two-dimensional link and place matrix to define the relative weighting of each role, at a coarser level to what is produced within the M&P framework. The purpose of "Link and Place" is to classify road sections, prioritize areas for improvement and develop and assess design options from an urban planning context. Following on from the application of "Link and Place" by transport agencies in London (Transport for London, 2014), the main transport body of New South Wales in Australia, Transport for New South Wales (TfNSW) developed the Movement and Place (M&P) framework. The framework served as an equitable and accountable means of appraisal of infrastructure designed to develop consistent road planning into the future. Principally the M&P framework mimics that of Link and Place, where roads serve two primary roles for users: (1) Facilitate the movement of people and goods and/or (2) Act as a place for people.

Roads are defined under the following functional classifications (Transport for New South Wales, 2017a):

- **Motorways –** move people and goods over long distances (only focussed on movement)

- **Movement corridors –** main roads providing safe, reliable and efficient movement between regional centres and within urban areas (primarily movement but in certain scenarios place is also recognised)
- **Living Streets** – combines high demand for movement and high pedestrian activity with limited road space within urban areas and regional centres. (balance between movement and place with greater emphasis on movement)
- **Places for People** – combines high pedestrian activity and lower levels of vehicle movement compared to living streets, creating places of value for local communities and visitors (balance between movement and place with greater emphasis on place)
- **Local Streets** – facilitation of local community access (primarily encouraging the development of place and a community neighbourhood with movement offered for accessibility alone)

The M&P framework extends the work of Jones et al. (2007) by relating the concept to standard Traffic Engineering approaches of appraisal and connecting the concept with Level of Service. Detailed explanations and discussion of the M&P framework are presented within NSW Road Planning Framework (Transport for New South Wales, 2017a) and the Austroads Guide to Traffic Management Part 4: Network Management (Green and Wall, 2017). The M&P framework captures the multi-modal nature of the transport system and similar to the 2016 HCM, also considers the interrelationships between modes where increases in demand for one mode can affect the quality of the road section for the other modes and vice-versa.

2.3 Aggregation approaches to Level of Service Metrics

Aggregation of performance indicators into singular holistic metrics is not a universally appreciated methodology in the context of LoS literature. The NCHRP Report which presents the MMLOS methodology argues that "*individual modal levels of service are not combined into a single comprehensive level of service for this would disguise the disparities in the perceptions of quality of service for the four modes*" Dowling et al. (2008). Furthermore, Zuniga-Garcia et al. (2018) suggests that in addition to this reason, to date, there is no scientifically proven or accepted method that can maintain the integrity of each mode. This is a valid argument when attempting to assess the LoS for specific user classes or modes at a microscopic level. In this scenario, each independent indicator or set of indicators relating to the class or mode under investigation should be compared across the road segments. However, a single LoS metric would be useful for high-level investment prioritization of road segments considering the interaction across all modes of transport.

Rudolph and Szabo (2016) have recently reported an aggregation approach, the FLOW multimodal urban road transport network performance analysis methodology (the FLOW methodology), that reflected walking and cycling in a multimodal aggregated LoS metric, the Multimodal Performance Index (MPI). The MPI takes into consideration planning prioritization of modes through the priority factor however it does not seem to standardize the demands for each mode which can potentially result in biases towards modes with greater volumes present on the road segment. The FLOW methodology offered a foundation for the development of the DWLE method.

3. DEMAND WEIGHTED LEVEL OF SERVICE ESTIMATION METHODOLOGY

Developing the efforts of the FLOW program in Europe (Rudolph and Szabo, 2016), the Demand Weight LoS Estimation (DWLE) method developed in this project serves as a further complement. The DWLE method aggregates modal LoS indicators for both movement and place independently by multiplying each indicator with standardized weight derived from the relative demand for the mode and then summing all relevant indicators for the road segment being analyzed. Equitable aggregations of LoS metrics that measure place and movement functionalities of a road section require a base weighting variable that reflects both movement and place. The DWLE method utilizes 'demand' for each mode (or flow of each mode) as the base quantity. As a fundamental property of traffic, demand clearly provides a depiction of the movement functionality, where greater demands for a mode having a greater influence on the LoS. This also can be applied in the context of place, for example if there is a relatively greater demand of pedestrians in a road segment, the place LoS indicators for pedestrians should also receive a greater weight. Mode demand is also an indicator of the road environment further reflecting the balance between movement and place (Green and Wall, 2017). Consider a segment of a motorway, the demands for this road section will be dominated by general traffic and freight with a handful of buses and cyclists and no demand for pedestrians. The road environment is designed for movement without the intention of creating a place for people to gather and perform productive activities. In contrast, roads adjacent to urban centers, shopping precincts and education hubs will have greater access demands by people walking, cycling and using public transport. These road segments are within productive spaces where services are provided, members of the community gather to share knowledge and conduct business resulting in greater priority to create a place for people. Thus, mode demand provides a robust means of weighting LoS indicators in an aggregation process to develop singular holistic metrics.

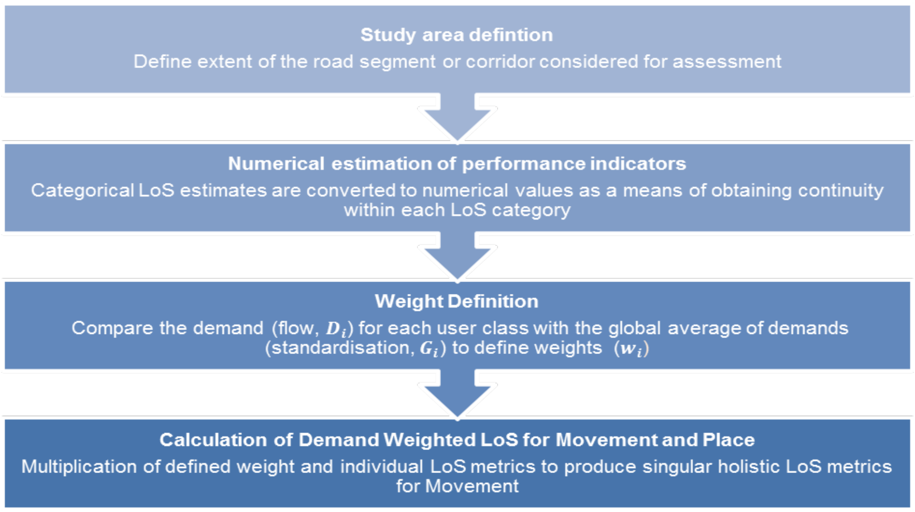

Figure 1: DWLE Method flow chart

The structure of DWLE method is presented in Figure 1. The DWLE method is simple in nature offering ease in practical application. Initially road segments and study areas are clearly defined; this is generally achieved by maintaining geometric and functional uniformity that may be linked to agency guidelines such as the M&P framework. Then, as the aggregation involves a weighting mechanism, categorical LoS measures (A-F letter grading) are converted into numerical values commonly applied throughout literature (Rudolph and Szabo, 2016, Dowling et al., 2008, Transportation Research Board, 2016, Transport for New South Wales, 2017a). A linear numerical conversion is applied for all continuous LoS indicators and discrete indicators are directly converted where A = 5, B = 4, C = 3, D = 2, E = 1, F = 0. Figure 2 presents an example of the conversion applied to the "Average Speed" LoS indicator for buses within the TfNSW M&P framework (Transport for New South Wales, 2017b).

LoS	Bus: Average Speed (km/hour)	TfNSW Scale	Numerical LoS (Assigned values under the DWLE Method)	Numerical LoS (Interpreted values under the DWLE Method)
A	>=30	6	5	5
B	20-30	5	4-5	4-5
C	15-20	4	3-4	3-4
D	12-15	3	2-3	2-3
E	10-12	2	1-2	1-2
F	<10	1	0	0-1

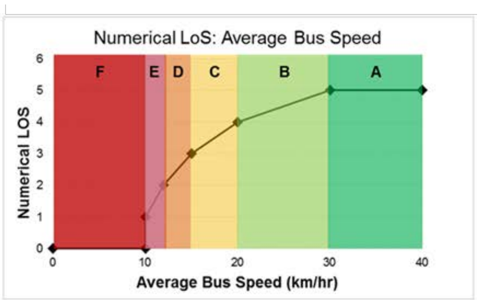

Figure 2: Conversion of categorical LoS measurements to Numerical LoS measurements (Example Indicator - Average Bus Speed, (Transport for New South Wales, 2017b))

Weights (w_i) are assigned to each LoS indicator defined by mode based on the relative demand for each mode considered in the LoS assessment. As the range of values for demand can vary considerably from mode to mode, the demands are standardized based on "global average demand" values (G_i) for each mode. The weights applied to each LoS indicator defined by mode are calculated using the following equation.

$$w_i = \frac{\left(\frac{D_i}{G_i}\right)}{\sum_{\forall i}\left(\frac{D_i}{G_i}\right)}$$

Where: w_i = weighting for mode "i", D_i = demand for mode "i", G_i = global average of demand for mode "i".

The value of the standardization "global average demand", G_i can be estimated using a variety of different approaches. One strategy could be based on calculating the average of all observed demands on roads that are defined by the same functional classification. An alternative method to estimate G_i could be to base it on a standard capacity value for each mode of transport for each functional classification of road. The second approach will not be tailored to the context of the study area however it provides a stable standard value which can be used throughout any assessment. Demand changes based on the design horizon of the LoS assessment. Appraisal of existing conditions will differ from future conditions due to population growth, changes to the transport network and emergence of disruptive technologies. Table 1 presents three possible appraisal scenarios: Existing Conditions, Forecasted Conditions and Desired Conditions, and the demand values considered under each scenario. Existing and forecasted conditions are common scenarios tested in traffic engineering assessments. Existing conditions can be appraised using observed demand values; future conditions can be appraised using forecasted demands estimated using a demand forecasting model. The final scenario, "Desired conditions" reflects a planning scenario that is desired by the governing authorities. Under this scenario, existing or future G_i values can be used depending on the design horizon, however desired demand values (D_i) will be defined by the planning authority in order to prioritize specific modes within the corridor.

Table 1: Appraisal scenarios and relevant demand values (D_i, G_i)

Existing Conditions	Forecasted Conditions	Desired Conditions
D_i = observed demand **G_i = observed global average demand** (weights LoS for each mode based on the existing demands)	**D_i = forecasted demand** **G_i = forecasted global average demand** (weights LoS for each mode based on the forecasted demands – depending on design horizon)	**D_i = desired demand** **G_i = observed or forecasted global average demand** (weights LoS for each mode based on the desired demands – observed or forecasted G_i values are used depending on design horizon)

These weights are then used to calculate the singular LoS metrics describing movement and place of each defined road segment using the equations presented below

$$LoS_{movement} = \sum_{i=0}^{n}(LoS_{m,i} \times w_i)$$

$$LoS_{place} = \sum_{i=0}^{n}(LoS_{p,i} \times w_i)$$

Where: w_i = weighting for mode "i", $LoS_{m,i}$ = Movement based LoS for mode "i", $LoS_{p,i}$= Place based LoS for mode "i", n = number of modes "i". The metrics are estimated by multiplying the calculated weights for each mode by the respective movement and place LoS indicators. The value of applying the DWLE method from a prioritization perspective is highlighted in the following multiple site hypothetical case.

4. HYPOTHETICAL EXAMPLE: POTENTIAL PRACTICAL APPLICATION

The following hypothetical example of a five-road-segment study area, shown in Figure 3 describes the potential practical application of the DWLE method, using TfNSW's M&P framework as the foundational estimate of LoS indicators for each of the sites.

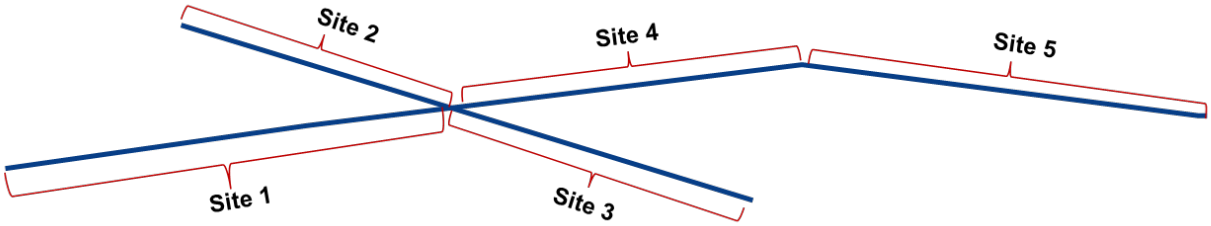

Figure 3: Hypothetical network of road segments

It is assumed that the study area is at the core of an urban center and each segment could be classified as a "Living Street" based on the M&P framework (Transport for New South Wales, 2017a). Associated hypothetical demands (D_i and G_i) consistent with the classification and calculated weights (w_i) for the 5 sites are presented in Table 7. As shown, weights are calculated independently of the estimation of any LoS metrics which highlights the robustness and generality of the DWLE method. Assume further that these demands are associated with existing conditions and the purpose of the exercise of identifying which of the sites should be prioritizes for further investment considering all modes that are present on the network.

Table 2: Hypothetical demands and weights considering an "existing conditions" assessment

Mode	G_i	Site 1		Site 2		Site 3		Site 4		Site 5	
		D_i	w_i	D_i	w_i	D_i	w_i	D_i	w_i	D_i	w_i
Pedestrian (people/hr/m)	100	175	0.404	120	0.319	180	0.415	250	0.342	160	0.495
Cycling (cyclists/hr)	15	10	0.154	5	0.089	15	0.231	5	0.046	5	0.103
Bus (buses/hr)	3	2	0.154	3	0.266	2	0.154	10	0.456	2	0.206
Freight (veh/hr)	300	100	0.077	20	0.018	50	0.038	175	0.080	10	0.010
General Traffic	2500	2300	0.212	2900	0.309	1750	0.162	1400	0.077	1500	0.186

Consider that relevant and reliable data for each of the sites have been collected to estimate the M&P LoS indicators. Figure 10 presents the LoS outcomes a practitioner may face from a categorical and numerical perspective, highlighting the complexity of prioritization.

Site 2, 4 and 5 perform poorly from a movement perspective with each of these sites experiencing at least 2 "LoS F" grades and 3 "LoS E" grades. Though Site 4 has the most fail grades for movement it is not obvious that it is the weakest site. When viewing the modal LoS values, Site 3 may be the worst performing site as it contains a LoS F for Freight, LoS E for bus and only LoS D's across all other modes which is worse than Site 4 which received a LoS C for pedestrians and LoS B for general traffic. Similarly, when interrogating the place LoS outcomes Site 1, Site 2, Site 3 all contain multiple LoS E indicators however Site 4 and Site 5 contain a LoS F. Based on this information it may be possible to infer the sites in need of investment, however it is not quantitatively definitive. The numerical conversion, second step of the DWLE method, allows for an improved interpretation of the LoS assessment as it presents within grade performance allowing the opportunity to determine microscopic differences of individual indicators. Though this is useful, it still remains unclear exactly which site should be prioritized from a movement or place perspective.

Movement

Mode	Movement Indicator	(a) Categorical LoS: Movement LOS by Indicator Site 1	Site 2	Site 3	Site 4	Site 5	Movement LOS by Mode Site 1	Site 2	Site 3	Site 4	Site 5	(b) Numerical LoS: Numerical Movement LOS by Indicator Site 1	Site 2	Site 3	Site 4	Site 5	Numerical Movement LOS by Mode Site 1	Site 2	Site 3	Site 4	Site 5
Pedestrian	Pedestrian Flow (p/hr/m)	D	C	D	E	D	D	D	D	C	D	2.75	3.60	2.70	2.00	2.90	2.30	2.64	2.88	3.20	2.92
	Crossing point spacing	D	E	D	C	D						2.50	2.00	2.50	3.50	2.90					
	Universal accessibility	F	E	C	A	D						1.00	2.00	4.00	5.00	3.00					
Cycling	Path Type	E	F	D	E	F	E	F	D	D	E	2.00	0.00	3.00	2.00	1.00	2.00	0.75	3.00	2.25	1.75
	Cycling Environment	F	F	D	C	A						0.00	1.00	3.00	4.00	5.00					
	Interruptions	C	E	D	F	F						4.00	2.00	3.00	1.00	0.00					
Bus	Speed Ratio	B	A	D	E	C	B	C	E	F	D	4.40	5.00	3.00	2.00	4.00	4.16	3.50	1.86	0.80	2.68
	Journey Time Reliability	C	D	E	F	E						4.00	2.50	1.10	0.00	1.80					
Freight	Speed Ratio	C	C	E	F	D	D	D	F	E	E	3.29	3.59	1.10	0.00	2.40	2.94	2.94	0.44	1.68	1.98
	Journey Time Reliability	D	D	F	D	E						2.70	2.50	0.00	2.80	1.70					
General Traffic	Speed Ratio	C	B	C	C	C	C	B	D	B	D	3.88	4.11	3.71	3.29	3.29	3.29	4.04	2.98	4.08	2.22
	Journey Time Reliability	D	C	D	B	E						2.90	4.00	2.50	4.60	1.50					

Place

Mode	Place Indicator	Place LOS by Indicator Site 1	Site 2	Site 3	Site 4	Site 5	Place LOS by Mode Site 1	Site 2	Site 3	Site 4	Site 5	Numerical Place LOS by Indicator Site 1	Site 2	Site 3	Site 4	Site 5	Numerical Place LOS by Mode Site 1	Site 2	Site 3	Site 4	Site 5
Pedestrian	Vehicle Flow (veh/hr)	E	E	D	D	D						1.85	1.55	2.25	2.60	2.50					
	Posted Speed Limit	D	E	E	D	D						2.50	1.50	2.00	3.00	2.50					
	Occupancy	E	E	C	C	A	D	E	C	C	C	2.00	2.00	4.00	4.00	5.00	2.09	1.76	3.06	3.40	3.75
Cycling	Parking Facilities	E	C	D	C	F	E	C	D	C	F	2.00	4.00	3.00	4.00	1.00	2.00	4.00	3.00	4.00	1.00
Bus	Bus Stop Facility	D	D	E	F	A	D	D	E	F	A	3.00	3.00	2.00	1.00	5.00	3.00	3.00	2.00	1.00	5.00
Freight	Loading Zone Length (%)	D	C	E	D	D	D	C	E	D	D	2.50	3.50	1.25	3.00	2.38	2.50	3.50	1.25	3.00	2.38
General Traffic	Parking Length (%)	E	D	C	D	D	E	D	C	D	D	1.33	2.87	3.67	2.33	2.80	1.33	2.87	3.67	2.33	2.80

Figure 4: Hypothetical categorical LoS outcomes

Table 3 presents the final results of the application of the DWLE method multiplying the numerical LoS values of Figure 3 with the mode weights of Table 7. These results definitively suggest that Site 4 requires attention from a movement perspective while Site 1 performs worst from a place perspective.

Table 3: Application of the DWLE Method to derive singular movement and place LoS metrics

	Site 1	Site 2	Site 3	Site 4	Site 5
$LoS_{movement}$	2.80 (D)	3.14 (C)	2.67 (D)	2.01 (D)	2.61 (D)
LoS_{place}	2.09 (D)	2.66 (D)	2.91 (D)	2.22 (D)	3.53 (C)

Existing applications of multi modal LoS estimations such as through the M&P framework provides rich information regarding the relative performance of road segments on an indicator by indicator basis which is incredibly valuable for microscopic and operational decision making. The DWLE method enhances LoS frameworks by providing a means for high level prioritization accounting for multi-modal systems from the perspective of both movement and place, highlighting the potential practical application of the approach.

5. DISCUSSION AND CONCLUSION

This research study enhances the M&P framework by developing a LoS aggregation method, the DWLE method, valuable for the prioritization of road maintenance and investment schemes. The DWLE method aggregates modal LoS indicators for both movement and place independently by multiplying each indicator with standardized weight derived from the relative demand for the mode and then summing all relevant indicators for the road segment being analyzed.

A hypothetical demonstration of the DWLE method presented the potential applications, highlighting the advantages of simplification while retaining the details necessary for a practitioner to apply mitigation strategies. At a high level, multiple sites can be easily compared from a multi-modal perspective while once prioritization is completed at a microscopic level details can still be extracted using the underlying mode based LoS assessment. The demonstration revealed the generality and flexibility of the methodology to apply to the M&P framework as well as any other systems designed to measure LoS of multiple modes of transport.

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