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A DATA-DRIVEN APPROACH TO IMPROVE SIGNALISED JUNCTION SAFETY USING SCATS VARIATIONS

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Abstract

Safety performance at signalized intersections is intrinsically linked to the design of phasing sequences and the inter-green logic that governs vehicle movements. While adaptive systems such as the Sydney Coordinated Adaptive Traffic System (SCATS) are widely recognized for optimizing operational efficiency, their existing variation logic rarely incorporates explicit safety objectives. This study introduces a data-driven framework that embeds safety considerations into SCATS variations and action-list configurations to proactively reduce potential conflicts and the likelihood of red-light violations. Comprehensive operational data from the Doha SCATS network with more than 450 intersections were analyzed to identify phase patterns associated with elevated safety risks. Statistical examination of traffic demand profiles, phase-change frequencies and accidents/violation records revealed that the straight–straight phase during off-peak and night-time periods exhibited a disproportionate incidence of red-light entries and intersection conflicts. Based on these findings, a new safety-oriented variation strategy was developed, designed to skip the straight–straight phase under low-demand conditions, introduce extended all-red clearance intervals, and employ split-phase operation to eliminate opposing flow conflicts. Field implementation was conducted across selected Doha corridors, supported by pre- and post-intervention datasets, high-resolution SCATS data and video-based conflict analysis. The safety-driven variation achieved a reduction in red-light-entry probability and a decrease in identified conflict and high-risk points, with negligible increase in average operational delay per vehicle. The results demonstrate that targeted adjustments to SCATS variation and action-list logic can significantly enhance intersection safety without extra onsite works and compromising network efficiency. The paper concludes with a generalizable methodology for integrating safety performance indicators into adaptive traffic-signal control environments.

Keywords: SCATS, safety, red-light violations, synchro, decision support

1 Introduction

Over the last several decades, adaptive traffic signal control (ATSC) systems such as the Sydney Coordinated Adaptive Traffic System (SCATS) have become widely adopted as a means of improving operational efficiency in congested urban environments. SCATS and similar systems adjust cycle length, splits and offsets in real time based on detector occupancies and degree of saturation, with well-documented benefits in delay, travel time and reliability relative to fixed-time or simple actuated control [1, 2]. Empirical evaluations indicate that SCATS deployments can reduce delays and improve corridor-level performance, and some studies have also reported reductions in total and injury crashes [3-5]. Signalized intersections are among the most safety-critical elements of urban road networks, accounting for a substantial share of severe crashes, particularly those involving turning conflicts and red-light running.

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International guidance emphasizes that, beyond geometry and demand, phasing and clearance intervals strongly influence crash likelihood and severity [6-7], and in Doha, local calibration work has shown that base saturation flow rates at SCATS-controlled intersections are substantially higher than default handbook values, underlining the importance of exploiting local SCATS data when designing timing strategies and safety interventions [8].
In parallel, surrogate safety measures (SSMs) and traffic conflict techniques have evolved into practical tools that allow safety performance to be evaluated over relatively short observation periods. Tools such as the FHWA Surrogate Safety Assessment Model (SSAM) and video-based conflict analysis frameworks use micro-level behavioral indicators – including time-to-collision (TTC), post-encroachment time (PET) and evasive maneuvers – to infer the frequency and severity of near-miss events, and these measures have been shown to correlate with crash risk at signalized intersections [9-10]. In Doha and the wider Gulf region, several studies have already demonstrated the feasibility of applying simulation-based SSAM and conflict analysis to assess the safety implications of alternative signal timing and phasing options at intersections and signalized roundabouts [11–12]. The Doha SCATS network, comprising more than 450 SCATS intersections provides a suitable environment in which to explore how safety can be embedded explicitly into adaptive control logic at scale. In addition to high-resolution SCATS data and video streams, dedicated Traffic Signal Study (TSS) based on Synchro/Sim Traffic for representative junctions in the metropolitan area compared conventional lead–lag operation with split phasing and found that removing opposing straight-through concurrency led to insignificant increase in average delay with no Level of Service (LOS) degradation, when calibrated using locally observed saturation flows [6–8]. The present work also builds on operational experience from a SCATS-based vehicle-to-infrastructure (V2I) system deployed in Doha to provide priority for FIFA World Cup shuttle buses at a large number of signalized junctions, showing that the same platform can support complex, data-driven strategies at scale [13]. Against this background, the study pursues four main objectives:

- identify safety-critical phase sequences in the Doha SCATS network using high-resolution data and conflict-based indicators
- to develop a decision-support framework algorithm that defines an acceptable safety–efficiency envelope for skipping straight–straight (S-S) phases
- to design and implement safety-oriented SCATS variations and action-lists which suppress risky S-S operation during low-demand periods
- to evaluate the operational and safety impacts of these strategies using a before–after study with comparison sites at corridor and network level.

2 Background and literature review

SCATS is a widely deployed adaptive signal control system that adjusts cycle length, splits and offsets in real time from detector occupancies and degree of saturation to reduce delay, stops and queues. Corridor evaluations report mobility benefits and, in some cases, reductions in total and injury crashes; however, most assessments treat the adaptive logic as a black box rather than redesigning variations and action-lists around explicit safety objectives [1–5]. At signalized intersections, phasing structure and clearance (intergreen) settings strongly influence conflict exposure and red-light-running risk and are emphasized in major guidance documents [6-7]. Because crash-based evaluation requires long observation periods, surrogate safety measures and traffic-conflict techniques have become practical tools for proactive safety management. Simulation-based SSAM and video-based conflict analysis use indicators such as TTC and PET to quantify near-miss severity and have been applied to signal timing and phasing studies, including in Doha [9-12].

Recent research also demonstrates that safety outcomes such as red-light-running can be reduced using high-resolution signal data within adaptive control frameworks [14]. This study addresses the gap between evaluation and implementation by using high-resolution SCATS logs to identify safety-critical off-peak straight–straight concurrency and to encode safety-oriented interventions directly into SCATS variations and action-lists at network scale.

3 Study area and data

3.1 Doha SCATS network

The Doha SCATS network comprises more than 450 intersections that are shown in figure 1, handles around 24 million vehicle movements per day, with pronounced morning and evening commuter peaks and relatively free-flow conditions overnight.

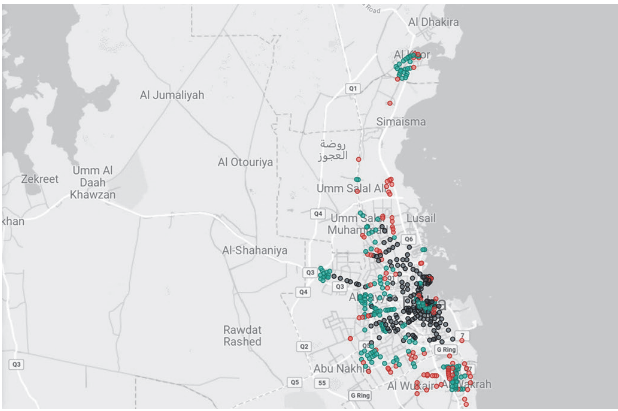

Figure 1 SCATS Traffic Signal Map

3.2 Synchro-based Traffic Signal Study for representative junctions

A Synchro/Sim Traffic Traffic Signal Study (TSS) for representative arterial intersections compared conventional lead–lag operation with concurrent opposing straight–straight (S–S) service against split phasing. When calibrated using locally observed saturation flows, split phasing increased average delay by less than 5% with no LOS downgrade, providing a conservative safety–efficiency envelope for off-peak interventions [8].

4 Methodology

4.1 Identification of high-risk phase sequences

High-risk phase sequences were identified using crash/violation history, high-resolution SCATS logs and conflict-based indicators. For each junction and time period, the analysis aggregated demand (detector counts), degree of saturation (DS), phase-change frequency, red-light entries per 1, 000 cycles, and conflict rates per entering vehicles (e.g. TTC and PET thresholds) to screen for elevated risk patterns. The screening combined three data layers: (i) high-resolution SCATS streams (phase-state time series, cycle transitions, detector counts/occupancies, DS and controller alarms), (ii) historical crash and enforcement/violation records aligned by junction and time-of-day, and (iii) time-synchronized short video samples at treated and comparison sites.

For surrogate safety evaluation, video clips were screened for interaction events and coded using standard conflict indicators. Post-encroachment time (PET) and time-to-collision (TTC) were used to characterize severity, and conflicts were classified by type (crossing, opposing straight–straight, rear-end/merging). Severe conflicts were flagged using conservative thresholds (e.g. TTC ‹ 1.0 s and/or PET ‹ 1.0 s) consistent with prior SSAM and video-based studies [9-11].

4.2 Decision-support framework for skipping straight–straight phases

Although SCATS and conflict analyses indicated that S–S sequences were safety-critical, implementing changes across a large urban network required clear evidence that any phasing modification would not cause unacceptable delay or LOS degradation. The Synchro-based TSS is used as an auxiliary decision-support tool. Using the calibrated models, approximate DS and flow thresholds were derived for which split phasing remained within this envelope. These thresholds were then translated into SCATS-compatible triggers; for example, the ratio in equation 1, (Left-U Turn to the Straight movement traffic volume considering the number of lanes) is more than 1.0, or DS on both opposing through approaches below approximately 0.30–0.35, residual queues not exceeding a small, site-specific limit and activation restricted to predefined off-peak and night-time time-of-day windows.

$$\beta = \frac{N_S \times V_{LT-U}}{N_{LT-U} \times V_S} \quad (1)$$

The resulting decision-support logic, implemented via SCATS variations and action-lists, is summarized in figure 2.

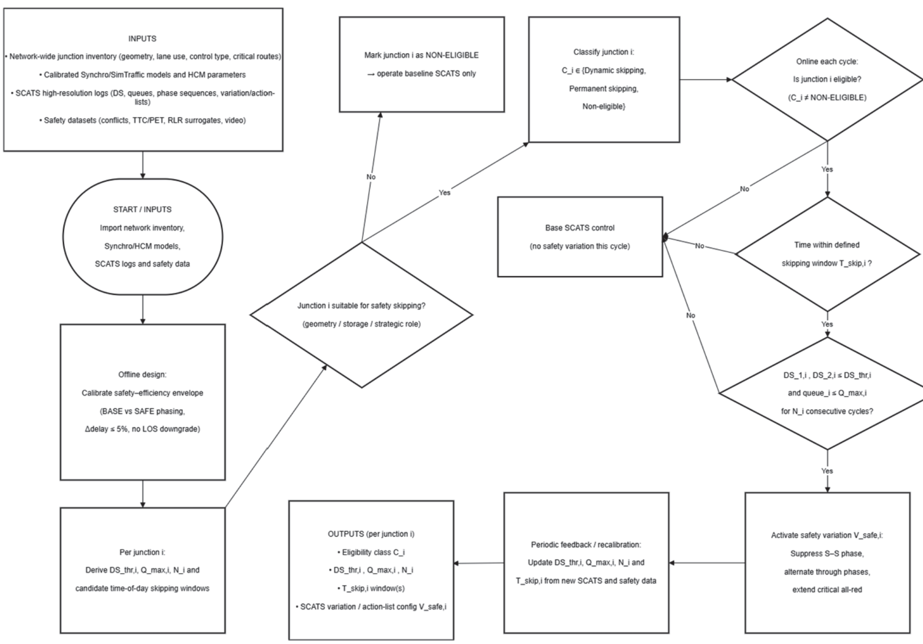

Figure 2 Algorithm of Safety-Oriented Skipping S-S Phases Decision Support

4.3 Design of safety-oriented SCATS variations and action-lists

Based on the thresholds described above, a family of safety-oriented SCATS variations was developed, each sharing four core design elements. First, demand-triggered suppression of S–S sequences means that when DS on both opposing through approaches falls below the calibrated threshold for N consecutive cycles within the active time-of-day window, the S–S phase is suppressed and the junction operates with alternating straight-through greens. Figure 3 shows a sample junction that the SCATS traffic counts drop in midnight due to low volume demand.

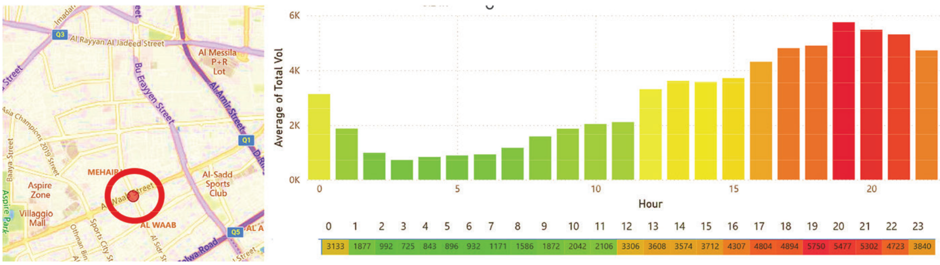

Figure 3 A Sample SCATS Daily Traffic Counts

Second, for critical approaches, the inter-green (all-red) interval is lengthened by approximately 3.0–4.0 s when the safety variation is active. This provides additional clearance time for late exiters and reduces the likelihood of red-light entry conflicts at the start of the next green, consistent with established guidance on change and clearance intervals. Third, where justified by geometry and demand, the safety variation imposes lead–lag or split-phase operation to avoid simultaneous opposition between high-volume straight-through and turning flows, in line with recommendations to use phasing as a conflict-management tool. All modifications were implemented using standard SCATS variation and action-list mechanisms, without hardware changes, presented in figure 4.

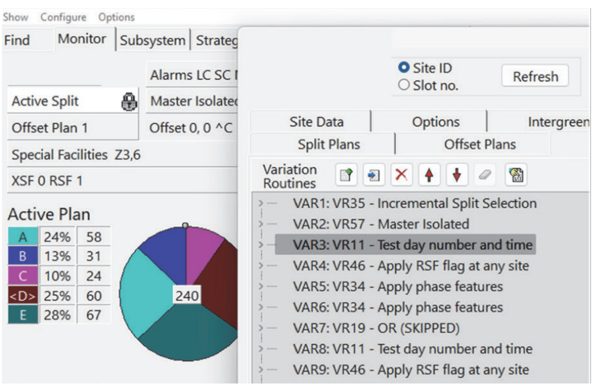

Figure 4 A Sample SCATS Variation Routine

5 Results

The proposed safety-oriented logic was successfully deployed at scale using SCATS functionality across a large network. During off-peak/night-time activation windows, the treatment produced meaningful safety improvements with minimal operational impact.

5.1 Network-wide time-of-day configuration of safety skipping

The safety-oriented phasing concept was encoded as time-of-day rules for 133 signalized junctions, classified as dynamic, permanent skipping, or non-eligible due to layout/operational constraints. Typical weekday activation starts around 23:00 and reverts by 05:00 and weekend windows are longer with later reversion on Fridays, aligning activation with low DS conditions, as shown in table 1.

Table 1 Summary of safety-skipping configuration across 133 junctions

Skipping category	Description	Number of junctions	Share of programme
Dynamic skipping	S–S / lead–lag phases skipped only within predefined low-demand windows	98	73.7%
Permanent skipping	One or more high-risk phases permanently suppressed	19	14.3%
Non-eligible for skipping	Junctions excluded due to layout, storage or strategic constraints	16	12.0%

5.2 Operational performance (before–after evaluation)

During off-peak/night-time activation windows, before–after evaluation showed minimal operational impact that average control delay increased by approximately 3–5% only and LOS generally remained unchanged (typically A–B), with stops and queues within normal day-to-day variability. Safety indicators improved consistently at treated sites which red-light entries per 1, 000 cycles decreased by about 18% while remaining broadly unchanged at comparison sites, and total conflicts per 10, 000 entering vehicles reduced by roughly 15–20%. Severe conflicts (e.g. TTC ‹ 1.0 s or PET ‹ 1.0 s) reduced by more than 25%, with the largest reductions in crossing and opposing-straight conflicts targeted by suppressing S–S concurrency. No increase in rear-end conflicts was observed, suggesting that the modest clearance enhancements did not introduce adverse stopping behavior. These findings show that a targeted “safety overlay” within adaptive signal control can reduce high-risk off-peak conflict exposure and red-light running without creating a congestion trade-off, because the treatment is only activated under low-demand conditions where operational sensitivity is low.

5.3 Practical implications for agencies and authorities

The high proportion of junctions suitable for dynamic implementation indicates that the approach is operationally feasible at network scale, can be scheduled consistently using time-of-day logic, and does not require roadside hardware changes. Road authorities and traffic-management agencies can use these results to deploy a scalable, low-cost safety treatment by (a) prioritizing junctions with off-peak opposing straight–straight concurrency, (b) implementing time-of-day activation windows tied to low DS conditions, and (c) monitoring outcomes measures (delay/LOS, stops/queues, red-light entries). This supports network-wide safety improvement programmes that can be iteratively refined through thresholds and scheduling rather than waiting for infrastructure upgrades.

6 Conclusion

This work demonstrates that safety-oriented phase skipping can be implemented at scale in SCATS using variations and time-of-day activation. Building on these findings, the next steps are:

- to extend monitoring across additional months and special-event periods to confirm robustness under demand variability
- to evaluate corridor-level effects (progression/offsets), equity across approaches, and impacts on pedestrians/cyclists and heavy-vehicle operations
- to test portability across different junction geometries, land-use contexts, and other adaptive platforms, and develop a standardized implementation checklist for agencies.

These future efforts will strengthen generalizability and support institutional adoption of a scalable, low-cost safety overlay within adaptive signal control networks.

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