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## The Evaluation of Traffic Control in Changsha City

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### Abstract

Different aspects of the traffic control system in the CBD of Changsha have been evaluated. A general issue is the safety conditions, which are evaluated qualitatively. The second issue is the low saturation flow observed on the intersections, that appear to be 20 to 30% lower than the ones in comparable situations in Europe or North America. Travel times could be determined rather well using GPS data from taxis. That method was validated using video observations. Bluetooth scanners have been tested for the measurement of travel time, but they appear less suited in urban areas. The paper evaluates the accuracy and reliability of the loop detectors in the traffic control system SCATS. Lastly, the signal timing of a 13-nodes network in the CBD of Changsha has been optimized with TRANSYT-14. This optimized (fixed time) control showed a significant better performance than the control by the SCATS system.

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### 1. Introduction

Changsha is a medium sized city in the centre of China with about 6.46 million inhabitants. Motor vehicles ownership is more than one million. Every day 800 new cars are sold, i.e. a yearly growth of at least 16% in car ownership. The congestion problem is serious at this moment and given the fast growth

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of the number of cars, the future of the urban accessibility is in danger. If the municipality does not take appropriate measures, the accessibility of the city, especially the downtown area, will be jeopardized. The extension of the road network in Changsha's CBD is nearly impossible, just the ring road around the city centre will be rebuilt and some new tunnels will be built under the river to improve the connection between the East and West parts of the CBD. The arteries, and especially the intersections inside the ring have to be utilized as good as possible.

The initial objective of the project was to assess the quality of a new traffic management system in the city centre. Recently, a network control system SCATS has been installed. The utilization of the intersection has been optimized by the reduction of the lane width (usually 3.50 m for traffic with a maximum speed of 50 km/h, which is wider than necessary for urban traffic) at the intersection so that the number of lanes could be increased. One roundabout has been converted into a signalized intersection. This upgrading of the intersection geometry has had positive effects, but compared to the standards in other countries one still can see many opportunities for improvement. A comparison of the performance of intersections in Changsha with similar intersections in other countries, especially in The Netherlands, shows that the structure of the signal control can be improved and that the saturation flow is much lower. The traffic control as implemented with the SCATS system is being evaluated by several means:

- 1) video recordings of 13 relevant intersections,
- 2) measurement of the saturation flow rates of 113 lanes from the video recording,
- 3) measurement of travel time distributions on the links between the intersections by probe vehicles (taxi with GPS that report their positions every 30 s), some dedicated probe vehicles with GPS that registered 3 times per second, cumulative counts on two special links and Bluetooth scanners),
- 4) simulation of the network with VISSIM, where VISSIM was calibrated for the specific behavior of the Chinese drivers,
- 5) analysis of the rerouting possibilities using a dynamic traffic assignment model (using Dynameq,
- 6) redesign of the traffic control schemes with a computer program VRIGEN,
- 7) re-optimization of the signal coordination using TRANSYT and MAXBAND,
- 8) analysis of characterization of urban traffic congestion by Taxi GPS data.

In this paper we will shortly specify the following elements of the evaluation:

- a) traffic safety at the signalized intersections,
- b) saturation flow measurement,
- c) delay and travel time measurement,
- d) evaluation of the quality of the detector data, and
- e) a re-optimization of the signal timing using TRANSYT-14.

## 2. Safety

Traffic signals should improve road safety, especially for the vulnerable road users. An adequate traffic control scheme, good visibility of the signals, appropriate intersection geometry and the exclusion of dangerous conflicts reduce the risk of dangerous situations. Traffic accidents at road junctions are nearly always caused by the behavior of drivers and other road users, but a good design of the roads, intersections and traffic control reduce the possibilities for dangerous actions and should reduce the chances that risky behavior results in serious accidents (Chen et al. 2009)..

In Changsha several opportunities for improvement have been identified, both in the layout of the intersections and the visibility of the signals. Since the lane width at many intersections has been reduced and lanes have been added over a short stretch of the links, the changes in lane widths and number of lanes causes frequent lane changing with considerable risks. Furthermore, the lane markings are discontinuous. The left and right turning traffic is often controlled in such a way that pedestrians have a

green signal while the conflict with turning vehicles is possible. The common assumption that a conflict free traffic control at an intersection reduces the capacity and creates additional congestion is not always true. A careful design and optimization of the traffic control can result in the same capacity of the intersection while all conflicts are controlled.

While the conflicts between streams of motorized traffic are controlled by the signals, the conflict with pedestrians still remains. Even in the case that this conflict is controlled by the signal, disobedience of the drivers often occur, bringing crossing pedestrians in danger. Since drivers do not sufficiently obey the traffic rules, the traffic safety is a serious problem. This has the consequence that drivers are cautious when driving over intersections, because they have to anticipate other drivers to disobey the rules and give a conflict with them. This is one of the reasons that saturation flows are lower in the studied intersections in Changsha and also in some other Chinese cities than those in the Western world (Li et al 2011).

The disobedience of drivers has been registered and it appears indeed that the number of such actions has a relationship with the traffic performance, i.e. the more disobedience occurs on an intersection, the lower the saturation flow is.

### 3. Saturation flow measurement

Saturation flows at intersections are an important characteristic of an urban road system. A few methods exist to measure saturation flow rates, but it is not often done in practice. Branston and van Zuylen (1978) developed a method based on multiple linear regression. The basic measurement is the counts of vehicles in fixed time periods, e.g. 5 seconds intervals. In the regression method it is essential that the observation time interval used for the determination of the saturation flow are all fully saturated. Van Zuylen and Li (2010) defined another method, the product limit method, in which also under-saturated time periods can be used. The method defined in the Highway Capacity Manual (HCM 2000) does not measure saturation flow rates but average headways. Conversion of the average headway to saturation flow rates gives a bias due to the variance of the headway (van Zuylen and Li 2010).

The pcu values for busses and trucks can also be directly determined by the regression method or by comparable methods such as the headway ratio (Kimber et al. 1985) or the minimization of differences between observations and model (Radhakrishnan et al. 2009).

In this study, the saturation flow was measured from video observations of the intersections. Meta-analysis reveals certain important characteristics. First of all, the saturation flow rates are 20 to 30% lower than the saturation flow rates of similar intersections in The Netherlands (van Zuylen and Li 2009, Li et al. 2011). The standard deviations are also larger in Changsha and, obviously, also the standard deviations of the headways.

The saturation flows appear to be dependent on the intersection size: lanes on larger intersections (> 4 lanes per approach) have a larger saturation flow rate than smaller intersections. There is also an influence of the lane width and the traffic flow rate:

$$s = 949.184 + 147.6 * Lw + 91.5 * INTs + 0.262Q \quad (1)$$

where  $s$  is the saturation flow rate [pcu/h/lane],  $Lw$  is the lane width [m],  $INTs = 1$  for larger intersections and  $0$  otherwise and  $Q$  is the flow rate on the lane [pcu/h/lane].

The influences of the intersection size and the traffic flow rate have not been reported in literature before. In the present signal control scheme no all red clearance times are given. The conflicting vehicles at the intersection increase the start lag with 0.33 s per conflicting vehicle. That means that in general the absence of an all red phase increases the capacity of an intersection. Furthermore we found that lane changing on a short distance before the intersection reduces the saturation flow with 1.4 vehicles for each lane-changing maneuver.

#### 4. Measuring the delays and travel times

Travel times in Changsha can be measured most easily by using GPS data from the 6000 taxis. Before we could do that we had to validate this methodology. The taxi data had to be processed to derive trajectories, the accuracy of the trajectories had to be assessed and the quality of the measured travel times had to be analyzed.

We compared the taxi GPS data with the data obtained from another GPS device, which collected its data 3 times per second. The consistency was very good, no significant differences were found as can be seen in Fig. 2.

The taxi GPS is registered only every 30 seconds. The passing moments of the beginning and end of a link has to be determined by interpolation. Since the GPS data do not only contain position but also speeds, the interpolation could be made using both data. The accuracy is more than sufficient ( $< 1$  s).

The question whether the travel times measured by the taxi GPS were valid was analyzed by an independent test. In that study, video movies were made on two links. From the movies the cumulative counts were made and from the cumulative counts the average travel times were determined. This was compared with the travel times from the taxi GPS.

The consistence between both methods is satisfactory.

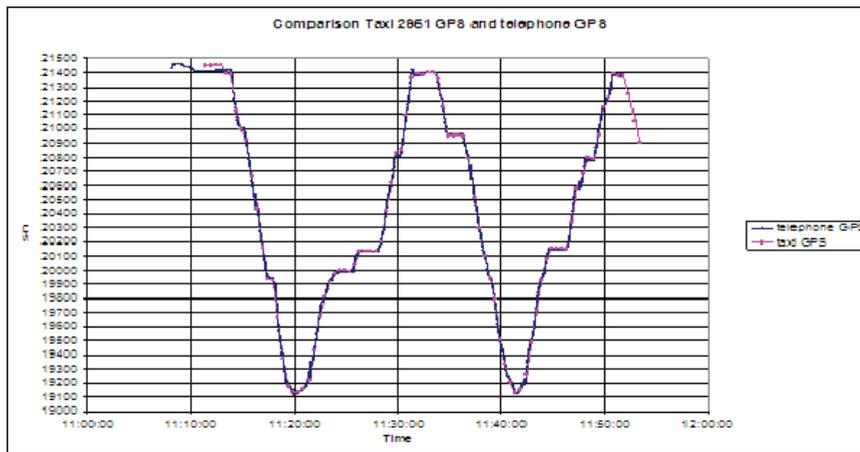


Fig. 2. Comparison of trajectories measured by the taxi GPS and an independent high frequency GPS

Table 1 Comparison of the measurements of travel time with the cumulative count method and GPS

Traffic Direction	Distance (m)	Average travel time by Cumulative Counts (s/veh)	Average travel time by GPS Data(s/veh)	Relative Error (%)
The east second ring road	South-North	108	106	1.9
	North-South	68	66	3.0
The third bridge of Xiangjiang River	East-West	107	103	3.8
	West-East	123	119	3.3

We also verified the relation between average travel time and average speeds on a link. For one link we found a strong correlation between the inverse of the average travel time and average speed. This means that an analysis of the average speeds might be suited for the assessment of the traffic state, e.g. travel time. An example of taxi GPS speed is illustrated in Fig. 3.

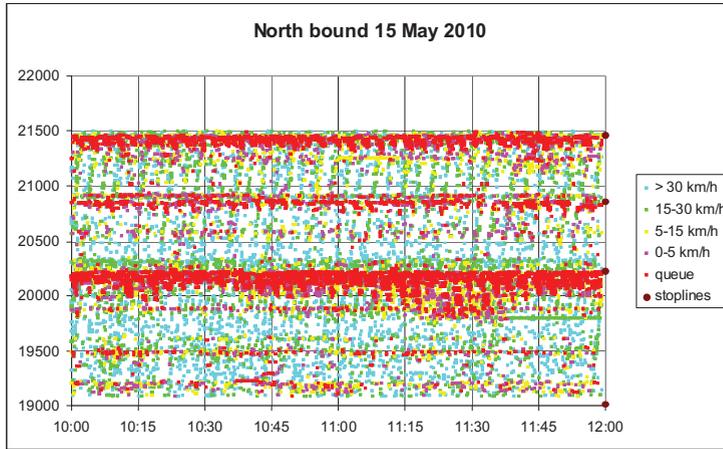


Fig. 3. Speed data from taxis travelling Northwards (towards the intersection at position 21500)

Recently the method to determine travel times with use of Bluetooth scanners has become popular. Bluetooth scanners identify passing vehicles when a Bluetooth device is on board (Granig and Young 2009). A comparison of the GPS travel time data with Bluetooth measurements shows that Bluetooth scanners are less suited in urban environments (Li et al. 2011). The main reason is that many vehicles deviate from the straight route to park, turn to another road and come back later etc. Furthermore there is the uncertainty whether a Bluetooth device that is registered is carried by a motorized vehicle or by a pedestrian or cyclists. On roads with congestion a pedestrian might be faster than a car! The elimination of outliers is rather easy for GPS data but difficult for Bluetooth since the valid data and the outliers have overlapping distributions.

The GPS data from taxis successfully have been used to calibrate and validate travel time models (Zheng and van Zuylen 2012).

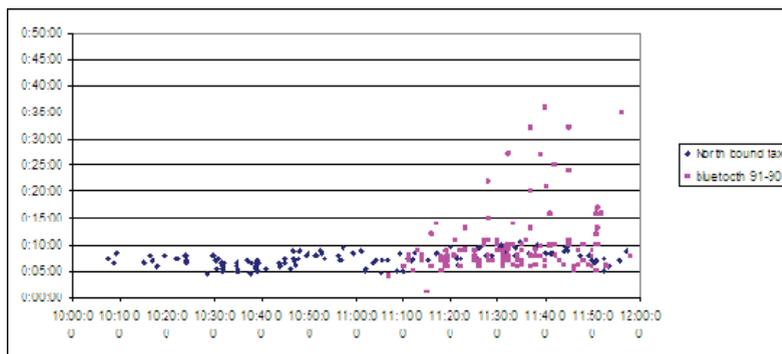


Fig. 4. Travel times of taxis and vehicles with Bluetooth. The outliers of Bluetooth cannot easily be eliminated

### 5. Evaluation of the quality of the detector data

Since SCATS is a closed loop control system, the detector data should be sufficiently accurate for an estimation of the flows and degree of saturation.. In order to assess the quality of the detector data, the traffic volumes counted by the loop detectors and used as input for SCATS have been compared with the counts obtained from video recordings. Both counting procedures have been carefully synchronized. The morning peak (8:00 to 10:00) of May 14, 2010 was used for the evaluation. Total traffic volumes have been counted on 208 lanes. Not all the investigated lanes have loop detectors: only 164 lanes (78.84%) have loop detectors installed. Among these detectors, only 142 loop detectors were working on the day of the survey. A check of the SCATS dataset shows that these 142 loop detectors created and sent data on 78.48% of the periods of the survey day (Fig. 5).

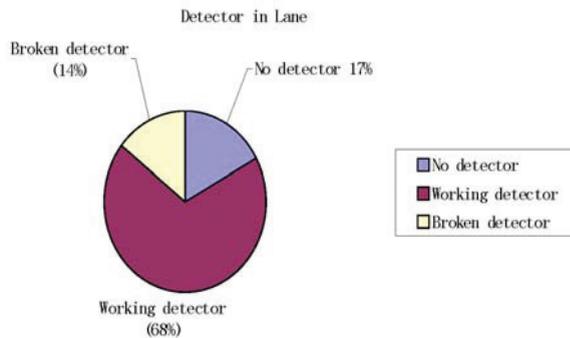


Fig. 5. Status of the detection of different lanes in the area controlled by SCATS



Fig. 6. The proportion of error rates of the working detectors

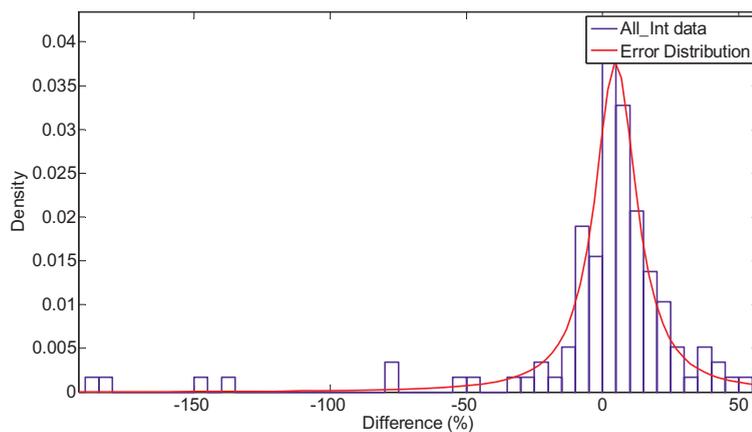


Fig. 7. Probability distribution of the errors of the working detectors in the area controlled by SCATS

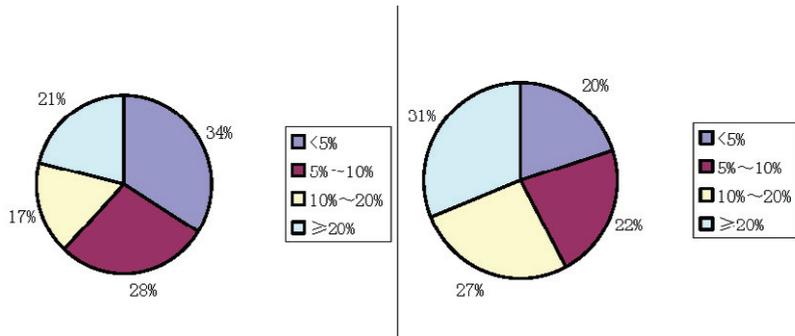


Fig. 8. Proportion of error rates in the detectors data on lanes with only through going traffic (left) and lanes with mixed utilization (through going and turning).

After comparing the volume data from the loop detectors and the volume data from the video movie in the same period on 14, May, all 142 loop detectors data errors have been statistically analyzed. The results are shown in the following Figs. 6 and 7.

The character of the detector data errors is a little different in different lanes and the comparison between lanes with only going through traffic and lanes that carry both through going and turning traffic (mixed lanes) are shown in the following Fig. 8.

The conclusion from the check on the loop detectors is that the reliability of these detectors should be improved in order to give good input to the SCATS system and that use of loop detectors for statistical purposes is only warranted when the quality of the data is well controlled.

Furthermore, SCATS should be robust with respect to data errors: if the detectors are not working well, the control system should still keep a satisfactory performance by applying ‘graceful degradation’.

## 6. Re-optimization of the signal timing using TRANSYT-14

In 2009, SCATS traffic control system has been installed at 99 intersections in the CBD of Changsha. The principle of SCATS is to adjust saturation of the green time saturation by adjusting the cycle time and green time. Furthermore, SCATS can couple the signals of adjacent intersections by imposing coordination in one direction. However, SCATS does not execute any optimization such as the minimization of a Performance Index (PI), such as e.g. delay, vehicle queue length, stop rate, etc. Although SCATS is an closed loop control system, using traffic measurements as input for the selection of control parameters, it is not an optimizing control system. The system performance of SCATS was evaluated by a comparison with an alternative network traffic control. We optimized the signal timing using TRANSYT-14 and compare the SCATS plan and TRANSYT-14 plan. The evaluation road network is a 13-nodes network in downtown of Changsha, illustrated in Fig. 9.

For the optimization of the signal timing we have used the “full optimization” mode of TRANSYT-14. The optimization parameters are offsets and green splits. The optimization has been done with the Hill Climb method.

Transyt-14 determined an optimized common cycle time of 138 seconds. For evaluating the original SCATS plan, we have used the “evaluation” mode of TRANSYT-14, which only runs the signal timings exactly as entered and doesn’t perform an optimization. The SCATS signal timing has been obtained directly from the SCATS system. The results are compared in Table 2.

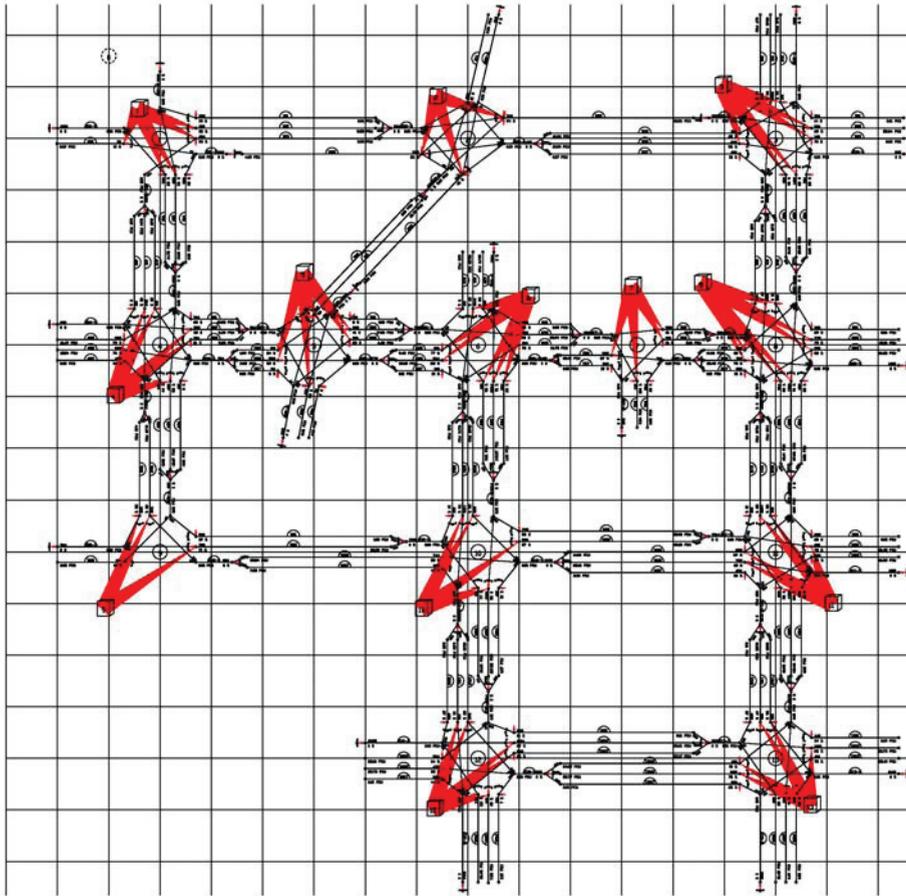


Fig. 9. The 13-nodes evaluation road network by TRANSYT-14

Table 2. comparison of the performance of the fixed time settings optimized by TRANSYT-14(left) and the signal settings of SCATS (right)

	Full optimization mode	Evaluation mode
Common cycle time (s)	138	No common cycle time
Total network delay [PCU-hr/hr]	649.86	928.72
Highest Degree of Saturation [%]	89.95	133.54
Number of oversaturated LTS	0	10
Network within capacity	Yes	No
Mean delay per PCU [s]	18.11	26.03
Mean stops per PCU [%]	35.94	36.68
Mean journey speed [kph]	24.06	20.67

From Table.2, we can see the optimization by TRANSYT results in a better traffic performance, with less delay, lower degree of saturation, and higher mean speed.

## 7. Conclusions

The paper analyzes that the road and intersection design and control in Changsha. Some opportunities for improvement have been found. The lane width and number of lanes that suddenly change on a short distance from intersections makes lane changing necessary, which decreases the saturation flow. Allowing partial conflicts, especially between motorized traffic and pedestrians create risky situations. Furthermore, the placement of traffic signals can give confusion: drivers cannot clearly see which signals apply to which streams.

The saturation flow at intersection is 20 to 30% lower than what is observed in European and (North) American countries. If this could be improved, the network capacity could handle the growth of the traffic for about 1 or 2 years.

The paper shows that the travel times are well estimated by the use of GPS data from taxis. The accuracy and reliability is good and the data can be used to calibrate and validate traffic network models. The loop data that have to provide SCATS with input for the selection of control parameters, is not very reliable. The consequence is that SCATS has to be robust with respect to failing detectors.

Finally, the study showed that performance of traffic control can considerably be improved if a program like TRANSYT-14 is used to optimize the signal setting. The degree of saturation becomes about 40% less in the peak hour, which means that more traffic can be handled.

Still the improvement of the traffic situation with about 50% is still only a postponement of the accessibility problems. A yearly growth of 16% will absorb the possible improved performance in 3 years. The question is whether the growth will continue to the level of Beijing (5 million cars on 22 million population) or even surpass that level. In any case, the traffic situation and especially the accessibility of the city center is a challenge now and in the future.

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## References

- Binning, J., Crabtree, M., Burtenshaw, G., (2010). "Transyt 14 user guide", *Transport Research Laboratory, United Kingdom*.
- Branston, D., H.J. van Zuylen (1978). The estimation of saturation flow, effective Green time and passenger car equivalents at traffic signals by multiple linear regression. *Transpn Res.* Vol 1. 12, P47-53
- Chen Y., Guo J., Yuan A., Wang S., Wang Z., Meng H. (2009). "Design and Operational Guide for Vulnerable Road User Safety at Junctions", *Global Road Safety Partnership Office China*; [www.GRSProadsafety.org](http://www.GRSProadsafety.org).
- HCM (2000). Highway Capacity Manual - 2000, Transportation Research Board, Washington, D.C.

Kimber, R.M., M. McDonald, N. Hounsell (1985). Passenger car units in saturation flows: Concept, definition, derivation. *Transpn. Res:B* Vol. 19B, No. 1, pp. 39-61.

Li, J, Van Zuylen, H.J., Chen, Y,& Lu, R (2011). “Comparison Of Driver Behavior And Saturation Flow In China And The Netherlands”, To be published in *ITE journal ITS*

Li J., Van Zuylen, Liu Chunhua, Lu Shoufeng (2011). Monitoring travel times in an urban network using video, GPS and Bluetooth. 14th Meeting of the Euro Working Group on Transportation, *Procedia - Social and Behavioral Sciences*, Vol. 20, pp. 630-637.

Radhakrishnan, Padmakumar, Tom V. Mathew (2009). Passenger car units and saturation flow models for highly heterogeneous traffic at urban signalised intersections. *Transportmetrica*, 1944-0987

Van Zuylen, H.J., Chen, Y, Li, J & Lu, R (2009). “A comparison of driver behavior and saturation flow between China and the Netherlands”. In s.n. (Ed.), *Proceedings 16th ITS World Congress* , Stockholm: Ertico ITS Europe.

Van Zuylen H.J., Li Jie (2010). Measuring the saturation flow, lost time and passenger car equivalent values of signalized intersections”. In B. Mao, Z. Tian, H. Huang and Z. Gao Eds. *Proceeding 7th International Conference on Traffic and Transportation Studies Reston USA: ASCE*, 312 – 329.

Zheng, F., Van Zuylen H.J. (2012). A Link travel time distribution prediction on urban signalized roads, *Transportation Research Board 91<sup>st</sup> Annual Meeting*, Paper #12-0286, Washington DC, Date: 2012-1-22 to 2012-1-26.