A Quantitative Measure of Congestion in Stellenbosch using Probe Data

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Abstract*—This paper aims to quantify and evaluate congestion in Stellenbosch, a historic university town located approximately 50 kilometres east of Cape Town, South Africa, using probe data. It is known that Stellenbosch experiences traffic congestion, but the scientific extent of this congestion has not been fully determined, as the present volume counts alone are not a sufficient form of assessment. Its residents complain about congestion suffered in town and express frustration. This, along with the fourth annual TomTom South African Traffic Index publication, which revealed that Cape Town (with a congestion index of 27%) is the most congested city in South Africa, instigated this study. Literature bares that the level of service concept (LOS) defined in the Highway Capacity Manual (HCM) has been widely used as a basis for congestion measures, although travel-time-based measures are suggested to satisfy the need for congestion information best. Travel time is well understood by both the general public and professional community, but the collection of travel time, travel speed, travel rate and travel delay data is historically deemed somewhat more complex and onerous than traffic volume counting procedures, and together with limited financial resources has restrained its application. The methodology applied in this study comprises the utilisation of TomTom Traffic Stats Portal that contains historic travel-time-based data from TomTom in-vehicle navigation systems and supporting devices. The platform and associated configuration is state-of-the-art and brings new light to travel-time-based congestion measures. The data was statistically analysed over various date and time periods, and standard congestion index concepts were applied. Congestion measures were considered along the major arterials leading into and out of Stellenbosch, as well as on part of its central road network. This paper shows that Stellenbosch evidently faces increased levels of congestion. Travel times on the inbound arterials are on the rise, and in-town traffic is becoming unsustainable.

***Keywords*—TomTom; probe data; congestion measurement**

I. Background

According to the 2011 census, Stellenbosch Municipality, Western Cape, South Africa, (governing the towns of Stellenbosch, Franschhoek, Pniel and surrounding rural areas) has a population of 155733, and 43200 households covering an area of 831km^2 [3]. The town Stellenbosch has a surfaced road network of 235777m, and 0.9 private cars per household, according to a household survey conducted in 2008 [5]. Stellenbosch is home to University of Stellenbosch with approximately 28156 enrolled students and a personnel size of around 3085 (2013) [4]. Over the ten-year span from 2004 to 2013, the number of students increased by 28%. A study conducted by the Stellenbosch Municipality in 2009 reported that one third of the students reside in or near campus; another third reside in the town or the immediate surrounding area; and the final third reside in the surrounding towns or the Cape Metro [5]. Furthermore, 51% of the students use the passenger vehicle as their mode of transport to and from campus, of which 85% are also the driver of the vehicle [5]. Of all the personnel, 83% use the passenger vehicle to work daily and 87% of them are also the driver [5]. 27 schools are located in Stellenbosch, spread across the various suburbs and township. 8 of these schools are high schools, attracting learners from neighbouring towns and even other parts of the country.

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II. Introduction

Congestion (and its associated bottlenecks) is observed in Stellenbosch on a daily basis, and results in complaints and frustration expressed by its residents. The fourth annual TomTom South African Traffic Index publication revealed that Cape Town is the most congested city in South Africa of late, with a congestion index of 27%. The Stellenbosch Smart Mobility Lab (SSML) deemed that this necessitated a quantitative measure of the true extent of the congestion in Stellenbosch, located only 50km east of Cape Town, which goes beyond volume counts and personal perception. Congestion is here defined as a condition that occurs on roadways as the demand increases to its carrying capacity, and the number of vehicles arriving is greater than the number of vehicles discharged. It is characterised by slower speeds, longer travel times and increased vehicular queuing. Two methodologies, namely the Level of Service Concept and Use of Probe Data, are explained and compared before the use of TomTom probe data is carried through in the rest of the paper. The compilation of the TomTom datasets/queries is discussed, after which congestion indices (speed reduction index and congestion index) and other congestion measures (travel rate, delay rate, relative delay rate and delay ratio) are explained and applied to the given output. An evaluation of the resulting numerical values finally follows.

III. Methodology

A. Methodologies used in congestion measurement

1) Method of the past: level of service concept

The Highway Capacity Manual uses the level of service (LOS) concept to represent a range of roadway operating conditions. This concept has been widely applied to congestion measurement [2]. A shortcoming of the LOS technique is its use of letter grades in place of a numerical scale, and that there is no consensus regarding the LOS range corresponding to the threshold of congestion [2]. It also gives no detailed subclassification within LOS F (worst condition). Although most congestion management agencies commonly used the LOS concept as their measure of congestion, delay and travel time/speed were the suggested measures for use by most agencies [2]. The most frequently cited reason for not using delay and travel time/speed was limited financial resources, as

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data collection techniques such as the floating car and licence plate matching were used before probe data became available [2].

2) State-of-the-art method: use of probe data

Probe data is information amassed while monitoring a sample of transportation system users as they pass predefined points along a segment of thoroughfare. TomTom probe data sources include connected GPS devices, GSM devices, road sensors and incident data. In this paper, only motorised transportation is considered, but ideal probes span multiple modes of transit. Probe data has the advantage that it is more accurate and/or less expensive than most current data collection devices and techniques; and as a non-infrastructure solution, it avoids the following predicaments: theft/vandalism, collisions, communications, power, etc. Although the field of Intelligent Transportation Systems (ITS) exists for a number of decades already, the use of probe data only intensified recently (last decade). Probe data finally enabled professionals to measure a fundamental performance indicator, travel time, readily and with greater precision.

B. Methodology of this paper

1) Specification of routes

7 routes were studied for this paper (in both directions). These are shown in *Fig.1*, with their lengths given in brackets. These routes are the major arterials leading into and out of Stellenbosch, and also some of the interior roads linked to these arterials and observed to be exceptionally congested.

2) Specification of analysis date and time periods

Probe data was collected using the TomTom Stats Portal containing historic data. The date period was set to a typical day (Tuesday to Thursday, February to the end of March) for the years 2011 to 2014. 7 time periods were selected for each day of the defined date period. These are: (1) 12am to 6am (free flow), (2) 6am to 7am, (3) 7am to 8am, (4) 8am to 9am, (5) 1pm to 3pm, (6) 4pm to 5pm and (7) 5pm to 6pm.

3) Analysis of the output

The TomTom Traffic Stats Portal generates 4 output formats for each submitted dataset. These are (1) a KML file, (2) a XLS file, (3) a shapefile and (4) charts that open in the portal. These outputs provide segment, speed and travel time information. It was ensured that all sample sizes are adequate. Where the sample size is below 50 for the comparative time periods and below 10 for the base period, comparisons were made to the previous year to assess the correctness of the output. Most comparative-time-period sample sizes lie between 100 and 600.

To obtain a general overview of the congestion level in Stellenbosch, the peak-hour delay was computed for each route, for each analysed year from the obtained outputs. Delay is here defined as the difference between the actual travel time and free-flow travel time, and is a simple, easily-understood measure for attaining a first impression. The typical delays are shown in *Table I*, with two non-typical time periods included for 2013. (The date period was once altered to include Fridays, i.e. Tuesday to Friday, and then modified to the June/July school and university vacation period.) It was immediately evident that the 6-7am time period provides no pertinent data and was thus ignored.

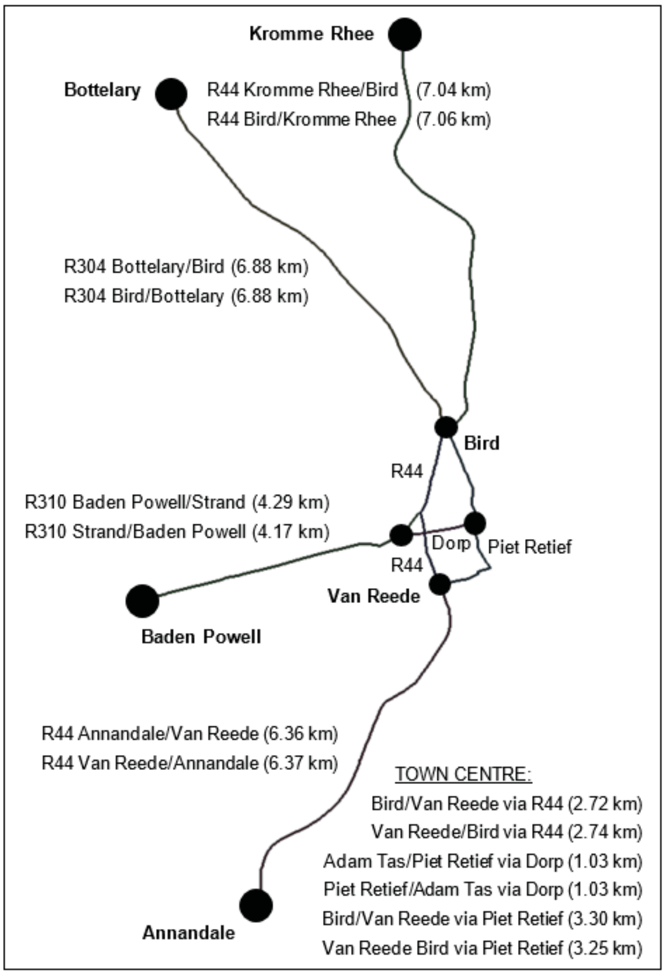

Fig. 1. Map of selected routes.

The more complex and scientific congestion indices and measures are enlightened below.

a) Speed reduction index

The speed reduction index reflects the ratio of the relative speed change between congested and free-flow conditions. Congestion usually occurs when the index exceeds 4 to 5 [2]. This concept provides a value that is easily understood by all audiences (nontechnical and technical), and its continuous scale (with numerical values between 0 and 10) offers more information on the magnitude of congestion in severely congested operating conditions than the LOS concept.

Speed reduction index = [1– (*actual travel speed* / *free-flow travel speed*)] x 10 (1)

b) Congestion index

The congestion index was developed by D'Este et al. and Taylor [1], and is computed as follows:

Congestion index = [(*actual travel time*) – (*free-flow travel time*)] / [*free-flow travel time*] (2)

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TABLE I. PEAK HOUR AND DELAY PER ROUTE PER YEAR FOR A TYPICAL AND NON-TYPICAL DAY

Peak Hour and Delay per Route per Year	***Year***											
	2011		***2012****		***2013***		***2013 (incl. Fri)***		***2013 (holiday)***		***2014***	
Route	***Peak Hour***	***Delay (min)***	***Peak Hour***	***Delay (min)***	***Peak Hour***	***Delay (min)***	***Peak Hour***	***Delay (min)***	***Peak Hour***	***Delay (min)***	***Peak Hour***	***Delay (min)***
R304 Bottelary/Bird	7-8am	7.83	7-8am	6.94	7-8am	10.81	7-8am	10.48	7-8am	2.60	7-8am	12.01
R304 Bird/Bottelary	5-6pm	2.45	-	-	5-6pm	3.29	5-6pm	3.30	5-6pm	3.14	5-6pm	6.34
R44 Kromme Rhee/Bird	7-8am	4.02	7-8am	4.17	7-8am	6.17	7-8am	6.12	7-8am	4.47	7-8am	9.96
R44 Bird/Kromme Rhee	7-8am	1.85	-	-	5-6pm	1.77	-	-	-	-	7-8am	1.41
R44 Annandale/Van Reede	7-8am	7.90	7-8am	8.10	7-8am	8.86	7-8am	8.76	4-5pm	1.43	7-8am	8.09
R44 Van Reede/Annandale	5-6pm	3.74	-	-	5-6pm	4.31	5-6pm	4.28	4-5pm	1.06	5-6pm	4.87
R310 Baden Powell/Strand	7-8am	4.85	7-8am	5.36	7-8am	6.48	7-8am	6.41	5-6pm	2.02	8-9am	2.13
R310 Strand/Baden Powell	4-5pm	1.55	-	-	4-5pm	1.35	-	-	-	-	5-6pm	9.88
Adam Tas/Piet Retief via Dorp	7-8am	2.83	-	-	4-5pm	2.70	4-5pm	2.53	4-5pm	1.26	7-8am	2.53
Piet Retief/Adam Tas via Dorp	4-5pm	7.02	-	-	1-3pm	3.37	1-3pm	3.45	7-8am	2.01	4-5pm	4.97
Bird/Van Reede via Piet Retief	5-6pm	8.74	-	-	5-6pm	7.04	5-6pm	7.09	4-5pm	2.10	7-8am	8.04
Van Reede/Bird via Piet Retief	5-6pm	8.80	-	-	5-6pm	9.26	5-6pm	9.17	5-6pm	8.33	5-6pm	9.33
Bird/Van Reede via R44	5-6pm	12.79	-	-	5-6pm	6.54	5-6pm	6.56	7-8am	6.81	4-5pm	6.45
Van Reede/Bird via R44	5-6pm	8.50	-	-	7-8am	12.92	7-8am	12.73	7-8am	5.87	5-6pm	6.51

*For 2012, only the peak-hour congestion of each arterial was studied.

A value of 0 indicates a very low level of congestion, as the travel condition is close to the free-flow condition in this case [1]. A value greater than 2 corresponds to a very congested condition [1].

c) Travel rate

Travel rate is the rate of motion, in min/km, for a specified roadway segment or trip. It is the inverse of speed and is calculated by dividing the segment travel time (min) by the segment length (km):

$$\textit{Travel rate} = \textit{travel time} / \textit{segment length} \quad (3)$$

d) Delay rate

Delay rate is the rate of time loss for vehicles operating in congested conditions, in min/km, for a specified roadway segment or trip. It is calculated as the difference between the actual travel rate and the acceptable travel rate. Literature suggests that acceptable congestion standards may be related to congestion perceived by travellers. Motorists are usually aware of congestion when travel speeds reduce to 60 to 70 % of the free-flow speeds. This theory was adopted in this paper, applying an awareness at 70%.

$$\textit{Delay rate} = (\textit{actual travel rate}) - (\textit{acceptable travel rate}) \quad (4)$$

e) Relative Delay Rate

Relative delay rate is a dimensionless measure that is used in this paper to compare the relative congestion on the various selected routes. It is calculated as the delay rate divided by the acceptable travel rate.

$$\textit{Relative delay rate} = (\textit{delay rate}) / (\textit{acceptable travel rate}) \quad (5)$$

f) Delay ratio

Delay ratio is a dimensionless measure also used to compare the relative congestion levels on the various selected routes. It is calculated as the delay rate divided by the actual travel rate.

$$\textit{Delay ratio} = (\textit{delay rate}) / (\textit{actual travel rate}) \quad (6)$$

IV. RESULTS

The results of the applied congestion indices and measures for a typical day are presented in *Addendum A*. The greater the value, the more severe the congestion. Negative values result when the actual travel conditions are better than the acceptable travel conditions. After computing the arterial speed reduction and congestion indices, it was apparent that the outbound and inbound arterials experience little congestion in the morning and afternoon, respectively. The remaining congestion measures were thus not applied to these routes.

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The results of route Van Reede/Bird via Piet Retief for 2014 are typed in italics and underlined, as there must be an error in the obtained free-flow data. The sample size was less than 10, which possibly explains this error.

V. Discussion of Results

Beginning with the speed reduction index, all morning values have been above 4 since 2011, except for the previously-mentioned outbound arterials. In 2014, they are all above 5 in fact, with the exception of the R310 Strand/Baden Powell route. There was a construction/maintenance zone on this route at the time, which influenced the data. Noteworthy is however the impact this zone had on the outbound afternoon traffic. The negative delay rates, relative delay rates and delay ratios of 2011 and 2013, amplified to values above 0 in 2014. Overall, the afternoon arterial traffic conditions were all below 4 in 2011 and 2013, but increased slightly above 4 on the R304 Bird/Bottelary and R44 Van Reede/Annandale arterial routes. Opposed to the R310 Strand/Baden Powell route, there are not any other known factors that could account for only a temporary increase in congestion for any of the other studied routes (e.g. long-lasting adverse weather, special events, major accidents, etc.).

The congestion index of the more congested routes lies around 1.3 and 1.7 for 2013 and 2104. This is an increase from 2011, where almost all values lay below 1.4. The afternoon congestion of the segment of R44 in town (both directions), however, encountered its worst congestion in 2011, with improvements visible since then. This is substantiated by all congestion measures applied to the probe data. These improvements are most likely not explained by less motor vehicles, but rather efficiency improvements of the traffic signals. This route nevertheless remains amongst the most congested routes in Stellenbosch.

The slowest average travel speeds (highest travel rate) are currently encountered on the studied segment of Dorp Street (both directions) and the routes Bird/Van Reede and vice versa along Piet Retief.

Surprisingly, the comparison of a typical-day traffic to Friday-traffic showed little dissimilarity. On the arterials, peak delay on Fridays (am and pm) differs only slightly to typical-day peak delay. In truth, it is fractions of a minute less. The opposite was observed for the interior roads of Stellenbosch.

The holiday period results in a shift of the peak hour for some routes. Inbound arterials experience far less morning congestion during this time, with a vast decrease in delay occurring on the two ‘problem’ arterials: R304 Bottelary/Bird and R44 Annandale/Van Reede. In-town congestion decreases slightly for most routes.

VI. Conclusion

This paper aimed to quantify Stellenbosch, South Africa, congestion beyond traffic volume counts and personal perception.

To conclude, the current traffic condition in Stellenbosch, gives reason for concern. There are too many vehicles on the extended Stellenbosch road network at specific hours of the day.

The growth of congestion (since 2011) is inconsistent, but present (e.g. inbound peak delay on R44 Kromme Rhee/Bird increased by just over 60% from 2013 to 2014, and this route has become the most congested arterial in the morning). The other two heavily congested inbound arterials (R304 Bottelary/Bird and R44 Annandale/Van Reede) share similar morning congestion levels, but their afternoon outbound congestion has not only intensified over the years, but is almost twice that of R44 Bird/Kromme Rhee.

For 2014, the studied town-outbound segment of Dorp Street (Piet Retief/Adam Tas) has the most severe peak-hour congestion of all the studied routes. There are no alternative routes for its users, as all alternative routes in some way lead to those routes next on the list of most congested routes, for the same time period.

To generalise, the level of congestion on the arterials is worse in the morning (compared to the afternoon), but in-town adverse congestion is variable, tending to occur slightly more in the afternoon, however.

This study has verified the fact that the university and school traffic greatly contributes to the overall traffic-congestion problem in Stellenbosch, as holiday-time inbound morning arterial travel times are on average 54% that of term-time travel times.

The historical nature of Stellenbosch, its prominent aesthetic value and insufficient open land in the CBD, constrain the expansion of the existing road network. Solutions to the problem are thus limited to optimising the efficiency of the current system, but more importantly the search for alternative-mode transport systems (e.g. Park-and-Ride and Bus Rapid Transit schemes).

VII. Further Research

The use of (on-board) probe data is not entirely without cons. Probe data does not reflect on the vehicle type or trip purpose. The analysis of each of their contributions to the congestion should be performed, so that various focus groups can be identified. Solutions for these focus groups should be proposed and the benefits of these solutions assessed.

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ADDENDUM A. CONGESTION MEASUREMENT RESULTS FOR A TYPICAL DAY

Route	Year	Speed Reduction Index		Congestion Index		Travel Rate		Delay Rate		Relative Delay Rate		Delay Ratio	
		am[a]	*pm*[b]	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*
R304 Bottelary/Bird	2011	5.71	2.44	1.33	0.32	1.99	-	0.77	-	0.63	-	0.39	-
	2012	5.11	-	1.05	-	1.97	-	0.60	-	0.43	-	0.30	-
	2013	6.32	2.60	1.71	0.35	2.49	-	1.18	-	0.90	-	0.47	-
	2014	6.17	1.41	1.61	0.16	2.83	-	1.28	-	0.83	-	0.45	-
R304 Bird/Bottelary	2011	1.86	2.52	0.23	0.34	-	1.15	-	-0.08	-	-0.06	-	-0.07
	2013	1.33	2.97	0.15	0.43	-	1.33	-	-0.01	-	-0.004	-	-0.004
	2014	1.55	4.21	0.18	0.76	-	1.57	-	0.27	-	0.21	-	0.17
R44 Kromme Rhee/Bird	2011	4.12	1.68	0.70	0.20	1.39	-	0.22	-	0.19	-	0.16	-
	2012	4.32	-	0.76	-	1.37	-	0.26	-	0.23	-	0.19	-
	2013	5.14	1.61	1.06	0.19	1.70	-	0.52		0.44	-	0.31	-
	2014	6.52	2.54	1.88	0.34	2.17	-	1.09	-	1.01	-	0.50	-
R44 Bird/Kromme Rhee	2011	2.53	2.27	0.34	0.29	-	1.00	-	-0.10	-	-0.09	-	-0.10
	2013	2.21	2.04	0.28	0.26	-	1.04	-	-0.14	-	-0.12	-	-0.14
	2014	1.91	1.62	0.24	0.19	-	1.01	-	-0.20	-	-0.16	-	-0.20
R44 Annandale/Van Reede	2011	5.87	2.08	1.42	0.26	2.12	-	0.87	-	0.70	-	0.41	-
	2012	6.14	-	1.59	-	2.08	-	0.93	-	0.81	-	0.45	-
	2013	6.30	3.06	1.71	0.45	2.21	-	1.04		0.89	-	0.47	-
	2014	6.12	2.94	1.58	0.42	2.08	-	0.93	-	0.80	-	0.45	-
R44 Van Reede/Annandale	2011	2.24	3.41	0.29	0.53	-	1.34	-	0.08	-	0.06	-	0.06
	2013	2.73	3.70	0.38	0.60	-	1.41	-	0.14	-	0.11	-	0.10
	2014	3.21	4.32	0.47	0.77	-	1.48	-	0.28	-	0.23	-	0.19
R310 Baden Powell/Strand	2011	5.37	2.31	1.16	0.30	2.11	-	0.71	-	0.51	-	0.34	-
	2012	5.61	-	1.28	-	2.23	-	0.83	-	0.60	-	0.37	-
	2013	5.97	2.85	1.48	0.40	2.53	-	1.07		0.74	-	0.42	
	2014	3.15	3.04	0.46	0.44	1.38	-	0.03	-	0.02	-	0.02	-
R310 Strand/Baden Powell	2011	2.57	2.65	0.35	0.36	-	1.30	-	-0.07	-	-0.05	-	-0.05
	2013	2.48	2.56	0.33	0.35	-	1.25	-	-0.08	-	-0.06	-	-0.06
	2014	2.72	6.05	0.37	1.76	-	2.35	-	1.02	-	0.77	-	0.44
Adam Tas/Piet Retief via Dorp	2011	5.83	4.96	1.40	0.99	4.71	3.90	1.90	1.09	0.68	0.39	0.40	0.28
	2013	4.85	5.64	0.94	1.30	3.54	4.19	0.94	1.58	0.36	0.61	0.26	0.38
	2014	5.90	5.62	1.44	1.28	4.16	3.88	1.72	1.45	0.71	0.60	0.41	0.37
Piet Retief/Adam Tas via Dorp	2011	5.61	7.86	1.28	3.68	4.16	8.55	1.55	5.94	0.59	2.28	0.37	0.69
	2013	4.14	5.67	0.71	1.32	3.14	4.25	0.51	1.62	0.19	0.62	0.16	0.38
	2014	5.31	7.26	1.13	2.65	3.79	6.49	1.25	3.95	0.49	1.56	0.33	0.61
Bird/Van Reede via Piet Retief	2011	3.70	5.07	0.70	1.19	3.44	4.40	0.34	1.30	0.11	0.42	0.10	0.30
	2013	4.96	5.25	0.99	1.11	3.74	3.97	1.05	1.28	0.39	0.47	0.28	0.32
	2014	5.12	4.12	1.05	0.70	4.75	3.95	1.44	0.63	0.43	0.19	0.30	0.16
Van Reede/Bird via Piet Retief	2011	4.35	5.05	0.77	1.04	3.82	4.36	0.74	1.28	0.24	0.41	0.19	0.29
	2013	6.08	5.95	1.55	1.47	4.69	4.53	2.06	1.91	0.79	0.73	0.44	0.42
	2014	*-6.52*	*-3.66*	*-0.39*	*-0.27*	*3.82*	*4.62*	*-5.20*	*-4.40*	*-0.58*	*-0.49*	*-1.36*	*-0.95*

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Bird/Van Reede via R44	2011	6.55	7.57	1.90	3.21	3.55	5.04	1.80	3.29	1.03	1.88	0.51	0.65
	2013	6.27	6.48	1.68	1.84	3.46	3.67	1.62	1.83	0.88	0.99	0.47	0.50
	2014	6.30	6.51	1.70	1.86	3.42	3.63	1.61	1.82	0.89	1.00	0.47	0.50
Van Reede/Bird via R44	2011	6.55	6.83	1.90	2.23	3.27	3.56	1.66	1.95	1.03	1.21	0.51	0.55
	2013	7.80	6.26	3.54	1.74	6.06	3.57	4.15	1.67	2.18	0.87	0.69	0.47
	2014	6.08	6.24	1.55	1.71	2.93	3.06	1.29	1.42	0.78	0.86	0.44	0.46

[a.] 7-8am.

[b.] average of 4-5pm and 5-6pm.

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