A) **Left side driving countries**

1. **A study of the left-turn-on red (LTOR) traffic light scheme in Singapore**
   Sebastian, Beck
   Final year project, Nanyang Technology University, Singapore, 2015
   Since 1997, the LTA has been implementing the Left-Turn-On-Red (LTOR) traffic control scheme at selected signalised junctions in an attempt to increase left-turning capacity and reduce stationary time delays. The number of implementations numbered 44 in 2003. Currently, only 16 remain mainly because of a change in junction design and a general increase in pedestrian traffic in Singapore. In the past, this scheme has generally been shown to improve flow and lessen waiting time. However, a vehicle turning left on a red light theoretically poses an additional risk to some parties. Theoretically the main at-risk parties are a) pedestrian on a crossing with the green man showing, directly in front of the left turning vehicle and; b) the oncoming traffic heading straight on the adjoining roadway.

   The objective of this project is to assess both the effectiveness of the scheme in reducing delays at signalised junctions and the propensity of LTOR to encourage the above stated theoretical associated risks. Two signalised junctions were selected for this study. A field survey was done at each site by gathering footage and reviewing it on a monitor. Data gathered included information on general vehicle and pedestrian numbers, vehicle movement and signal compliance and road user interaction as a result of LTOR.

   It was discovered that LTOR is effective at providing the opportunity to turn for more than half left-turning vehicles before the green light as long as a dedicated lane is provided. At the junction using a shared left turn lane where only 1/3 of the traffic was turning left, little benefits were seen. It was observed that <10% of motorists were still not aware of the existence of this scheme as they failed to turn given appropriate circumstances.

   A key issue with the safety of this scheme is the fact that over 80% of vehicles which manage to turn on red violate the scheme by stopping beyond the stop line. 1/3 did not stop at all. Another problem noted includes the highly prevalent tendency of vehicles to creep into the junction unnecessarily.

   The number of cycles containing both non-compliant drivers and pedestrians was recorded. In total this overlap occurred in 16% of cycles. Over the 3 hours, that resulted in a maximum possible number of 25 opportunities for a collision to occur. There were 3 conflicts where the LTOR vehicle had to stop harshly and 1 conflict where a pedestrian chose to run across the junction.

   In all, the LTOR scheme clearly provides a benefit to left-turning vehicles. However, given that the scheme is necessarily restricted to those few junctions with low vehicle and pedestrian volume, its utility is questionable. The accident risk especially in these locations is undoubtedly as marginal as the advantages of the scheme.

   [https://repository.ntu.edu.sg/handle/10356/63403](https://repository.ntu.edu.sg/handle/10356/63403)

2. **Left turn on red (LTOR) scheme**
   Land transport Authority (LTA) Singapore
   The LTOR scheme is implemented at selected junctions. It allows motorists on a minor road to turn left onto the main road during a red signal when it is safe to do so.

   [https://www.onemotoring.com.sg/content/onemotoring/en/on_the_ roads/traffic_management/left_turn_on_r](https://www.onemotoring.com.sg/content/onemotoring/en/on_the_roads/traffic_management/left_turn_on_red)
3. **Left Turn on Red project**  
**Brisbane City Council**  
Brisbane City Council has introduced Left Turn on Red facilities across Brisbane following a successful trial at five intersections between November 2013 and April 2014. Overwhelming support for these facilities was received both from the wider Brisbane community and local residents who used the trial intersections. The Left Turn on Red facilities at intersections across Brisbane is a practical way of decreasing individual travel times and easing congestion, contributing to our vision for an accessible, connected city. All Left Turn on Red intersections were selected after being assessed for safety against Australian Standard requirements. (website)  

4. **Left turn on red traffic scheme in Singapore**  
**Wong, YD; Ho, JS, Foo, HYT**  
In 1997, left-turn-on-red (LTOR) was introduced in Singapore to permit motorists to turn left on a red traffic signal after stopping and giving way to conflicting vehicles and crossing pedestrians. More than 40 LTOR traffic controls currently are in operation in the country. Singapore operates a right-hand drive system, so Singapore's LTOR scheme is functionally the same as the right-turn-on-red scheme in the United States. This article describes the implementation of the LTOR scheme in Singapore and reports the results of an evaluation study on the vehicle stopped delay and accident experience at LTOR intersections. The vehicle stopped delay data were collected at the LTOR approaches of three intersections during three periods: within a month before LTOR implementation, between 6-12 months after, and several years after LTOR implementation. The results showed that traffic on the LTOR approach experienced a significant reduction in stopped delay soon after LTOR implementation, followed by minor changes in the long run. Fatal and injury accident crash situations located within 20 meters of the intersections were examined for 36 LTOR intersections that had accident data for at least 12 months after LTOR implementation. LTOR intersections generally had relatively low accident occurrences, but about three in five intersections experienced an incremental increase in accident occurrences after adopting LTOR. These results suggest that the LTOR scheme should continue to be monitored in order to establish its feasibility for continued application and possible expansion.  
[https://pdfs.semanticscholar.org/8b31/f4f2be6860539bfc370cafa8dd7b31169cc1.pdf](https://pdfs.semanticscholar.org/8b31/f4f2be6860539bfc370cafa8dd7b31169cc1.pdf)

5. **Traffic signal design : appendix E left turn on red**  
**Roads and Maritime services (NSW), 2016**  
The traffic signal design guidelines have been developed to assist in designing traffic control signals. The information contained in the various parts is intended to be used as a guide to good practice. Discretion and judgement should be exercised, taking into account all the factors that may influence the design of traffic signals at any particular site. The guidelines make reference, where relevant, to current Australian Standards or the Austroads Guides, and are intended to supplement and otherwise assist in their interpretation and application. If any conflict arises, the Australian Standards, the Austroads Guides and the RMS Supplements are to prevail. (website)  

**B) Right side driving countries**

1. **Empirical Study of Gap-Acceptance Behavior of Right-Turn-on-Red Drivers on Dual Right-Turn Lanes**  
**Chen, Xiaoming; Qi, Yi; Liu, Guanqi**  
Operational performance of right-turn-on-red (RTOR) at signalized intersections is a function of drivers’ gap-acceptance behavior. The objective of this study is to characterize gap-acceptance behavioral patterns of individual RTOR drivers turning from dual right-turn lanes. On the basis of direct field observation, binary logit models were developed, calibrated, and validated, and the attributes that have significant effects on gap-acceptance decisions were identified. The proposed model showed an improved capability of predicting gap-acceptance decisions as opposed to conventional, deterministic methods that
may overrepresent aggressive drivers, whereas the deterministic method represents a reasonable trade-off between accuracy and ease of use for dual right-turn lanes. For RTOR drivers turning from a curb right-turn lane, the critical headway decreases on average as they are waiting for an acceptable gap. RTOR drivers turning from an inside right-turn lane did not demonstrate statistically significant evidence of increased impatience while waiting.


2. **Estimating potential conflicts between right-turn-on-red vehicles and pedestrians at crosswalks**
   Kim, Wonho; Kim, Gur-joong; Lee, Dongmin
   The conflict between vehicles and pedestrians at crosswalks, defined as a potential collision that could lead to actual traffic accidents, is an important measure indicating the level of pedestrian safety. Past research, with advanced statistical methods, gathered and calibrated data from historical accidents to produce this important policy indicator. To perform such statistical analysis, however, requires a considerable amount of samples collected under controlled conditions. Putting aside the difficulty of creating a controlled condition, it is difficult to apply the model in different locations with various physical conditions. These are critical limitations in practice. This study aims to overcome these issues and develops an analytical model for estimating the conflict between vehicles and pedestrians. Since the proposed model considers pedestrian behaviour at crosswalks rather than actual collision samples, only a small number of field data are required. It appears that our model can be replicated to different times and places with a bias that is statistically insignificant.

3. **Estimating Right-Turn-on-Red Capacity for Dual Right-Turn Lanes at Signalized Intersections**
   Chen, Xiaoming; Qi, Yi; Li, Da
   Transportation Research Record, 2012, December, Vol. 2286, No. 1, pp.29-38
   Dual right-turn lanes are increasingly used as a design alternative at urban intersections, primarily to accommodate high right-turn demand. For dual right-turn lanes, an accurate estimate of right-turn-on-red (RTOR) capacity can contribute to better decisions about whether RTOR should be allowed or prohibited and may lead to refined delay estimation and improved signal timing. A gap-acceptance model was formulated for predicting lane-specific RTOR capacities at dual right-turn lanes. The proposed model can represent the unequal effects of conflicting traffic streams from different cross-street lanes on RTOR capacities of dual right-turn lanes. Existing probabilistic methods were adapted to adjust RTOR capacity for shared through and right-turn lanes. Microsimulation models were developed, calibrated based on field data, and used as benchmarks to validate the proposed model. Numerical experiments indicated that the proposed model exhibits a significantly improved ability to predict RTOR capacities for dual right-turn lanes compared with the classical Harders model.

4. **Is there a spill over effect of a right turn on red permission for bicyclists?**
   Ceunynck, Tim De; Daniels, Stijn; Vanderspikken, Bert ; Kris Brijs; Hermans, Elke; Brijs, Tom; Wets, Geert
   A number of countries allow bicyclists to perform a right turn on red (RTOR) at some specific intersections to promote cycling by reducing the required physical effort and trip time. Implementation of a rule that allows a RTOR for bicyclists at some intersections could lead not only to local effects at those intersections where the rule actually applies, but also to supralocal effects. Using an experimental survey approach, this study explores whether a so-called ‘spillover effect’ of the rule can be expected. This effect would imply that allowing bicyclists to turn right on red at some intersections causes them to also turn right on red more often at intersections where RTOR for bicyclists is not allowed. The answers from 768 respondents indicate that respondents with a high awareness of the existence of a RTOR rule for bicyclists (experimental group) turn right on red significantly more often at intersections where RTOR for bicyclists is not permitted than respondents with a low awareness of the rule (control group). This indicates that implementation of the RTOR rule for bicyclists can indeed lead to an increase in red light running at other intersections. This might lead to safety issues at intersections where RTOR for bicyclists is not permitted, since road authorities could have decided not to allow RTOR for bicyclists at these intersections for safety reasons. The study also finds that men, young people and people who generally perform more risky cycling behaviours have a higher tendency to perform non-permitted RTOR. These findings are in line with existing literature.
5. **Probability Model for Understanding the Effects of Detector Delays on Right-Turn-on-Red Traffic**

Zeng, Xiaosi; Zhang, Yunlong; Songchitraks, Praput
Transportation Research Record, 2013, December, Vol. 2355, No. 1, pp. 73-82

Detector delay as a useful detector timing feature is often recommended for minimizing disruptions on major movements caused by one or more minor movements. However, this benefit of detector delay is not always certain because the applicability of detector delay is subject to a combination of gap demand, gap availability, critical gap acceptance, follow-up headways, and other factors. The improper use of detector delay could be costly to traffic on minor streets. With little literature on the subject, the complex relationship between detector delays and different critical factors has not been fully understood. An analytical model that estimates the probability of clearing right-turn-on-red queues within the period of detector delay is presented. This probability is the first step toward an understanding of how this detector feature affects an intersection’s operational efficiency. The gap-finding process of multiple right-turn-on-red vehicles is divided into several realistic cases and analyzed in detail. Insights about the process described in each case are applied to derivation of a probability model. Validation of the model is conducted with more than 4,000 simulation runs. A close fit is found between the computed probability and the simulated data with errors no larger than 5.7% of the targeted values. The method for deriving the probability model provides a stepping-stone toward deriving the delay distributions for right-turn-on-red traffic.

https://trrjournalconline.trb.org/doi/pdf/10.3141/2355-08

6. **Right-Turn-on-Red Flow Profile Impacts on Urban Street Capacity Analysis**

Hale, David K; Ma, Jiaqi; Kondyli, Alexandra; Hu, Jia; Huang, Zhitong; Su, Peng
Transportation Research Record, 2016, September, Vol. 2553, No. 1, pp. 29-40

The Highway Capacity Manual 2010 (HCM 2010) contains computational procedures for evaluating traffic operational efficiency of urban street segments. These procedures have been implemented within several commercial software packages and are likely used by thousands of engineers and planners across the United States. The procedures for urban street capacity analysis contain no logic for handling right turns on red (RTORs) or for handling special cases of RTORs such as shielded and free right turns. A new proposed RTOR modeling framework is described for urban streets in the HCM 2010. When significant upstream RTOR flows exist, the proposed logic is designed to generate more realistic flow profiles. Three types of experimental results are presented: they demonstrate the improved modeling accuracy of the proposed logic. First, it is shown that macroscopic flow profile shapes are now more visually sensible because they now illustrate RTOR flows moving at the appropriate times. Second, macroscopic flow profile shapes are now more consistent with microscopic vehicle trajectories. Third, a statistical analysis shows that when the proposed logic is used, HCM 2010 performance measures become more consistent with the performance measures generated by microsimulation. Finally, case study results show that when the proposed RTOR logic is not used, control delays are sometimes be inaccurate by more than 30%. Given the experimental evidence presented, it is urgent that the proposed improvements be adopted and implemented so that RTOR corridors can be accurately analyzed by the HCM 2010 procedures.

7. **Right-Turn-on-Red Volume Estimation and Incremental Capacity Models for Shared Lanes at Signalized Intersections**

Creasey, F; Stamatiadis, Nikiforos; Viele, Kert
Transportation Research Record, 2011, December, Vol. 2257, No. 1, pp.31-39

The Highway Capacity Manual (HCM) is one of the most widely used transportation documents in the world. The signalized intersections methodology, one of the most frequently used portions of the manual, is used to estimate capacity and average control delay for individual lane groups and for intersections as a whole. The method does not estimate control delay for vehicles permitted to turn right on red, nor does it include these vehicles in the computation of capacity. It is recognized that vehicles making right turns on red (RTORs) increase intersection capacity. Thus, capacity, delay, and level of service may not be predicted accurately when RTORs occur. For the specific case in which a shared through and right-turn lane exists and RTORs are permitted, models were developed to estimate the number of RTORs that can be expected and the additional capacity that is realized. The models are deterministic and are consistent with the HCM methodology, are easily understood by analysts, produce reasonable results, and account for the probabilistic nature of RTORs occurring from shared lane approaches. The capacity model also demonstrates that, where RTORs are permitted and do occur, the HCM method results in an