Evaluating Traffic Congestion in Ulaanbaatar

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Abstract: This study aimed to analyze traffic congestion in Ulaanbaatar urban network. The speed performance index was adopted to evaluate the traffic congestion condition of main traffic corridors of existing urban road network. The speed performance data collected for selected three main traffic corridors on September and December of 2019, by JICA urban network transport studies program. The same date data for the rest of speed performance data for selected two main corridors collected by the Department of Public Transportation Department of Ulaanbaatar. Based on these analysis of speed performance index can well assess the evaluating traffic congestion of urban road network, more significantly, such an evaluation study provides an accurate and clear understanding of operation status of traffic network to make strategic policy making decisions on urban development including road and transport network design, specifically public transport renovation investment.

Keywords: Traffic Congestion, Speed Performance Index, Urban Network, Developing Countries, Mongolia

1. INTRODUCTION

Ulaanbaatar city is a predominant location having the highest level of accumulation and concentration of commercial and socio economic activities in Mongolia, which linked with an increase in motorization rapidly in last 20 years. Unfortunately, the supply of infrastructures has not been able to keep up with mobility growth as well as public transport service is the lack of attractive to giving up driving private vehicles. Congestion is particularly linked with motorization and the diffusion of the automobile, which has increased the demand for transport infrastructures.

In order to reduce traffic congestions, improve road and transport infrastructure system including public transport system is essential as well as improve the levels of service and efficiencies of urban transportation system, the advanced traffic control and management methods have become efficient and common approaches.

The main objective of this study is to evaluate traffic congestion level of urban road network based on the speed performance index. The total speed data provide over 54,696 records on weekdays of September 17 and December 5 and weekends of September 21 and December 7 of 2019. In present, there is no unified and fixed evaluation measure for evaluating traffic operation conditions. Evaluating traffic congestion levels of road network provide the information of location and time for congested road. Despite the fact that the assessment method and data source appear to be very traditional and typical, the traffic congestion data produced is almost the first survey for the Ulaanbaatar scenario in over 20 years. Therefore, the paper has practical significance to determine the level of traffic congestion based on variances in timing and seasons.

The rest of the paper is organized as follows. The second section describes the literature review of previous related studies and methods to evaluate the speed performance index and traffic congestion classification standard. The third section carried out an empirical analysis of Ulaanbaatar road network in terms of road network characteristics, road traffic congestion assessment based on speed performance index. Finally, the several important conclusions and recommendations are summarized in the last section.

2. LITERATURE REVIEW AND METHODS

In present, there is no unified and fixed evaluation measure for evaluating traffic operation conditions. In fact, there are various evaluation measures in different regions. Bureau of Transportation of the United States produced the Roadway Congestion Index (RCI), a measure of vehicle travel density on major roadways in an urban area. An RCI exceeding 1.0 indicates an undesirable congestion level, on an average, on the freeways and principal arterial street systems during the peak period. The urban areas included are those containing over 500,000 people and population group is based on 2010 population. The congestion evaluation index was defined as the average peak travel time (Bureau of Transport Statistics, 2013). The U.S. Federal Highway Administration's Highway Performance Monitoring System (HPMS) provides information on the extent, condition, performance, use, and operating characteristics of the Nation's highways. The HPMS Field Manual guidance for capacity is as follows: "The capacity of a roadway facility is the maximum reasonable hourly rate at which vehicles can be expected to transverse a point or a uniform section of lane or roadway during a given time period under prevailing road-way, traffic, and control conditions." (Federal Highway Administration, 2017) The U.S. Highway Capacity Manual (US-HCM) provides procedures, formulas, graphics, and tables in assessing roadway capacity. In the US-HCM defines six levels of service ranging from LoS A to F representing various service conditions ranging from free-flow conditions to the point of breakdown of vehicular flow (Federal Highway Administration, 2017). In China, Ministry of Public Security chose the average travel speed of a city road as the evaluation indicator to describe congestion conditions of road traffic (Ministry of Public Security, 2012).

A significant number of studies have explored the urban traffic condition in different ways using the single valuation indicator e.g. travel speed and travel time that can be directly obtained through the loop detector, GPS, video, etc. However, considering the complexity and dynamic nature of traffic, it is difficult to comprehensively assess traffic congestion conditions of urban road networks by single evaluation indicator. As a result, several studies began to evaluate the traffic state using multiple indicators. Urban traffic congestion has become a critical problem that not only affects the daily lives of the inhabitants' due to the loss of time, but also restricts the stable development of a city (He, Feifei; Yan, Xuedong; Liu, Yang; Ma, Lu , 2016). Estimating urban traffic congestion effectively is the first step to improve the travel time reliability for passengers and solve the urban traffic congestion problem (Quiroga, 2000). Recently, more research has used neural networks, support vector machines, heuristic algorithms, and fuzzy logic to estimate traffic congestion based on changes in traffic volume, occupancy, or speed (Wang, Y.; Papageorgiou, M.; Messmer, A., et al.,, 10-24). Studies provide many valuable insights into traffic congestion estimation, which can be used to ease congestion, increase safety, and improve the accuracy of traffic prediction. The good performance in traffic congestion estimation, which provides practical applications in the fields of urban planning and public transport network optimization.

Vehicle speed is an important indicator for measuring the road traffic of the city. The speed performance index is the ratio between vehicle speed and the maximum permissible speed and ranges from 0 to 100. This study uses this speed performance index to measure the

road traffic conditions using three threshold values (25, 50, 75) as the classification criterion of urban road traffic state, as described in Table 1. Based on this evaluation measure, traffic congestion level of urban road networks is determined.

$$R_v = \frac{v}{v_{max}} \cdot 100 \quad (1)$$

where, R_v - The speed performance index, %
v - The average travel speed, km/h
v_{max} - The maximum permissible road speed, km/h

Table 1. The Evaluation Criterion of Speed Performance Index on Road Network

Speed Performance Index	Traffic State Level	Description of Traffic State
[0, 25]	Heavy congestion	The average speed is low, road traffic state poor.
(25, 50]	Mild congestion	The average speed is lower, road traffic state bit weak.
(50, 75]	Smooth	The average speed is higher, road traffic state better.
(75, 100]	Very smooth	The average speed is high, road traffic state good.

Source: A Traffic Congestion Assessment Method for Urban Road Networks Based on Speed Performance Index (He, Feifei; Yan, Xuedong; Liu, Yang; Ma, Lu , 2016)

The ArcMap software used the speed performance index illustration. Created 50 m buffer zones adjunct to road right and left side lane to allow to show into the city and out of the city directions. The spline with barriers interpolation method uses from points of the speed performance index value to buffer zone.

3. CASE STUDY: TRAFFIC CONGESTION IN ULAANBAATAR

Characteristics of Road Network. Ulaanbaatar City within the six-core districts area of 35,206 hectares has 841.6 km of the paved road, of which 216.0 km of primary road and streets, 226.0 km of secondary road and streets, and 404.6 km of local district streets (Figure 1). Ulaanbaatar region road construction also showed rapid development over the past decade as 600 km of road in 2000 increased to 1,135.6 km in 2019 (Statistics Department of Ulaanbaatar, 2021). However, the growth of urban vehicles has been much faster than that of urban road construction. Paved road density is the highest in central part (high BCR and high FAR), medium in constructed area (medium BCR), the low in *ger* district area (low BCR) of the city (Figure 2, and Figure 3).

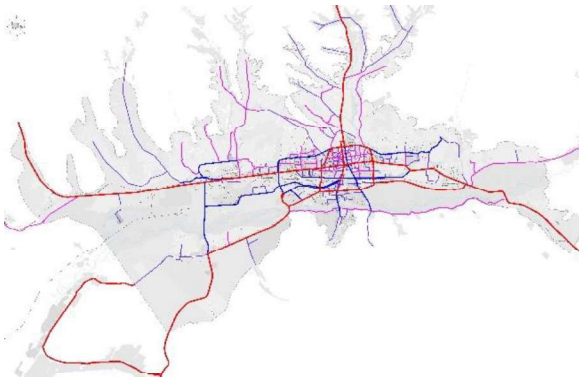


Figure 1. Road Network of Ulaanbaatar, 2020
Source: Urban Planning and Design Institute

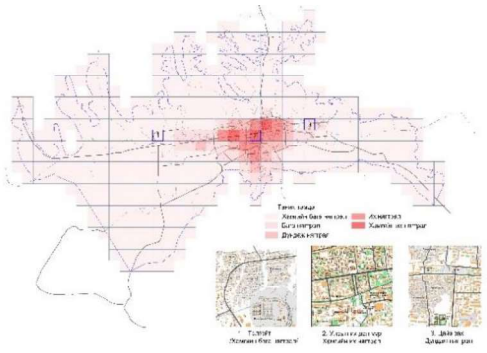
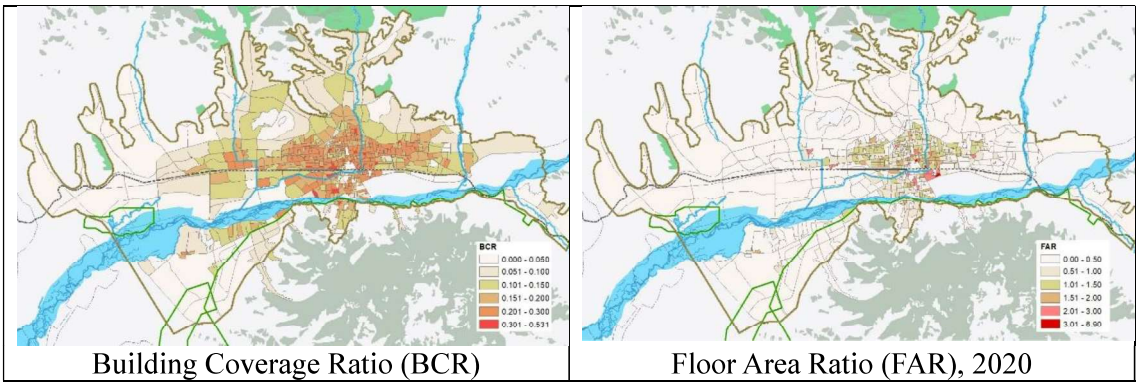


Figure 2. Road Density of Ulaanbaatar, 2020
Source: Urban Planning and Design Institute



Building Coverage Ratio (BCR) | Floor Area Ratio (FAR), 2020

Figure 3. Building Coverage Ratio (BCR) and Floor Area Ratio (FAR), 2020

Source: Asian Infrastructure Research Institute

As of 2019, the average road density in Ulaanbaatar City was 2.1 km per square km of land area, of which: (i) 0-4.1 km/km^2 road density accounting for 87.7% of the total area of the city (BAR Rate: 0.00-0.10 %, ger districts); (ii) 4.2-8.1 km/km^2 road density for 5.9% of the total area (BAR Rate: 0.100-0.150 %, mainly ger districts); (iii) 8.2-12.1 km/km^2 road density for 3.2% of the total area (BAR Rate: 0.151-0.201 %, mixture of constructed area and ger districts); (iv) 12.2-16.2 km/km^2 road density for 2.4% of the total area (BAR Rate: 0.201-0.301 %, constructed area); (v) 16.2-20.2 km/km^2 road density for 0.8% of the total area (BAR Rate: 0.201-0.531 %, mainly central part of the city) (Figure 1, Figure 2).

Ulaanbaatar's road network is the main node of the Mongolian road network, which is connecting centers of provinces. The total of 244.8 km international and state roads pass through the territory of Ulaanbaatar, including: (i) 64 km of East-West arterial links international road AH32 (It consists of the state roads of A0301 /3.7 km/ and A0501 /50.3 km/ and is named by Enhtayvan Avenue); (ii) 105.6 km of North-South links vertical international road of AH3 (It consists of the state roads of A0401 /52.7 km/ and A0101 /52.9 km/); (iii) 24.8 km of the state road A0201 for south western direction; and (iv) 30.5 km of the state road A24 for Terelj National Park.

Ulaanbaatar urban road network consists (i) 87.10 km of four horizontals links (green color) with 25 roads and streets; (ii) 85.10 km of eight vertical links (blue color) with 13 roads and streets; and (iii) 16.20 km of seven links (red color) with 45 roads and streets.

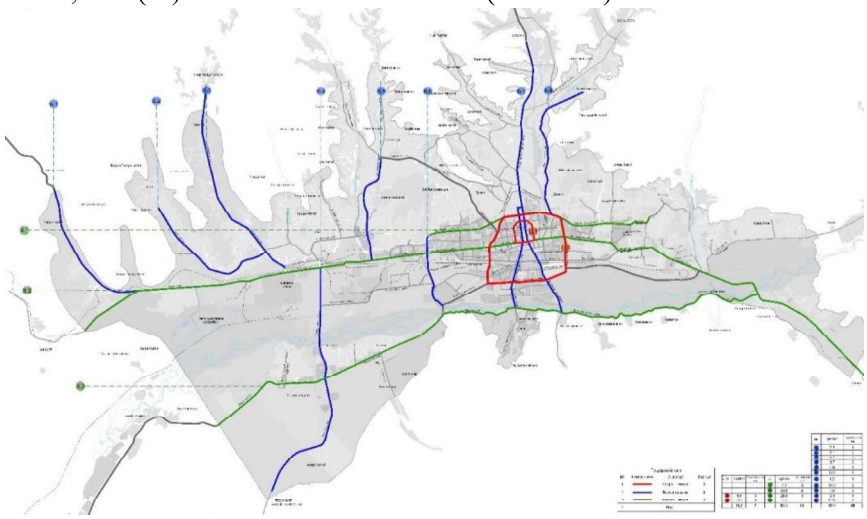


Figure 4. Major Corridors of Urban Road Network of Ulaanbaatar, 2020

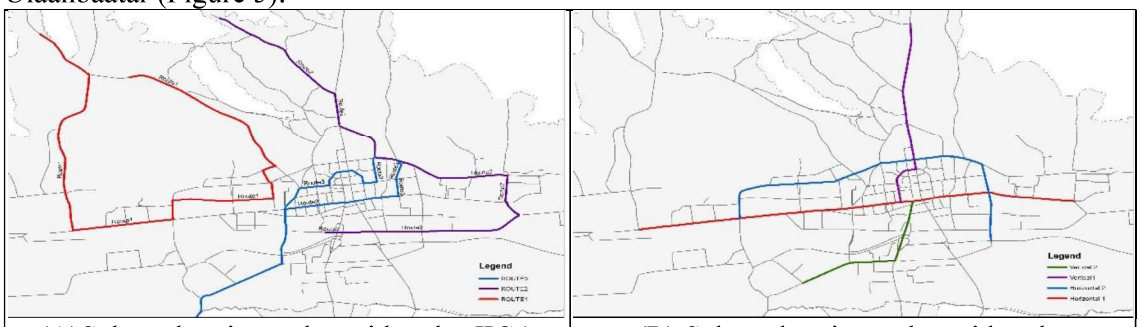
Source: Urban Planning and Design Institute

Table 2. Major Corridors of Urban Road Network of Ulaanbaatar, 2020

№	Direction	Number of Routes	Number of Related Roads and Streets	Total Length of Roads, km
1	Horizontal	4	25	87.10
2	Vertical	8	13	85.10
3	Circle	2	7	16.20
	Total	14	45	188.40

Source: Urban Planning and Design Institute

Traffic congestion. Traffic congestion has become a serious problem since 2010. It makes life in cities uncomfortable for people. The speed performance data collected for selected three main traffic corridors on September and December of 2019, by JICA urban network transport studies program. The same date data for the rest of speed performance data for selected four main corridors collected by the Department of Public Transportation Department of Ulaanbaatar (Figure 5).



(A)Selected main road corridors by JICA

(B) Selected main road corridors by Department of Public Transportation Department of Ulaanbaatar

Figure 5. Study Area

Based on the large number of data (54,696 records), this paper analyzes the characteristics of major corridors of Ulaanbaatar urban road network. As shown in Table 3 and Table 4, the assessments of speed performance index (SPI) for weekday and weekend of September and December by morning, afternoon, evening and night time respectively. The result shows a total 1,396 km road traveled during the speed measurement procedure, of which 18.2 % of the total length of the traveled road belongs heavy congestion classification with average speed of 5.95 km/h and 10.13 % SPI on average, 25.9% are mild congestion with average speed of 20.63 km/h and 35.75% SPI on average, and 33.8% (average speed of 35.32 km/h and 61.27% SPI on average)and 22.1% (average speed of 47.84 km/h and 84.57% SPI on average) consider smooth and very smooth respectively (Table 3, Figure 6). Total heavy and mild congested roads were 54.1% on weekday of September and 44.4% on weekday of December, and those were 54.1% and 44.4% for weekends of September and December respectively (Table 3). Table 3 shows by evaluation criterion of the SPI by average operating speed of vehicle, the speed performance index, and total length of traveled distance. The road congestion assessments by main three corridors which selected by JICA team are shown in the Table 1A-3A of annex.

Table 3. The Road Congestion Assessment by Average Speed, Speed Performance Index, Traveled Distance, Date and Time

Time	Road Congestion Assessment	09/17/2019 Weekday			09/21/2019 Weekend			12/05/2019 Weekday			12/07/2019 Weekend			Total		
		Ave. *V*, km/h	Ave. *Rv*, %	Tra. Dist., km	Ave. *V*, km/h	Ave. *Rv*, %	Tra. Dist., km	Ave. *V*, km/h	Ave. *Rv*, %	Tra. Dist., km	Ave. *V*, km/h	Ave. *Rv*, %	Tra. Dist., km	Ave. *V*, km/h	Ave. *Rv*, %	Tra. Dist., km
Total	Heavy	6.4	10.4	73.9	5.7	9.7	61.3	5.9	10.6	58.7	5.7	9.8	60.0	5.9	10.1	253.9
	Mild	21.5	35.3	102.6	21.1	36.4	89.4	19.5	35.4	81.5	20.4	35.9	88.6	20.6	35.8	362.1
	Smooth	36.2	60.5	102.1	35.8	61.5	141.8	33.7	61.3	100.3	35.4	61.6	127.7	35.3	61.3	472.0
	Very Smooth	48.7	84.0	47.7	48.7	84.4	89.0	45.7	84.5	75.4	48.2	85.0	96.2	47.8	84.6	308.4
	Total	13.6	22.4	326.3	15.5	26.6	381.6	13.5	24.6	316.0	14.4	25.1	372.6	14.2	24.7	1396.4
Morning	Heavy	6.2	10.5	21.6	7.0	11.3	3.8	5.7	10.6	17.1	6.1	9.6	3.4	6.1	10.5	45.9
	Mild	20.3	34.7	32.8	23.1	37.8	14.6	19.7	36.2	24.3	23.7	38.2	13.6	21.0	36.2	85.4
	Smooth	35.2	60.7	28.5	38.6	62.8	39.1	33.2	60.9	30.2	39.0	62.2	35.4	36.5	61.7	133.1
	Very Smooth	46.2	84.4	16.7	51.9	84.4	36.7	44.9	84.4	20.8	49.9	84.7	36.5	48.8	84.5	110.7
	Total	12.9	22.3	99.6	27.8	45.2	94.2	13.7	25.3	92.5	27.1	44.2	88.8	17.1	29.3	375.1
Afternoon	Heavy	6.2	10.0	25.3	5.4	9.1	28.5	6.2	10.6	24.1	5.7	9.1	26.4	5.8	9.6	104.4
	Mild	21.5	35.0	28.5	20.4	35.5	28.5	20.1	34.5	26.1	21.5	35.2	27.7	20.8	35.1	110.8
	Smooth	36.1	60.9	29.7	34.9	61.0	24.9	35.0	61.1	31.2	36.8	61.1	27.6	35.6	61.0	113.3
	Very Smooth	49.9	84.5	14.2	48.3	85.6	15.9	48.4	84.4	17.0	50.5	84.5	13.9	49.2	84.7	60.9
	Total	12.4	20.4	97.6	11.3	19.5	97.8	12.4	21.3	98.5	10.9	17.8	95.6	11.7	19.7	389.4
Evening	Heavy	6.6	10.3	20.2	5.7	10.2	18.9	5.4	10.1	14.1	5.5	10.0	24.6	5.8	10.1	77.8
	Mild	22.0	35.4	23.2	20.1	36.1	24.0	18.5	34.3	19.2	18.9	35.0	29.3	19.7	35.2	95.7
	Smooth	36.7	59.6	19.7	33.5	61.0	33.9	32.6	61.3	17.6	32.9	60.8	31.0	33.7	60.8	102.3
	Very Smooth	50.8	83.2	8.5	45.1	84.0	20.7	44.2	85.4	15.9	46.0	84.9	14.9	46.1	84.4	59.9
	Total	12.3	19.7	71.6	14.1	25.5	97.5	11.3	21.2	66.7	10.9	20.1	99.8	12.0	21.4	335.7
Night	Heavy	8.2	12.9	6.8	6.2	10.3	10.1	7.2	13.6	3.4	6.7	12.3	5.5	6.9	11.8	25.8
	Mild	23.1	36.9	18.1	21.7	37.0	22.2	19.6	37.1	11.9	19.7	36.7	18.0	21.0	36.9	70.2
	Smooth	37.2	60.6	24.2	36.1	61.2	44.0	33.5	62.2	21.3	33.4	61.8	33.8	35.1	61.4	123.3
	Very Smooth	49.7	83.0	8.4	47.4	84.0	15.8	45.2	84.3	21.7	46.5	85.6	30.9	46.7	84.6	76.9
	Total	21.6	34.8	57.5	18.8	32.0	92.1	22.2	41.6	58.3	21.7	40.2	88.3	20.8	36.6	296.1

Speed performance index by road congestion assessment group are illustrated in the Figure 5. Heavy congested road exist predominantly along the horizontal corridors of Enhtayvan Ave., Dilav Hutagt St., Ard Ayush St., and Dorj St., vertical corridors of Bayanhoshuu St., Nam Yan Ju St, and Chinggis Ave on both weekday and weekend of Autumn and Winter (Figure 6). From morning to evening 60-70% of the roads are heavy and mild congested always on weekdays, of which into direction predominantly congested into city direction in the morning peak and out city direction in the evening (Table 4). Weekend traffic congestion exists during afternoon time. On the weekend of September has the heavy congested road along the Chingeltey Ave and Haylaast St. toward summer home/cottages in addition (Figure 6).

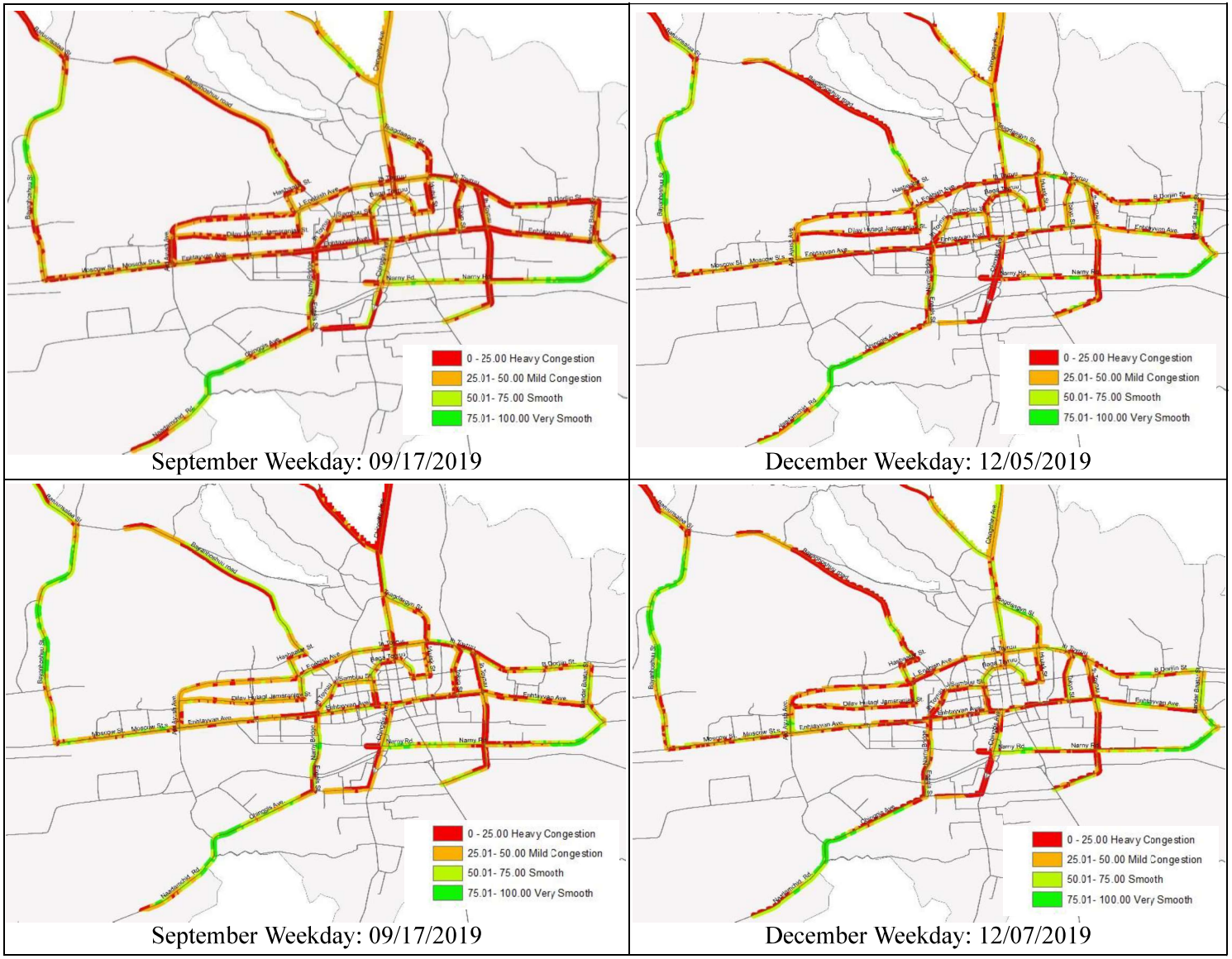
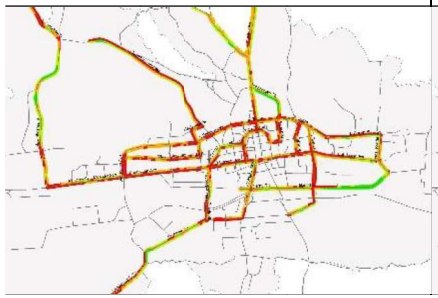
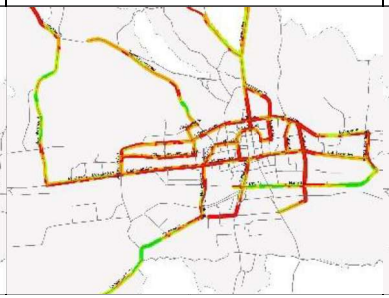
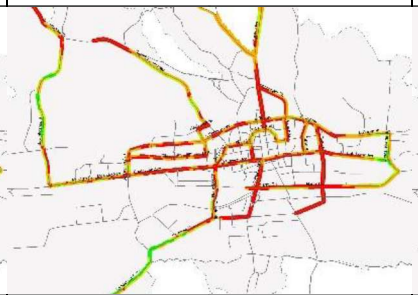
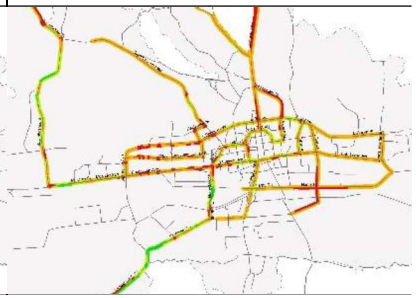


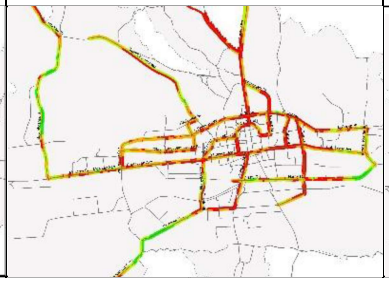
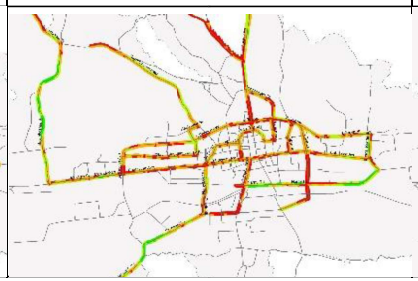
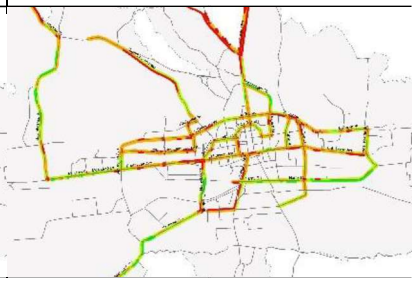
Figure 6. The Road Congestion Assessment by Date

Table 4. Road Performance Index by Hours for September

Morning: 7:00AM-9:30 AM	Afternoon: 1:00PM-3:30 PM	Evening: 5:00PM-7:30 PM	Night: 10:00PM-11:30 PM
			

09/17/2019 -Weekday

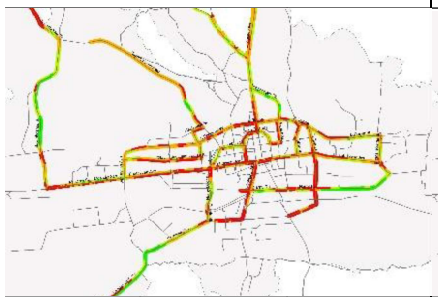
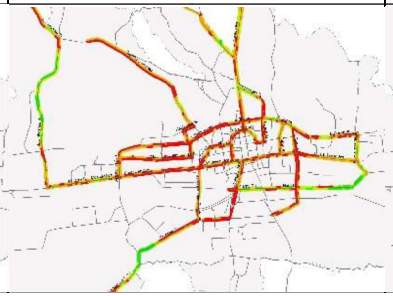
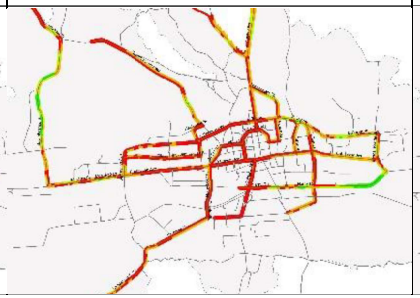
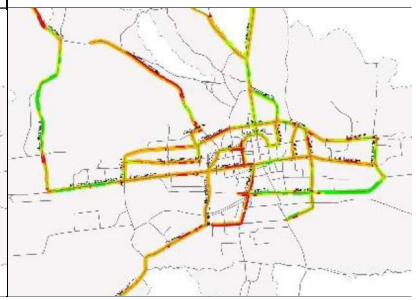
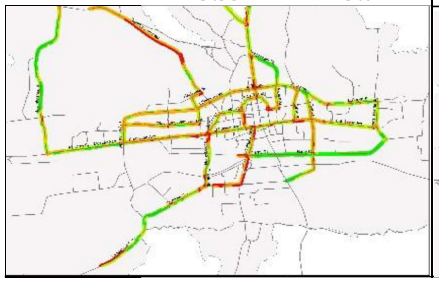
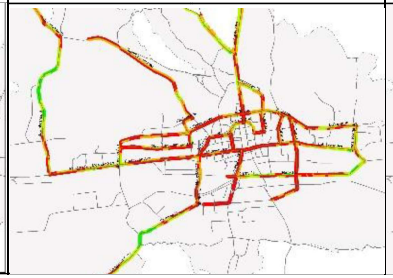
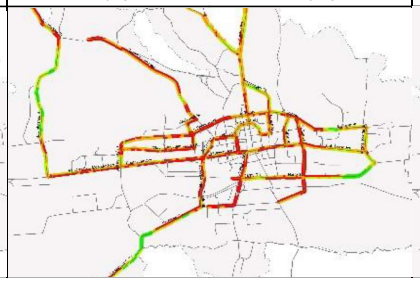
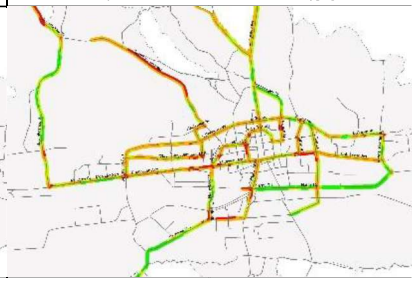
Direction	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %
Dir1	13.21	24.17	11.93	19.21	11.55	18.48	21.22	37.57
Dir2	12.69	20.38	12.88	21.74	13.30	21.32	21.98	32.61
Total	12.95	22.25	12.37	20.39	12.33	19.74	21.64	34.84

09/21/2019 - Weekend

Direction	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %
Dir1	29.73	46.78	10.97	18.40	13.81	25.21	17.85	30.73
Dir2	26.08	43.92	11.74	20.71	14.38	25.78	19.89	33.45
Total	27.78	45.25	11.35	19.53	14.07	25.47	18.77	31.95

Table 5. Road Performance Index by Hours for December

Morning: 7:00AM-9:30 AM			Afternoon: 1:00PM-3:30 PM		Evening: 5:00PM-7:30 PM		Night: 10:00PM-11:30 PM	
								
09/17/2019 -Weekday								
Direction	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %
Dir1	13.57	24.71	11.46	19.57	10.53	20.87	22.27	41.88
Dir2	13.87	25.99	13.67	23.76	12.11	21.47	22.16	41.32
Total	25.33	13.72	12.38	21.32	11.29	21.16	22.21	41.58
								
09/21/2019 - Weekend								
Direction	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %	Ave*V*,km/h	Ave *Rv* %
Dir1	26.59	43.83	9.85	16.81	9.50	16.82	21.28	41.74
Dir2	27.56	44.54	12.34	19.23	13.12	25.02	22.18	38.44
Total	27.09	44.20	10.90	17.83	10.95	20.09	21.71	40.17

The histogram for the SPI shows in Figure 7, frequency corresponding to the different speed performances with an increment of 5 percent, and logarithmic line segments represent the cumulative probability density of speed performance. The result shows that the proportion of speed performance which under 25% is more than 62.8% or heavy congestion, 21.2% of the data have mild congestion with the SPI between 25-50%, and 16% are having the SPI with more than 50% or smooth and very smooth states of road.

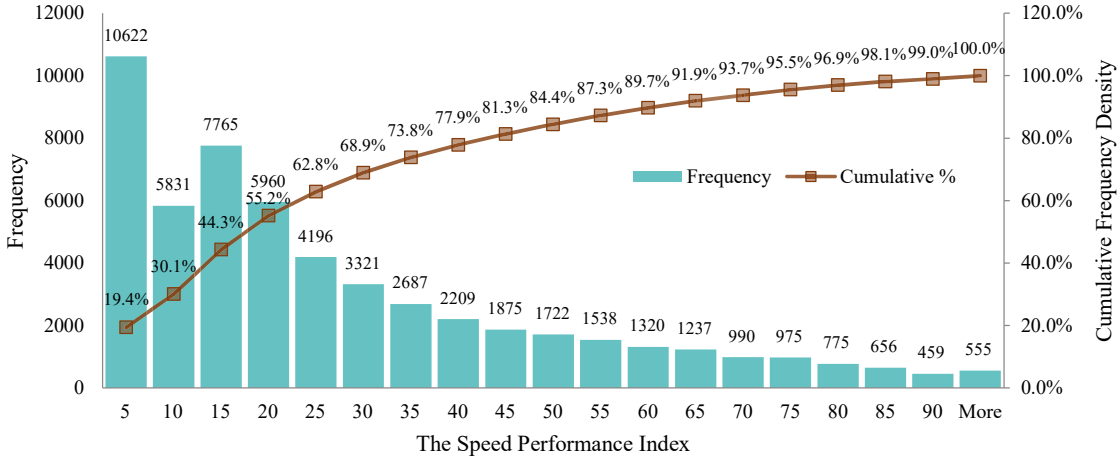


Figure 7. Frequency Distribution of the Speed Performance Index on Ulaanbaatar Road Network

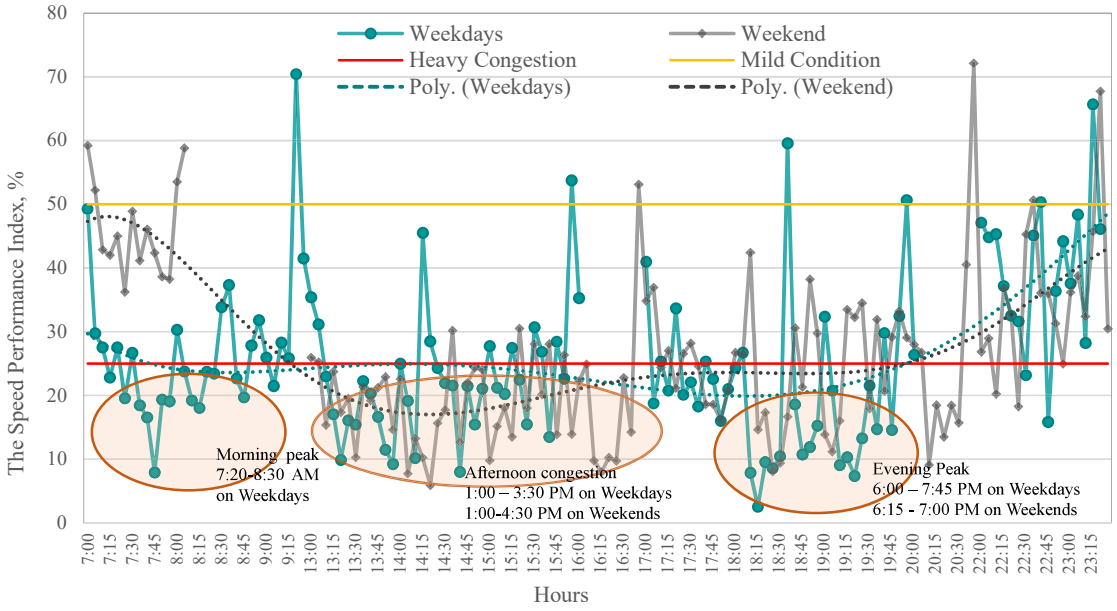


Figure 8. Speed Performance Index with 10 Minutes Increments on Ulaanbaatar Road Network

Figure 8 illustrates the 10-minute average Speed Performance Index on weekdays and weekends. The figure shows that the morning peak hour is often from 7:00AM to 9:00AM, of which the highest morning peak is between 7:20AM-8:30AM and the evening peak hour is from 5:00PM to 8:00PM, of which the heaviest congestion time is between 6:00PM-7:45PM on weekdays. Shown in the curve of weekdays, there are obvious morning and evening peak hours as well as afternoon congestion. The lowest points during morning and evening peaks are respectively at 7:45AM and 18:15 PM. The evening peak is from 17:00 to 19:00. On weekends, the speed performance is better than weekdays, the peak hours appear between 1:00

PM and 4:30 PM and the speed performances of morning and evening are better than the afternoon. Afternoon peak hours on weekend are worse than afternoon peak hours on weekdays. More detailed graphical illustrations of frequency distribution of the 1-minute average speed performance index on weekdays and weekends by direction of road are shown in Figure 9 – Figure 12.

Morning traffic. In the both morning weekdays of autumn and winter time, the morning peak period traffic often is started from 7:10AM to 8:25AM. During morning peak period, the morning congested road segment present at the central part of city and traffic towards into the city. The result shows that the proportion of speed performance with under 25% is 62.3% or heavy congestion, 33.7% of the data have mild congestion with the SPI between 25-50%, and only 4% are having the SPI with more than 50% or smooth and very smooth states of road for September weekday. The proportion of speed performance under 50% of the total records are 90.7%, of which 54.0% are heavy congested road segment under 25% of SPI and 36.7% are mild congestion with the SPI between 25-50% for December weekday. The smooth and very smooth traffic states of road with over 50% of SPI are only 9.3% for winter weekdays in morning. Mild congestion and smooth traffic are mainly in the outer areas of the city.

During morning time of weekends for both seasons, smooth and very smooth traffic states of total speed performance data are over 30% (33.8% SPI for September and 31.9% SPI for December) and mild congested road are over 60% (61.8% for September, 60.9% for December). The proportion of speed performance with under 25% is 4.4% of the total data for September and 7.2% for December.

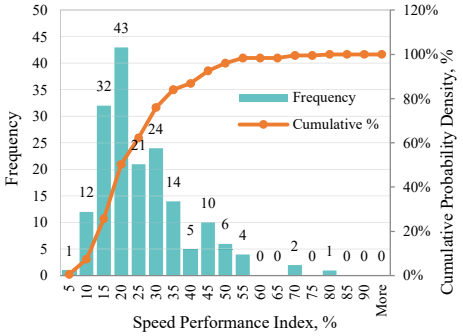
Afternoon traffic. The result shows that the heavy congestion proportion of the total speed performance records is over 50% (56.9% for autumn and 54.0% for winter) for weekdays and 70-80% (69.7% for autumn and 81% for winter) for weekends. Mild congestion states of the total data are 23.8% for autumn weekday, 27.6% for autumn weekend, 31.5% for winter weekday and 17.4% for winter weekend. The afternoon congestion for weekends is heavier than weekdays. Heavy congestion period continues from 1:10 PM to 2:40PM for both weekdays and weekend. On weekdays, the traffic congestion of directions 1 (traffic toward mainly into city center) is heavier than direction 2 (mainly traffic radiate out from the center city). On weekend of September, from 1:00PM to 2:05 PM, the traffic congestion of direction 1 is heavier than direction 2, then from 2:05 PM to 2:40 PM the traffic congestion of direction 1 is better than direction 2. On weekend of December, from 1:00PM to 1:40 PM, the traffic congestion of direction 2 is heavier than direction 1, then from 1:40 PM to 2:40 PM the traffic congestion of direction 1 is worse than direction 2.

Evening traffic. In the evening weekdays and weekends of September and December, the total heavy and mild congestion proportion of the total speed performance are over 96% (97.5% for September weekday, 96.4% for September weekend, 96.3% for December weekday, and 95.9% for December weekend), of which the heavy congestion is about 70% (70.4% for September weekday, 61.0% for September weekend, 68.3% for December weekday, and 73.1% for December weekend) and mild congestion is over 27% (27.1% for September weekday, 35.4% for September weekend, 28.0% for December weekday and 22.8% for December weekend). Traffics are almost not moving from 6:00PM-6:40PM for weekday and weekend of September. Similar characters of speed performance data for weekend December, but the speed performance index is better than weekend of December. Only less than 4% of the total speed performance are shown smooth traffic indices.

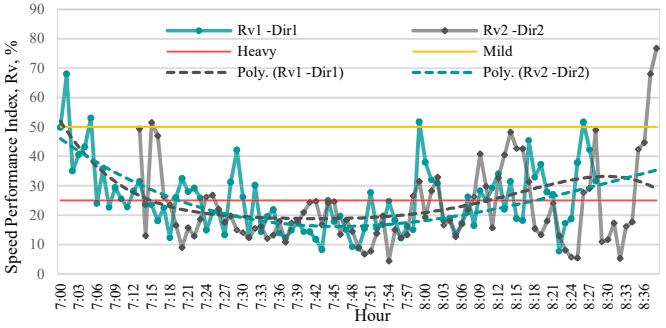
Night traffic. In the night time of both weekday and weekend of September, the heavy congestion proportion of the total data are over 20% (22.1% for weekday, 23.2% for weekend) for September and over 12% (13.4% for weekday and 12.4% for weekend) for December. The mild congestion of the total data are around 70% (77.4% for weekday and 66.7% weekend) for September and about 60% (56.1% for weekday and 66.3% for weekend) for December. The

smooth and very smooth traffic proportion of the total speed performance data are 3.5% for September weekday, 10.1% for September weekend, 30.5% for December weekday, and 21.3% for December weekend respectively. During night time mild traffic congestion records are dominated in the speed performance data.

Autumn: 09/17/2019 – Weekday Morning

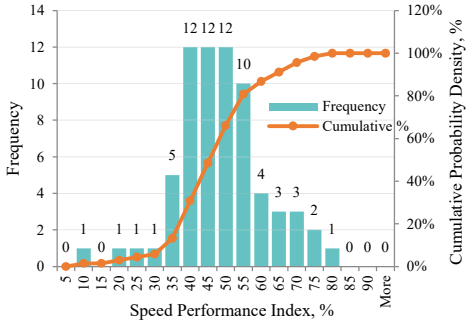


(A) Frequency Distribution of SPI

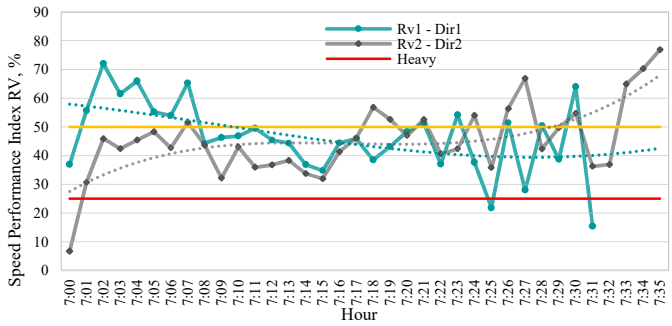


(B) SPI by Road Direction

Autumn: 09/21/2019 – Weekend Morning

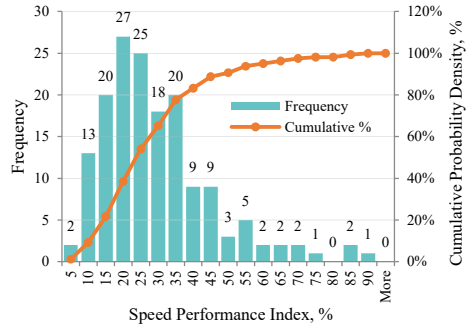


(A) Frequency Distribution of SPI

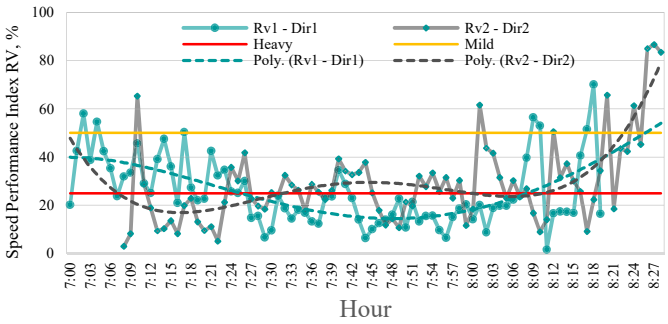


(B) SPI by Road Direction

Winter: 12/05/2019 – Weekday Morning

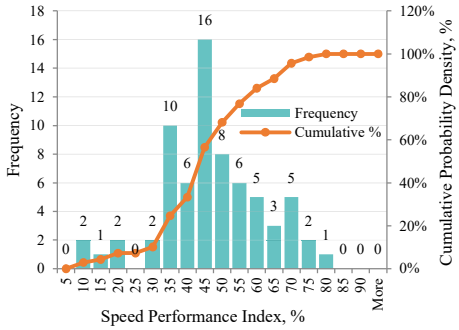


(A) Frequency Distribution of SPI



(B) SPI by Road Direction

Winter: 12/07/2019 – Weekend Morning



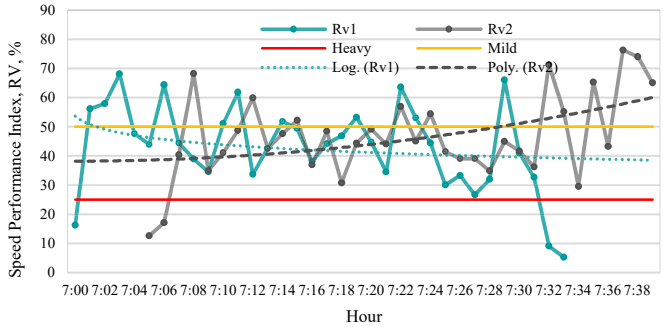
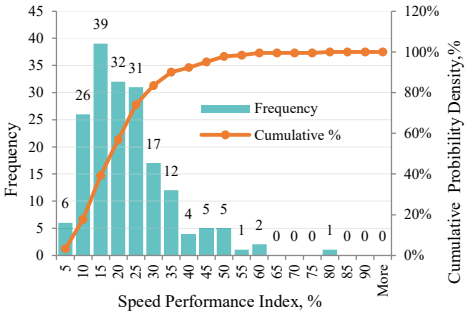


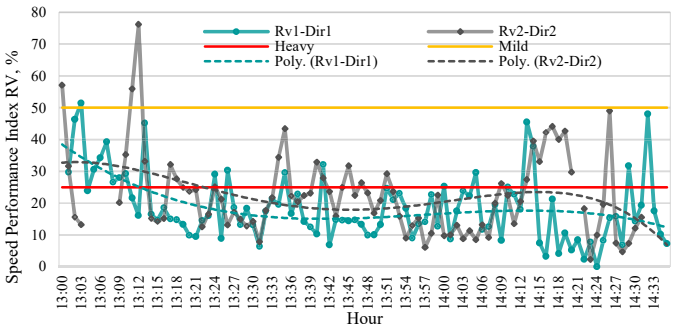
Figure 6. Morning Road Congestion Assessment by Date and Road Direction

Autumn: 09/17/2019 – Weekday Afternoon

Autumn: 09/17/2019 – Weekday Afternoon

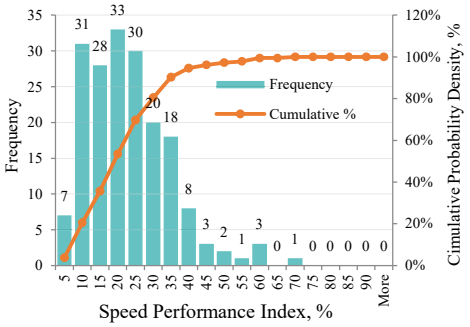


(A) Frequency Distribution of SPI

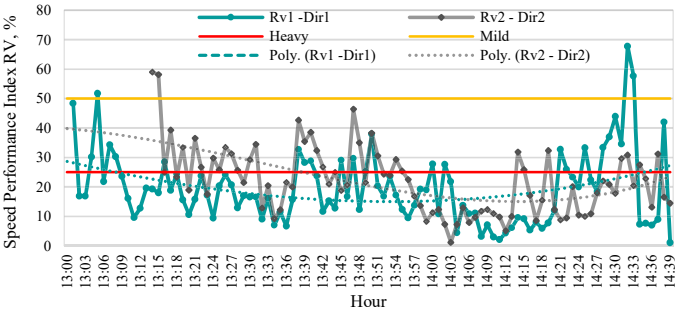


(B) SPI by Road Direction

Autumn: 09/21/2019 – Weekend Afternoon

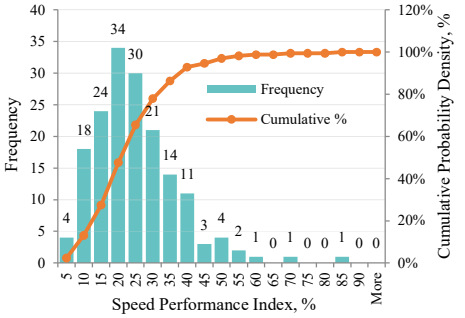


(A) Frequency Distribution of SPI

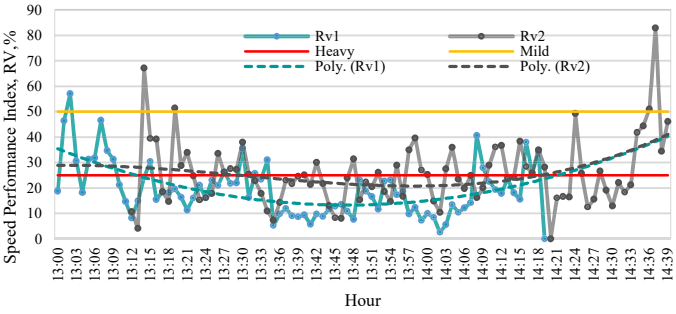


(B) SPI by Road Direction

Winter: 12/05/2019 – Weekday Afternoon

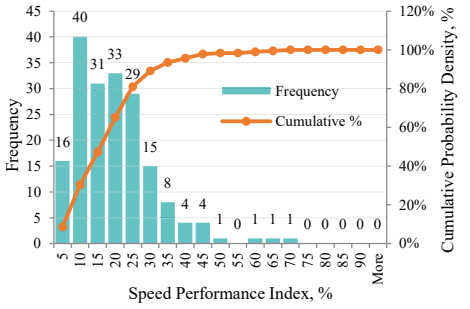


(A) Frequency Distribution of SPI



(B) SPI by Road Direction

Winter: 12/07/2019 – Weekend Afternoon



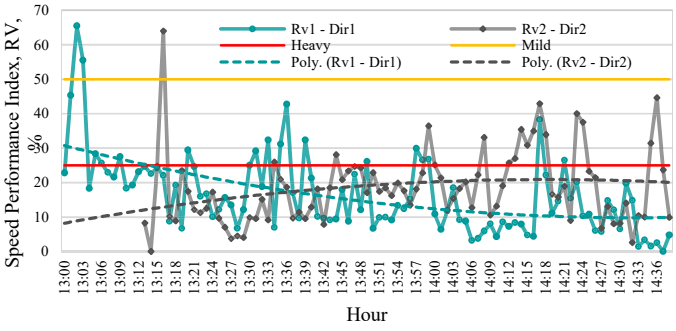
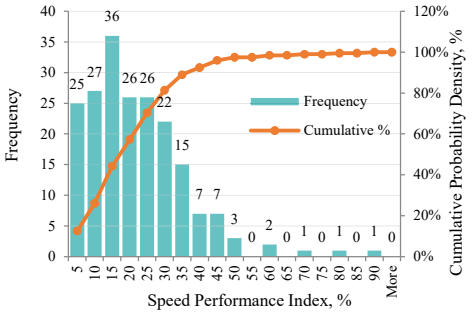


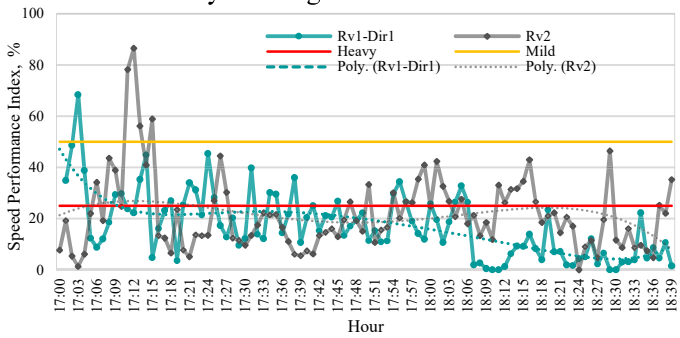
Figure 7. Afternoon Road Congestion Assessment by Date and Road Direction

Autumn: 09/17/2019 – Weekday Evening

Autumn: 09/17/2019 – Weekday Evening

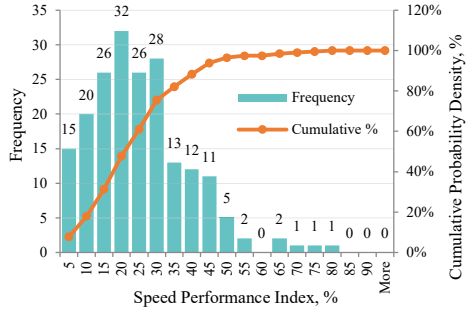


(A) Frequency Distribution of SPI

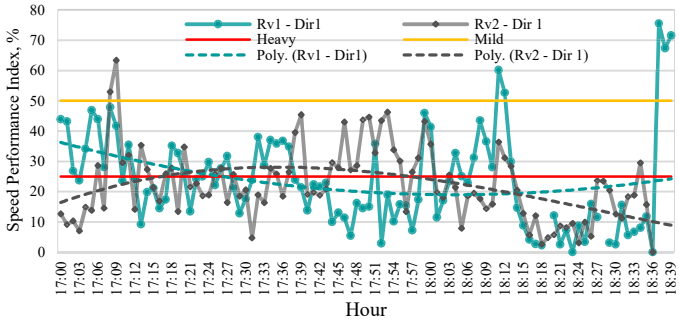


(B) SPI by Road Direction

Autumn: 09/21/2019 – Weekend Evening

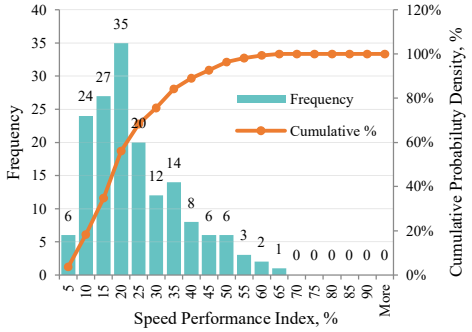


(A) Frequency Distribution of SPI

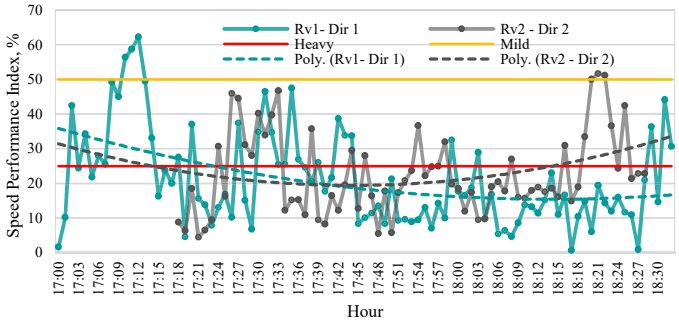


(B) SPI by Road Direction

Winter: 12/05/2019 – Weekday Evening

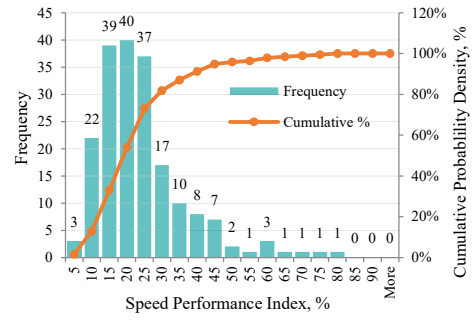


(A) Frequency Distribution of SPI



(B) SPI by Road Direction

Winter: 12/07/2019 – Weekend Evening



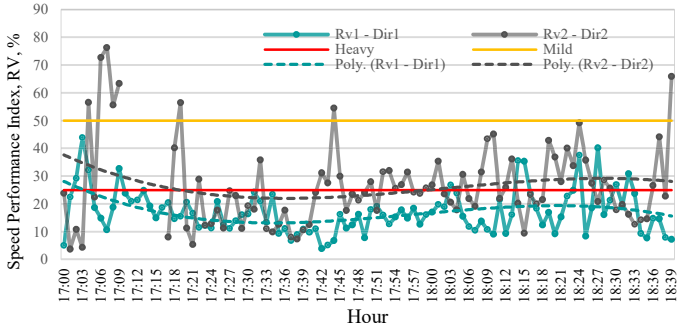
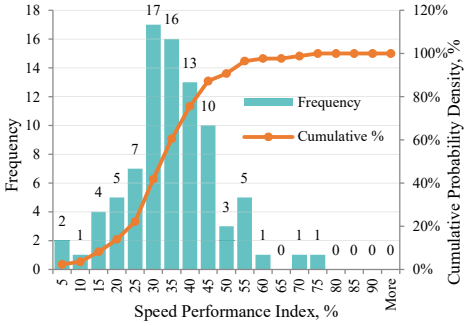


Figure 7. Afternoon Road Congestion Assessment by Date and Road Direction

Autumn: 09/17/2019 – Weekday Night

Autumn: 09/17/2019 – Weekday Night



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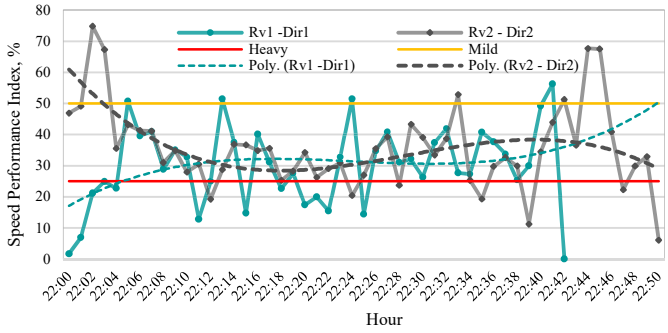
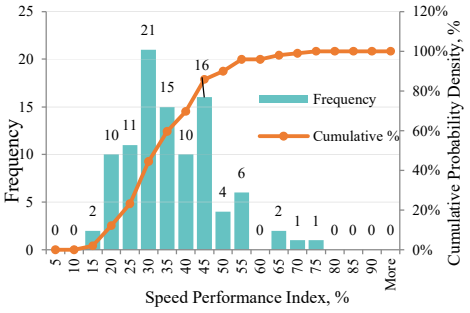


(B) SPI by Road Direction

Autumn: 09/21/2019 – Weekend Night



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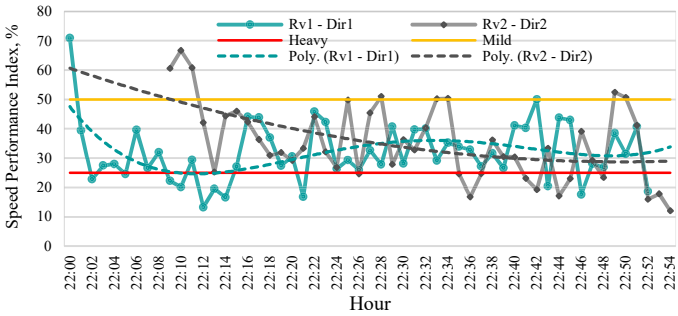
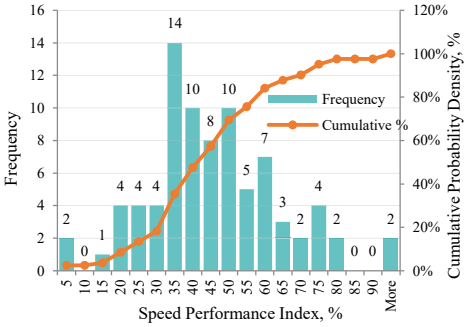


(B) SPI by Road Direction

Winter: 12/05/2019 – Weekday Night



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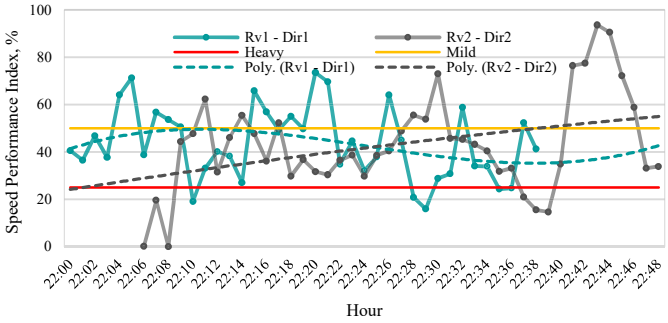
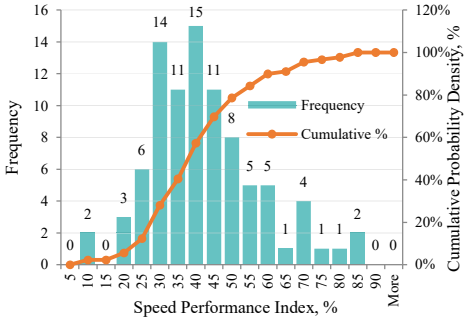


(B) SPI by Road Direction

Winter: 12/07/2019 – Weekend Night



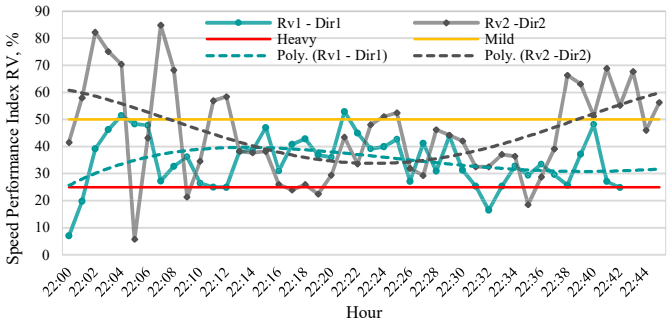


Figure 7. Afternoon Road Congestion Assessment by Date and Road Direction

The study finds that around 30 % of the selected roads have heavy congestion and more than 30% of them have mild congestion during peak hours. There are significant number of factors, which cause or aggravate congestion of Ulaanbaatar urban road network. Figure 9 shows fishbone diagram for Ulaanbaatar road congestion causes. As shown in the figure, the factors affect to the traffic jam classified into six categories such as management, infrastructure, motorization, public transport system, work force and environment.

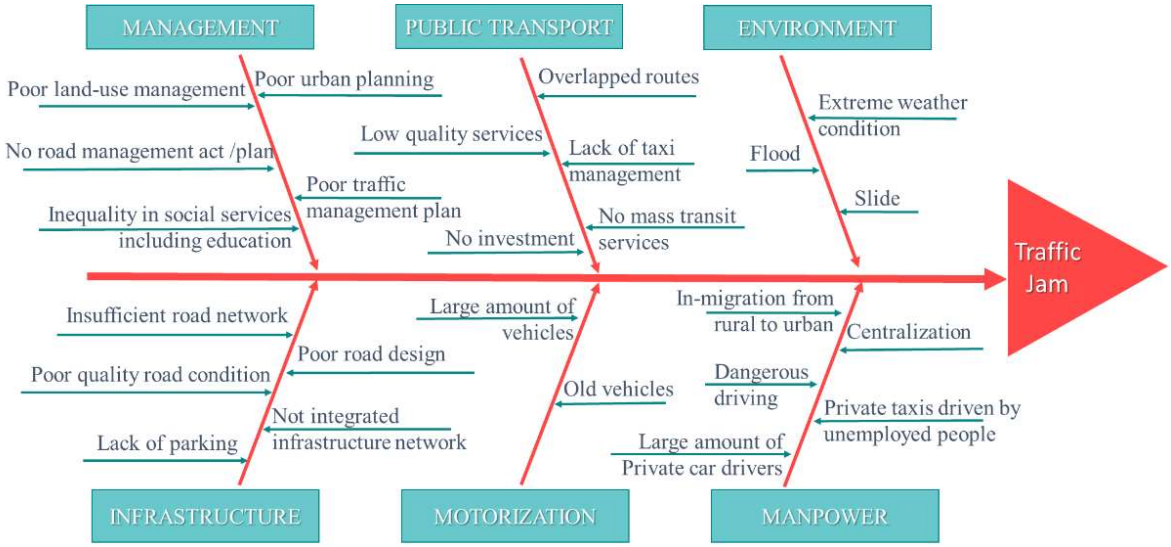


Figure 9. Fishbone Diagram for Influence Factors on Ulaanbaatar Road Congestion I

4. CONCLUSION

This study chose the speed performance index as the road network state evaluation indicator. Based on the traffic state classification standards, the study presented the road network congestion degree by location, season, weekday and weekend and direction. The result shows detailed traffic operation status of the Ulaanbaatar urban road network, which provides important information for future road and traffic management and urban development planning. Overall, the result shows that the proportion of speed performance which under 25% is more than 62.8% or heavy congestion, 21.2% of the data have mild congestion with the SPI between 25-50%, and 16% are having the SPI with more than 50% or smooth and very smooth states of road. According to road congestion assessment, the Ulaanbaatar urban road network is severely congested from morning to evening. The traffic flow on the main road corridors of Enhtayvan Ave., Dilav Hutagt St., Ard Ayush St., and Dorj St., vertical corridors of Bayanhoshuu St., Nam Yan Ju St, and Chinggis Ave has the worst traffic congestion. There is no one quick-fix for traffic congestion. The traffic congestion is a primarily problem in the Ulaanbaatar city, so need to solve the issues.

Since 2010, Ulaanbaatar's traffic congestion has gotten worse by the day, and there aren't many extensive scientific investigations on the subject unless it comes down to politics. Despite the fact that the evaluation method and data source appear to be very traditional and conventional, the traffic congestion data obtained is the first over 20 years for Ulaanbaatar. As a result, the study is useful in determining the level of traffic congestion based on seasonal and timing variations for future studies.

ANNEX

Table 1A. Speed Performance Index and Condition of Road Congestion For Route 1

Date	Indicators	Morning 7:00AM-9:30 AM			Afternoon 1:00PM-3:30 PM			Evening 5:00PM-7:30 PM			Night 10:00PM-11:30 PM		
		1*	2*	Total	1*	2*	Total	1*	2*	Total	1*	2*	Total
09/17/2019 Weekday	Ave. Distance, m	16519	15280	31799	15912	16470	32382	34687	15616	48708	14228	15505	29748
	Ave. Spee,km/h	11.3	14.4	12.6	11.8	19.9	14.8	11.0	12.0	10.9	22.3	20.2	21.1
	Ave. Rv, %	22.6	21.2	22.0	20.2	31.6	24.5	27.4	21.5	24.0	39.8	30.9	34.7
	Congestion Type	Heavy	Heavy	Heavy	Heavy	Mild	Heavy	Mild	Heavy	Heavy	Mild	Mild	Mild
09/21/2019 Weekend	Ave. Distance, m	14875	17521	32396	14569	14587	29156	15944	14539	30483	15157	15020	30178
	Ave. Spee,km/h	27.7	27.7	27.6	14.7	19.3	16.7	19.8	17.7	18.7	20.6	22.9	21.6
	Ave. Rv, %	44.2	44.8	44.5	29.0	37.8	33.0	38.1	33.5	35.7	39.2	33.9	36.9
	Congestion Type	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild
12/05/2019 Weekday	Ave. Distance, m	15908	14830	30738	16838	15029	31867	21285	14776	36062	15125	14485	29610
	Ave. Spee,km/h	11.0	16.2	12.9	10.9	13.2	11.8	8.4	12.3	9.7	21.9	19.4	20.5
	Ave. Rv, %	24.0	31.6	26.8	17.4	24.6	20.2	19.5	22.2	20.7	37.7	39.6	38.7
	Congestion Type	Heavy	Mild	Mild	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Mild	Mild
12/07/2019 Weekend	Ave. Distance, m	14727	14932	29659	15895	15533	31428	16824	15996	32820	15414	14191	29605
	Ave. Spee,km/h	25.0	28.3	26.7	9.9	13.0	11.2	10.2	8.4	8.5	20.7	12.1	13.4
	Ave. Rv, %	46.4	43.2	44.7	17.3	22.2	19.4	20.0	26.8	23.2	42.8	36.6	40.0
	Congestion Type	Mild	Mild	Mild	Heavy	Heavy	Heavy	Heavy	Mild	Heavy	Mild	Mild	Mild

Note: 1*- Traffic flow into the city; 2*Traffic flow from out of the city

Table 2A. Speed Performance Index and Condition of Road Congestion For Route 2

Date	Indicators	Morning 7:00AM-9:30 AM			Afternoon 1:00PM-3:30 PM			Evening 5:00PM-7:30 PM			Night 10:00PM-11:30 PM		
		1*	2*	Total	1*	2*	Total	1*	2*	Total	1*	2*	Total
09/17/2019 Weekday	Ave. Distance, m	17490	15155	32644	15453	15483	30936	15488	14442	29900	13486	14649	28116
	Ave. Spee,km/h	15.3	13.3	14.3	11.8	11.1	11.4	11.0	12.0	11.5	26.4	26.5	26.5
	Ave. Rv, %	30.6	24.1	27.0	24.3	18.7	21.1	23.0	20.7	21.8	48.1	44.7	46.4
	Congestion Type	Mild	Heavy	Mild	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Mild	Mild
09/21/2019 Weekend	Ave. Distance, m	18113	13345	31458	14679	17732	32411	18155	15544	33700	15326	14738	30064
	Ave. Spee,km/h	33.7	30.6	32.3	7.5	8.1	7.8	10.3	11.6	10.9	17.4	17.0	17.2
	Ave. Rv, %	50.4	52.0	51.1	11.6	14.3	12.9	19.9	19.3	19.6	20.4	26.6	23.5
	Congestion Type	Smooth	Smooth	Smooth	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Heavy
12/05/2019 Weekday	Ave. Distance, m	14914	15810	30724	15413	15961	31374	15075	15580	30655	14052	14623	28675
	Ave. Spee,km/h	19.1	14.9	16.7	15.2	13.3	14.0	11.0	12.0	11.5	26.4	26.5	26.5
	Ave. Rv, %	30.9	28.1	29.4	26.4	28.2	27.3	23.0	20.7	21.8	48.1	44.7	46.4
	Congestion Type	Mild	Mild	Mild	Mild	Mild	Mild	Heavy	Heavy	Heavy	Mild	Mild	Mild
12/07/2019 Weekend	Ave. Distance, m	14711	14866	29577	13888	17971	31859	17940	15441	33381	14945	14658	29603
	Ave. Spee,km/h	16.3	15.6	15.9	6.1	6.4	6.3	5.8	6.6	6.2	14.0	15.1	14.6
	Ave. Rv, %	56.4	54.3	55.3	23.0	21.3	22.1	20.4	24.5	22.3	50.7	52.8	51.7
	Congestion Type	Smooth	Smooth	Smooth	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Mild	Mild

Note: 1*- Traffic flow into the city; 2*Traffic flow from out of the city

Table 3A. Speed Performance Index and Condition of Road Congestion For Route 1

Date	Indicators	Morning 7:00AM-9:30 AM			Afternoon 1:00PM-3:30 PM			Evening 5:00PM-7:30 PM			Night 10:00PM-11:30 PM		
		1*	2*	Total	1*	2*	Total	1*	2*	Total	1*	2*	Total
09/17/2019 Weekday	Ave. Distance, m	16777	18380	35157	16744	17557	34302	20806	19475	40280	12760	14137	26896
	Ave. Spee,km/h	13.0	11.4	12.1	10.6	11.3	10.9	8.8	14.5	10.7	19.5	22.8	21.0
	Ave. Rv, %	22.1	17.4	19.3	15.7	18.9	17.2	13.8	21.1	16.3	35.0	35.1	35.1
	Congestion Type	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Mild	Mild
09/21/2019 Weekend	Ave. Distance, m	14897	15437	30335	16556	19665	36221	16826	16498	33324	16364	15461	31824
	Ave. Spee,km/h	30.6	25.1	27.6	11.7	11.2	11.5	13.7	15.0	14.3	17.9	23.0	20.0
	Ave. Rv, %	46.4	37.9	41.8	19.5	18.4	18.9	23.4	26.9	24.9	32.2	41.3	35.9
	Congestion Type	Mild	Mild	Mild	Heavy	Heavy	Heavy	Heavy	Mild	Heavy	Mild	Mild	Mild
12/05/2019 Weekday	Ave. Distance, m	15375	15661	31036	17768	17454	35222	20806	19475	40280	12760	14137	26896
	Ave. Spee,km/h	14.7	11.9	13.1	7.3	13.0	8.6	9.0	14.0	10.8	18.8	21.4	20.0
	Ave. Rv, %	22.1	21.5	21.8	18.1	20.1	18.9	19.5	22.2	20.7	37.7	39.6	38.7
	Congestion Type	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Mild	Mild
12/07/2019 Weekend	Ave. Distance, m	14608	14985	29593	16621	15654	32275	18304	15336	33640	14413	14698	29111
	Ave. Spee,km/h	25.2	25.9	25.5	8.0	6.5	6.3	6.4	12.6	8.1	19.6	21.8	20.6
	Ave. Rv, %	35.5	39.0	37.2	14.1	15.2	14.5	13.6	23.2	16.6	37.4	39.8	38.1
	Congestion Type	Mild	Mild	Mild	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Mild	Mild	Mild

Note: 1*- Traffic flow into the city; 2*Traffic flow from out of the city

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