# Traffic congestion analysis using travel time ratio and degree of saturation on road sections in Palembang, Bandung, Yogyakarta, and Surakarta

*Budi* Hartanto Susilo[1,*], and *Ivan* Imanuel[1]

[1] Maranatha Christian University, Depart. of Civil Engineering, Bandung, Indonesia

**Abstract.** Traffic performance have been measured based on degree of saturation, velocity, travel time, and delays. However, they weren't enough to measure the traffic fluctuation that happen on normal days. This study aims to develop some modified analysis about traffic congestion based on the degree of saturation (DS) and travel time ratio (TTR). The travel time ratio is defined as a ratio between the travel time at peak hour and the travel time at off-peak hour in a certain road section. Traffic congestion conditions are classified into 4 categories: Peak-hour Congestion, Lengthy Congestion, Momentary Congestion, and Smooth Traffic. Based on survey results on road sections in Palembang, Bandung, Yogyakarta, and Surakarta, it can be concluded that peak-hour congestion occurs when TTR > 1,40 and DS > 0,75, lengthy congestion occurs when TTR < 1,40 and DS > 0,75, momentary congestion occurs when TTR > 1,40 and DS < 0,75, and smooth traffic when TTR < 1,40 and DS < 0,75.

## 1 Introduction

Traffic and road transport as mandated by Indonesian Government [1] must have criteria for a secure, safe, orderly, smooth, and integrated with other transport modes. Muhtadi [2] said that at the moment, traffic congestions often arise in large cities in Indonesia because of the increasing number of vehicles that pass by affecting the capacity of the road that had been planned earlier. One of the treatments for the congestion problems the periodical evaluation of performance of urban road traffic to ensure the optimal performance of the road.

Speed, travel time, and delays are measures commonly used as indicators of the performance of traffic [3]. In addition, traffic performance is also measured by the degree of saturation. The relationship between the flow and travel time can be expressed as a function where if the flow increases then the travel time will also increase [4]. However, the degree of saturation still can't explain more about the fluctuations of flows that occur on each day. As a result, it often occurs a smooth traffic flow on a road which has a degree of saturation above one or vice versa. This study aims to provide further understanding

* Corresponding author: budiharsus@yahoo.com

regarding the performance of traffic, especially congestion conditions that may occur on a road.

## 2 Desk study

The Traffic flow is affected by drivers and vehicles interacting with other vehicles, infrastructure, and surrounding environment. The volume that occurs is not always fixed but fluctuating due to several factors such as: time, composition, split portion, lane configuration, the kind of area use, road classification, road feature, the number and types of access control, shape and geometry of the streets [5]. The existence of unbalanced daily variation pattern between peak and off-peak time becomes a major concern for transportation planners experts because of congestion problems encountered in the big city usually happens at peak hours [4]. Generally the flow of traffic is divided between peak hour and off-peak hour.

Travel time is the time it takes to travel the full length of observed path. This study gives information about the running speed, the travel speed, the speed fluctuations, delays between two stations. There are two kinds of delay, namely fixed delay and operational delay. Fixed delay is a delay due to a temporary traffic signal while operational delay is a delay due to the traffic movements such as as turning vehicles, in and out activities, pedestrian crossing, parking, heavy traffic volume, insufficient capacity, and traffic accidents. [6].

According to Indonesian Highway Capacity Manual [7], Degree of saturation (DS), is defined as the ratio of the traffic flow/volume (V) and the road capacity (C) of a certain road section. The volume and capacity are both in passenger car units per hour (PCU/hour). The degree of saturation, also called V/C ratio or volume capacity ratio, is the major indicator in suggesting the traffic performance. The higher the degree of saturation value the lower the traffic performance.

$$DS = \frac{V}{C} \tag{1}$$

*where,*
*DS = degree of saturation*
*V = traffic volume (PCU/hour)*
*C = road capacity (PCU/hour)*

The congestion increases when the flow is so high resulting vehicles get very close to each other. Total congestion occurs when vehicles have to stop or move very slowly [4]. Conditions of traffic congestion are often expressed with the level of service from A through F [8].

## 3 Study method

This study aims to provide a modified classification on traffic congestions in order to ease us solving the congestion problems. Two parameters, travel time ratio and the degree of saturation, are used in this study as indicators of traffic congestion. Figure 1 shows basic framework of this study.

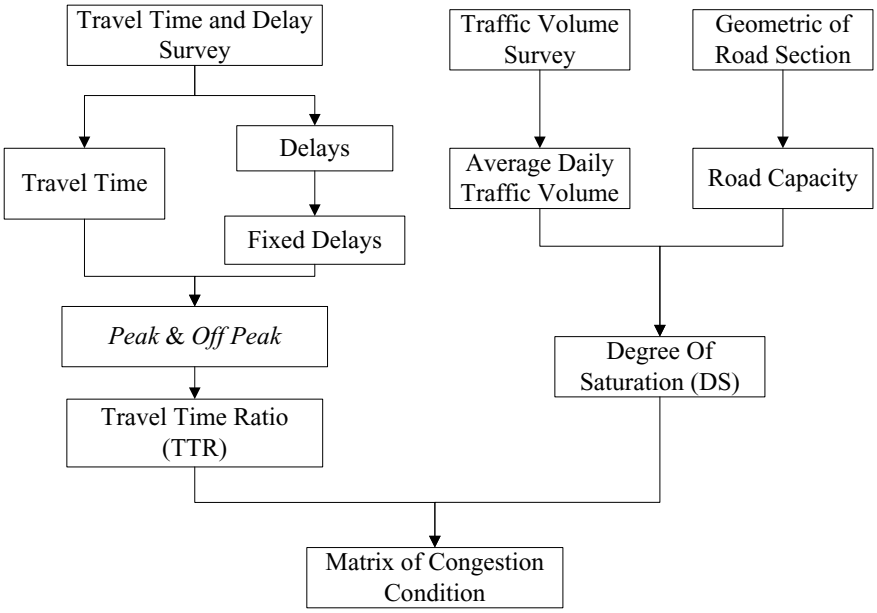


**Fig. 1.** Study framework

While the travel time ratio has been well known as ratio of travel time between various transportation modes [9], the proposed Travel time ratio (TTR) is a comparison between travel time on a road section during peak hours and off-peak hours. During rush hour, a large traffic volume tends to produce a lengthy travel time. It is influenced by the low speed due to the high density of traffic and the large amount of operation delays due to high level of transportation activities during rush hour. As the travel time during peak hours and off-peak hours have been recognized, TTR is proposed to be calculated as follows:

$$TTR = \frac{TT_P}{TT_0} \tag{2}$$

where,

$TTR$ = travel time ratio

$TT_P$ = travel time during peak hour (s)

$TT_0$ = travel time during off-peak hour (s)

If the number of surveys on each peak hour and off-peak hour is limited, then the travel time needs to be corrected against fixed delays such as signal controls and railway crossing. Corrections are intended to anticipate the significant influence of fixed delays on both time of the survey. For example, if there aren't any fixed delays occurred during the peak hour survey because of the green lights at all intersections while there are some during off-peak hours survey, then this may result in travel time during peak hours becoming shorter than travel time during off-peak hours.

$$TT = TS - FD \tag{3}$$

where,

$TT$ = corrected travel time (s)

$TS$ = real travel time (s)

FD = fixed delay time (s)

T By knowing its degree of saturation and travel time ratio, the condition of congestion that occurred on a road section can be assessed. Conditions of congestion based on the degree of saturation and the travel time ratio are classified into four types as shown in Table 1, namely:

a) Peak hour congestion: a condition of congestion where there are high traffic flow and activities at peak hours (0,5-2 hours) resulting significant delays and low speed. Both the degree of saturation and the travel time ratio on this road section are high. This condition expectedly happens on road sections with number of lane > 4 and high side frictions.
b) Lengthy congestion: a condition of congestion where high traffic flow and activities occur for several hours in a day (> 2 hours). The degree of saturation is high but the travel time ratio is low. This condition expectedly happens on road sections in downtown of major cities.
c) Momentary congestion: a condition of congestion where the traffic flow is considerably low all day but sometimes it becomes high for a short period of time. This condition expectedly happens on road sections with low capacity that a minor change in traffic flow can cause significant effects.
d) Smooth traffic: a condition where there is no congestion on a road sections all day. The traffic flows and side activities are both low and do not reduce traffic speed significantly nor cause any great operational delay.

**Table 1**. Matrix of congestion condition

| Parameter | High TTR | Low TTR |
|---|---|---|
| **High DS** | Peak-hour congestion | Lengthy congestion |
| **Low DS** | Momentary congestion | Smooth traffic |

The data were obtained from surveying on road sections in four cities in Indonesia, namely Palembang, Bandung, Yogyakarta and Surakarta. The road network includes national road network as well as urban road network. Three types of surveys had been conducted, namely travel time and delay survey, traffic volume survey, and road geometry survey. Travel time and delays survey was done to get travel time experienced by a normal moving vehicle on the road sections. This survey produced travel times and delays along with the location and cause. Traffic volume survey was done by counting the various passing vehicle on a certain spot location and generally conducted for 16 hours with the types of vehicles include motorcycles, light vehicles, heavy vehicles, and unmotorized vehicles. The geometry survey was conducted to identify the width and number of lanes, the median, the width of road shoulders/curb, and the land use/side friction along the road sections to calculate the road capacity.

# 4 Data and analysis

## 4.1 Determination of travel time ratio

Based on the results of calculations shown in Table 2 the lowest TTR on the road network in Palembang is 1.1 (Jend. Sudirman), while the highest TTR is 1.91 (Demang Lebar Daun). As the average value on all surveyed road sections is 1.57, the travel time ratios in Palembang are relatively high. Most of the delays are caused by the high density of traffic flow and oversaturated condition at the intersections.

**Table 2.** Travel time ratio of road sections in Palembang

| Name of Road Section | Direction | Real Travel Time (s) | | Fixed Delay Time (s) | | Corrected Travel Time (s) | | TTR |
|---|---|---|---|---|---|---|---|---|
| | | $TS_P$ | $TS_0$ | $FD_P$ | $FD_0$ | $TT_P$ | $TT_0$ | |
| Kol. H. Burlian | South | 1071 | 627 | 113 | 48 | 958 | 579 | 1.65 |
| Kol. H. Burlian | North | 865 | 637 | 84 | 82 | 781 | 555 | 1.41 |
| Jend. Sudirman | South | 1599 | 888 | 217 | 147 | 1382 | 741 | 1.87 |
| Jend. Sudirman | North | 1083 | 822 | 366 | 175 | 717 | 647 | 1.11 |
| Residen Abdul Rozak | West | 216 | 166 | 0 | 0 | 216 | 166 | 1.30 |
| Residen Abdul Rozak | East | 177 | 151 | 0 | 0 | 177 | 151 | 1.17 |
| Basuki Rahmat | West | 362 | 290 | 19 | 44 | 343 | 246 | 1.39 |
| Basuki Rahmat | East | 521 | 232 | 16 | 31 | 505 | 201 | 2.51 |
| Demang Lebar Daun | West | 649 | 757 | 64 | 451 | 585 | 306 | 1.91 |
| Demang Lebar Daun | East | 753 | 493 | 85 | 61 | 668 | 432 | 1.55 |

The lowest TTR on surveyed road sections in Bandung is 1.08 (Ahmad Yani and Jend. Sudirman) whereas the highest TTR is 1.25 (Soekarno-Hatta) as shown in Table 3. With the average value of 1.18, the travel time ratios in Bandung are relatively low. Most of the delays are caused by the high side frictions such as parked vehicles, pedestrian activities, and entering or exiting vehicles.

**Table 3.** Travel time ratio of road sections in Bandung.

| Name of Road Section | Direction | Real Travel Time (s) | | Fixed Delay Time (s) | | Corrected Travel Time (s) | | TTR |
|---|---|---|---|---|---|---|---|---|
| | | $TS_P$ | $TS_0$ | $FD_P$ | $FD_0$ | $TT_P$ | $TT_0$ | |
| Soekarno-Hatta | East | 4080 | 3600 | 1080 | 960 | 3000 | 2640 | 1.14 |
| Soekarno-Hatta | West | 5400 | 3720 | 2100 | 1080 | 3300 | 2640 | 1.25 |
| Kebon Jati | East | 314 | 240 | 16 | 0 | 298 | 240 | 1.24 |
| Ahmad Yani | East | 674 | 704 | 227 | 290 | 447 | 414 | 1.08 |
| Ahmad Yani | West | 888 | 652 | 244 | 128 | 644 | 524 | 1.23 |
| Jakarta | West | 159 | 129 | 0 | 0 | 159 | 129 | 1.23 |
| Sudirman | West | 867 | 795 | 102 | 89 | 765 | 706 | 1.08 |

From the results of the calculations in Table 4, the lowest TTR on surveyed road sections in Yogyakarta is 1.06 whereas the highest TTR is 1.73 (Laksda Adi Sucipto). With the average value of 1.16, the travel time ratios in Yogyakarta are relatively low. Most of the delays are caused by the high density of traffic flows.

**Table 4.** Travel time ratio of road sections in Yogyakarta.

| Name of Road Section | Direction | Real Travel Time (s) | | Fixed Delay Time (s) | | Corrected Travel Time (s) | | TTR |
|---|---|---|---|---|---|---|---|---|
| | | $TS_P$ | $TS_0$ | $FD_P$ | $FD_0$ | $TT_P$ | $TT_0$ | |
| Janti | North | 3180 | 2700 | 258 | 231 | 2922 | 2469 | 1.18 |
| Janti | South | 3180 | 2700 | 258 | 231 | 2922 | 2469 | 1.18 |
| Jend. Sudirman | West | 4500 | 4440 | 241 | 411 | 4259 | 4029 | 1.06 |
| Jend. Sudirman | East | 4500 | 4440 | 241 | 411 | 4259 | 4029 | 1.06 |
| Laksda Adi Sucipto | East | 2670 | 2340 | 211 | 269 | 2459 | 2071 | 1.19 |

| Name of Road Section | Direction | Real Travel Time (s) | | Fixed Delay Time (s) | | Corrected Travel Time (s) | | TTR |
|---|---|---|---|---|---|---|---|---|
| | | $TS_P$ | $TS_0$ | $FD_P$ | $FD_0$ | $TT_P$ | $TT_0$ | |
| Laksda Adi Sucipto | West | 2580 | 1680 | 106 | 253 | 2474 | 1427 | 1.73 |
| Kolonel Sugiyono | East | 4500 | 4440 | 241 | 411 | 4259 | 4029 | 1.06 |
| Kolonel Sugiyono | West | 4500 | 4440 | 241 | 411 | 4259 | 4029 | 1.06 |
| Malioboro | South | 4500 | 4440 | 241 | 411 | 4259 | 4029 | 1.06 |
| Ring Road Utara | East | 780 | 780 | 127 | 182 | 653 | 598 | 1.09 |
| Ring Road Utara | West | 2880 | 2700 | 198 | 308 | 2682 | 2392 | 1.12 |

Based on the calculation shown at Table 5, the lowest TTR on surveyed road sections in Surakarta is 1.14 (Slamet Riyadi) while the highest TTR is 2.83 (Yosodipuro). With the average value of 1.61, the travel time ratios in Surakarta are relatively high. Most of the operational delays are caused by the public transport vehicles making stops on the narrow streets.

**Table 5.** Travel time ratio of road sections in Surakarta.

| Name of Road Section | Direction | Real Travel Time(s) | | Fixed Delay Summary (s) | | Corrected Travel Time (s) | | TTR |
|---|---|---|---|---|---|---|---|---|
| | | $TS_P$ | $TS_0$ | $FD_P$ | $FD_0$ | $TT_P$ | $TT_0$ | |
| Slamet Riyadi | East | 485 | 628 | 27 | 227 | 458 | 401 | 1.14 |
| Slamet Riyadi | West | 613 | 382 | 167 | 97 | 446 | 285 | 1.56 |
| Kol. Sutarto | East | 148 | 126 | 46 | 45 | 102 | 81 | 1.26 |
| Kol. Sutarto | West | 374 | 126 | 64 | 5 | 310 | 121 | 2.56 |
| Ir. Sutami | East | 269 | 239 | 36 | 60 | 233 | 179 | 1.30 |
| Ir. Sutami | West | 278 | 238 | 16 | 72 | 262 | 166 | 1.58 |
| Veteran | East | 569 | 226 | 202 | 13 | 367 | 213 | 1.72 |
| Veteran | West | 428 | 250 | 140 | 0 | 288 | 250 | 1.15 |
| Yosodipuro | East | 240 | 207 | 56 | 74 | 184 | 133 | 1.38 |
| Yosodipuro | West | 427 | 138 | 62 | 9 | 365 | 129 | 2.83 |

## 4.2 Degree of saturation analysis

The degree of saturation is calculated by dividing the traffic volume by the road capacity. The used rush hour factor for general urban roads is 0.09 according to IHCM 1997 [7]. From the results of the calculations shown Table 6, the DS on road network in Palembang is relatively high with an average of 0.9. The highest degree of saturation occurs at Demang Lebar Daun, reaching 1.41 while the lowest degrees of saturation occurs at Sudirman direction, about 0.56.

**Table 6.** Degree of saturation of road sections in Palembang.

| Name of Road Section | Direction | V (PCU/hour) | C (PCU/hour) | DS |
|---|---|---|---|---|
| Kol. H. Burlian | South | 2506 | 4299 | 0.58 |
| Kol. H. Burlian | North | 2494 | 4299 | 0.58 |
| Jend. Sudirman | South | 3990 | 4153 | 0.96 |
| Jend. Sudirman | North | 3892 | 4153 | 0.94 |
| Residen Abdul Rozak | West | 1963 | 2884 | 0.68 |

| Name of Road Section | Direction | V (PCU/hour) | C (PCU/hour) | DS |
|---|---|---|---|---|
| Residen Abdul Rozak | East | 1775 | 2884 | 0.62 |
| Basuki Rahmat | West | 3322 | 2884 | 1.15 |
| Basuki Rahmat | East | 2930 | 2884 | 1.02 |
| Demang Lebar Daun | West | 6339 | 4481 | 1.41 |
| Demang Lebar Daun | East | 5771 | 4481 | 1.29 |

The DS of surveyed road sections in Bandung as shown in Table 7 are relatively normal with an average of 0.71. The highest DS is 1.1 (Ahmad Yani) while the lowest is 0.51 (Soekarno Hatta and Jend. Sudirman).

**Table 7.** Degree of saturation of road sections in Bandung.

| Name of Road Section | Direction | V (PCU/hour) | C (PCU/hour) | DS |
|---|---|---|---|---|
| Soekarno-Hatta | East | 3865 | 5860 | 0.66 |
| Soekarno-Hatta | West | 4080 | 5860 | 0.70 |
| Kebon Jati | East | 2723 | 4206 | 0.65 |
| Ahmad Yani | East | 1236 | 2058 | 0.60 |
| Ahmad Yani | West | 1128 | 1029 | 1.10 |
| Jakarta | West | 4999 | 5042 | 0.99 |
| Jend. Sudirman | West | 2162 | 4206 | 0.51 |

Generally shown in Table 8, the DS in Yogyakarta are relatively high with an average value of 0.89. The highest DS is 1.35 (Jend. Sudirman) while the lowest is 0.47 (Kolonel Sugiyono).

**Table 8.** Degree of saturation of road sections in Yogyakarta.

| Name of Road Section | Direction | V (PCU/hour) | C (PCU/hour) | DS |
|---|---|---|---|---|
| Janti | North | 3422 | 3935 | 0.87 |
| Janti | South | 2549 | 3935 | 0.65 |
| Jend. Sudirman | West | 3499 | 2596 | 1.35 |
| Jend. Sudirman | East | 2999 | 2596 | 1.16 |
| Laksda Adi Sucipto | East | 2601 | 2650 | 0.98 |
| Laksda Adi Sucipto | West | 2498 | 2426 | 1.03 |
| Kolonel Sugiyono | East | 1196 | 2568 | 0.47 |
| Kolonel Sugiyono | West | 2602 | 2568 | 1.01 |
| Malioboro | South | 2713 | 2400 | 1.13 |
| Ring Road Utara | East | 2588 | 4033 | 0.64 |
| Ring Road Utara | West | 2372 | 4033 | 0.59 |

As shown in Table 9, the DS in Surakarta are relatively low with an average value of 0,58. The highest DS is 0.71 (Ir. Sutami) while the lowest DS is 0.46 (Slamet Riyadi).

**Table 9.** Degree of saturation of road sections in Surakarta.

| Name of Road Section | Direction | V (PCU/hour) | C (PCU/hour) | DS |
|---|---|---|---|---|
| Slamet Riyadi | East | 1374 | 2183 | 0.63 |
| Slamet Riyadi | West | 998 | 2183 | 0.46 |
| Kol. Sutarto | East | 1442 | 2769 | 0.52 |
| Kol. Sutarto | West | 1789 | 2769 | 0.65 |
| Ir. Sutami | East | 1588 | 2411 | 0.66 |
| Ir. Sutami | West | 1703 | 2411 | 0.71 |
| Veteran | East | 834 | 1756 | 0.47 |
| Veteran | West | 925 | 1756 | 0.53 |
| Yosodipuro | East | 841 | 1529 | 0.55 |
| Yosodipuro | West | 1053 | 1529 | 0.69 |

### 3.3 Determination of congestion condition

The highest TTR of all surveyed road sections in 4 cities is 2.83 (Yosodipuro, Surakarta) while the lowest TTR is 1.06 (Malioboro, Yogyakarta). The average value of TTR is 1.40. Based on these results, TTR with value above 1.40 is classified "High" while TTR with value between 1.00 and 1.40 is classified "Low". The DS with value above 0.75 is classified "high" according to IHCM 1997 (Directorate General of Bina Marga, 1997) and classified low below 0.75. Therefore, the condtions of cogestion of road networks in 4 cities can be identified, according to Table 1, as given in Table 10.

**Table 10.** Identification of congestion condition.

| Name of Road Section | Direction | DS | TTR | Congestion Condition |
|---|---|---|---|---|
| Kol. H. Burlian | South | Low | High | Momentary congestion |
| Kol. H. Burlian | North | Low | High | Momentary congestion |
| Sudirman | South | High | High | Peak-hour congestion |
| Sudirman | North | High | Low | Lengthy congestion |
| Residen Abdul Rozak | West | Low | Low | Smooth traffic |
| Residen Abdul Rozak | East | Low | Low | Smooth traffic |
| Basuki Rahmat | West | High | Low | Lengthy congestion |
| Basuki Rahmat | East | High | High | Peak-hour congestion |
| Demang Lebar Daun | West | High | High | Peak-hour congestion |
| Demang Lebar Daun | East | High | High | Peak-hour congestion |
| Soekarno-Hatta | East | Low | Low | Smooth traffic |
| Soekarno-Hatta | West | Low | Low | Smooth traffic |
| Kebon Jati | East | Low | Low | Smooth traffic |
| Ahmad Yani | East | Low | Low | Smooth traffic |
| Ahmad Yani | West | High | Low | Lengthy congestion |
| Jakarta | West | High | Low | Lengthy congestion |
| Jend. Sudirman | West | Low | Low | Smooth traffic |
| Janti | North | High | Low | Lengthy congestion |

| Name of Road Section | Direction | DS | TTR | Congestion Condition |
|---|---|---|---|---|
| Janti | South | Low | Low | Smooth traffic |
| Jend. Sudirman | West | High | Low | Lengthy congestion |
| Jend. Sudirman | East | High | Low | Lengthy congestion |
| Laksda Adi Sucipto | East | High | Low | Lengthy congestion |
| Laksda Adi Sucipto | West | High | High | Peak-hour congestion |
| Kolonel Sugiyono | East | Low | Low | Smooth traffic |
| Kolonel Sugiyono | West | High | Low | Lengthy congestion |
| Malioboro | South | High | Low | Lengthy congestion |
| Ring Road Utara | East | Low | Low | Smooth traffic |
| Ring Road Utara | West | Low | Low | Smooth traffic |
| Slamet Riyadi | East | Low | Low | Smooth traffic |
| Slamet Riyadi | West | Low | High | Momentary congestion |
| Kol. Sutarto | East | Low | Low | Smooth traffic |
| Kol. Sutarto | West | Low | High | Momentary congestion |
| Ir. Sutami | East | Low | Low | Smooth traffic |
| Ir. Sutami | West | Low | High | Momentary congestion |
| Veteran | East | Low | High | Momentary congestion |
| Veteran | West | Low | Low | Smooth traffic |
| Yosodipuro | East | Low | Low | Smooth traffic |
| Yosodipuro | West | Low | High | Momentary congestion |

## 5 Conclusions

Based on the analysis, travel time ratio (TTR) along with the degree of saturation (DS) can classify the traffic congestion conditions on road sections in Palembang, Bandung, Yogyakarta, and Surakarta. Furthermore, it can be classified into 4 categories, namely:

1. Peak-hour congestion, if TTR ≥ 1,40 and DS ≥ 0,75.
2. Lengthy congestion, if TTR < 1,40 and DS ≥ 0,75.
3. Momentary congestion, if TTR ≥ 1,40 and DS < 0,75.
4. Smooth traffic, if TTR < 1,40 and DS < 0,75.

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