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Enhancing Urban Mobility: A Road Diet Approach to Improve Traffic Capacity and Pedestrian Safety

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ABSTRACT: Urban intersections often face the dual challenge of managing high traffic volumes while ensuring pedestrian safety. This study investigates whether road diet strategies—reducing travel lanes while reallocating space for pedestrians—combined with signal timing optimization, can improve both vehicle throughput and safety at complex urban intersections. The North Washington Street corridor in Boston, including City Square and Keany Square, was selected due to its congestion and long pedestrian crossing distances. Data were collected via sensors and manual counts in December 2022. Microscopic simulations were conducted in PTV Vissim, calibrated to field observations within ±5% accuracy. The intervention included lane reductions, a new northbound receiving lane, pedestrian refuge islands, split crossings, and revised signal timing using VisVAP. Results show average vehicle delays decreased from 171.97 to 31.12 veh-s at City Square and from 146.60 to 64.88 veh-s at Keany Square. Queue lengths dropped by over 50%, and intersection capacities rose by 34.59% and 24.98% respectively. Pedestrian exposure times were cut significantly, particularly at long crossings. These findings challenge conventional assumptions about road diets limiting capacity. Instead, the combined approach fostered safer and more efficient intersections, suggesting that balanced urban mobility can be achieved through thoughtful design. The study provides a replicable model for cities pursuing Vision Zero and sustainable mobility goals.

KEYWORDS: Road diet; urban intersection design; pedestrian safety; traffic signal optimization; urban mobility.

1. INTRODUCTION

Each year, tens of thousands of pedestrians lose their lives in traffic incidents, underscoring a global crisis in urban mobility and safety (Stoker et al., 2015). These fatalities highlight the urgent need for innovative strategies that prioritize the well-being of vulnerable road users (Nogayeva et al., 2020). Conventional urban intersection designs, often optimized for vehicular throughput, frequently lead to safety compromises, particularly for pedestrians navigating complex and high-volume traffic environments (Rodríguez et al., 2003). The established designs, while aiming to enhance traffic flow, can inadvertently increase pedestrian exposure to risk, creating conflicts between vehicles and individuals on foot (Chaudhari et al., 2020). These traditional approaches often neglect the intricate balance required to ensure both efficient transportation and a secure pedestrian environment (Zegeer, 1983). Integrating safety considerations into transportation planning is crucial, requiring a paradigm shift from vehicle-centric designs to people-oriented solutions that acknowledge the shared use of urban spaces (Sunarti et al., 2019). The rise in pedestrian fatalities, despite overall improvements in road safety, has prompted initiatives like Vision Zero, emphasizing the need for proactive measures to eliminate traffic-related deaths and serious injuries (Ulak et al., 2020). This requires a fundamental rethinking of urban street design, incorporating elements that promote walkability and prioritize pedestrian safety within the broader transportation ecosystem (Forsyth & Southworth, 2008).

Prior research on road diets, which involve reducing the number of travel lanes to improve safety and create space for other modes of transportation, has predominantly focused on low-traffic contexts. While these studies provide valuable insights into the potential benefits of road diets, their applicability to high-volume urban intersections remains limited (Rui & Othengrafen, 2023). The unique challenges posed by these intersections, including higher traffic volumes, complex signal timings, and diverse user groups, necessitate further investigation to determine the effectiveness of road diets in such demanding environments. The existing body of literature lacks comprehensive analysis of road diet implementations in high-traffic urban areas, leaving a significant gap in understanding the potential trade-offs between traffic capacity and pedestrian safety. It is vital to address this gap to ascertain whether road diets can effectively mitigate pedestrian risk without causing unacceptable levels of congestion and delay. Specifically, the effects of lane reductions coupled with optimized signal timings need to be thoroughly evaluated in the context of urban areas characterized by heavy traffic flow. The design and operation of traffic signals at intersections often involve making choices that balance the dual objectives of safety and mobility (Wang et al., 2021). This often involves prioritizing vehicular movement, which may compromise safety, particularly for pedestrians, thus there is a growing need for studies in this area (Yang & Sun, 2013). The complexities of signal timing optimization and its impact on pedestrian safety require a detailed analysis, considering factors such as pedestrian crossing times, vehicle speeds, and intersection geometry.

This study aims to address this gap by examining the effects of a road diet implemented in a high-traffic area of Boston, Massachusetts. We hypothesize that by reducing the number of lanes and optimizing signal timings, it is possible to simultaneously improve both traffic capacity and pedestrian safety in this challenging urban environment. The overarching objective is to determine whether a road diet can reconcile the conflicting demands of efficient vehicular movement and enhanced pedestrian protection, thereby creating a more balanced and sustainable transportation system. Baseline measurements at the City Square intersection in Boston revealed substantial queues of up to 1,677 feet on the northbound approach, indicating significant congestion during peak hours. Furthermore, pedestrian exposure times for crossing the 118-foot intersection were recorded at 33.89 seconds, highlighting the potential risks associated with long crossing distances and exposure to vehicular traffic. By analyzing the data collected before and after the road diet implementation, this research will offer empirical evidence of the potential benefits and drawbacks of this approach in a high-volume urban setting. Understanding the risk factors associated with pedestrian crashes, such as vehicle speeds and pedestrian-vehicular volume ratios, is crucial for developing effective safety measures (Mukherjee & Mitra, 2020). To comprehensively evaluate the impacts on safety, the study incorporates a rigorous assessment of conflicts, classifying them by frequency, severity, type (e.g., vehicle-pedestrian, vehicle-vehicle), and precise location within the intersection (Alozi & Hussein, 2021).

The critical question this research seeks to answer is: Can a road diet effectively reconcile traffic capacity and pedestrian safety in high-volume urban intersections? Answering this question will involve a thorough evaluation of the effects of the road diet on various performance metrics, including vehicle queue lengths, travel times, pedestrian crossing times, and crash rates. This will provide valuable insights into the effectiveness of road diets as a tool for enhancing urban mobility and creating safer, more livable communities. Optimizing variable signal timing profiles for congested intersections, regulated by fixed-time traffic signals, could significantly reduce traffic congestion (Labib et al., 2019). These alternative designs could be studied for different traffic scenarios with the use of traffic simulation, and the results showed better performance during peak hours than that of similar corresponding conventional designs (Bared et al., 2005). Additionally, future studies in this area could integrate geographic information system tools to evaluate how road space is allocated among various transportation modes, thereby identifying potential opportunities for rebalancing street space to promote sustainable and equitable transportation (Lefebvre-Ropars et al., 2021).

2. METHODS

2.1 Study Area

The study focuses on two critical intersections along the North Washington Street corridor in Boston, Massachusetts: City Square and Keany Square (Figure 1). Both intersections are located within the urban core and are characterized by high vehicular and pedestrian traffic volumes, rendering them ideal candidates for a road diet intervention (Kamel et al., 2017). The corridor serves as a primary arterial route connecting Charlestown to Downtown Boston and facilitates access to major regional destinations.

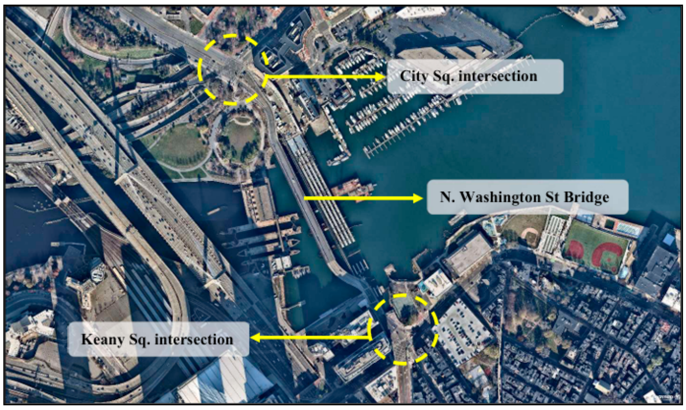


Figure 1. Study Area

The rationale for selecting this corridor lies in its persistent congestion, extended queue lengths, and compromised pedestrian safety, which have been identified as critical points for improvement (Riggs & Gilderbloom, 2017). Observations indicate that during peak periods, northbound queues at City Square extend up to 1,677 feet, exceeding available storage and impeding upstream flows. Additionally, both intersections exhibit high saturation flows, estimated at 1,800 vehicles per hour per lane (veh/hr/lane), which emphasizes the operational stress experienced during peak demand, underscoring the urgency for effective traffic management strategies (Lefebvre-Ropars et al., 2021). The presence of long crossing distances (exceeding 100 feet in some approaches) further underscores the vulnerability of pedestrians and the need for safety-focused redesign. The study's methodological rigor ensures that the proposed interventions are grounded in empirical evidence and are tailored to address the specific challenges posed by these intersections, thereby maximizing the potential for enhanced urban mobility and safety for all users (Thomas et al., 2015).

2.2 Data Collection

2.2.1 Traffic Data

Traffic data were collected in December 2022, during the bridge reconstruction, using a combination of automated sensors and manual turning movement counts at both intersections. Data included peak-hour volumes, vehicle classifications, and turning movements—specifically Southbound Through (SBT), Westbound Left (WBL), and other critical flows, providing a detailed snapshot of traffic patterns (Zegeer, 1983). Saturation flow rates were assumed at 1,800 veh/hr/lane, consistent with Highway Capacity Manual (HCM) standards and validated through field observations.

2.2.2 Pedestrian Data

Pedestrian crossing data were obtained through direct field measurements, while the number of pedestrians on each crossing was not collected. Crossing distances ranged from 76.4 feet to 118.62 feet, depending on approach geometry. Pedestrian exposure time was computed using Equation 1. These measurements informed evaluations of pedestrian safety under existing and proposed conditions.

$$(1) \quad t = \frac{W}{v}$$

where:
t = pedestrian exposure time (seconds)
W = width of the crossing, crossing length (feet)
v = assumed pedestrian walking speed = 3.5 ft/s

2.2.3 Signal Control Data

Signal timing data were obtained from the City of Boston's Traffic Management Center. City Square operates under an actuated control system with a 140-second cycle length, while Keany Square uses a 175-second cycle. Details regarding phase splits, pedestrian intervals, and detector configurations were incorporated into the simulation model to ensure accurate replication of field conditions.

2.3 Simulation Framework

A microscopic traffic simulation model was developed using PTV Vissim (version 2020.00-14). The model included the North Washington Street corridor and its adjacent intersections. Calibration was conducted to ensure the model's output aligned with field observations, particularly for queue lengths (e.g., observed SB queue at Keany Square: 1,812 feet), further solidifying the model's credibility and predictive power (Labib et al., 2019). Calibration parameters—such as desired speed distributions, car-following behavior (Wiedemann 99), and lane-change aggressiveness—were iteratively adjusted to maintain queue length discrepancies within ±5% of observed values.

2.3.1 Key Model Inputs

The simulation incorporated two geometric and operational scenarios: the baseline configuration and a proposed intervention scenario reflecting road diet and signal optimization strategies.

a. Baseline Geometry: The existing cross-section includes two eastbound and westbound receiving lanes on Causeway Street, conducive to high vehicle speeds and unsafe pedestrian conditions. The extensive south pedestrian crossing at City Square puts pedestrians at long exposure to traffic, increasing the level of unsafe pedestrian crossing.

b. Proposed Interventions:
1. Lane Configuration Adjustments:
   - A northbound receiving lane was added across the North Washington Street Bridge, extending approximately 785 feet to improve downstream flow capacity and prevent bottlenecks.
   - A southbound lane reduction was implemented shortly after 151 feet south of City Square, converting four lanes to three to mitigate weaving-related congestion and allocate space for pedestrian safety features.
2. Intersection Geometry Adjustments:
   - Split pedestrian crossings and phases were introduced at both intersections to reduce exposure time and improve pedestrian refuge opportunities.
   - Receiving lanes were narrowed at all Causeway Street approaches to encourage lower vehicle speeds, reduce the frequency of last-minute lane changes, and shorten pedestrian crossing distances.
3. Signal Timing Optimization:
   - City Square was transitioned from semi-actuated to fully coordinated control using the VisVAP optimization module, enhancing green wave consistency along the corridor.
   - Keany Square was retained as a coordinated-actuated control to preserve operational flexibility during fluctuating demand.
   - Pedestrian phases were shortened by splitting crosswalks, reducing the pedestrian green interval from 36 seconds to 19, 25, and 29 seconds, depending on crossing length and intersection approach.
   - Green time reallocation was implemented using a second green interval strategy to minimize queue spillback, particularly at high-volume approaches such as southbound Keany Square.

These model inputs were encoded in Vissim's network and signal control modules, with all configurations subject to calibration and validation procedures described in Section 2.3.2.

2.3.2 Model Validation

Validation focused on matching simulated queue lengths and delays to observed conditions. For example, southbound queues at Keany Square were modeled at 1,812 feet, consistent with field measurements. Intersection-level vehicle throughput and pedestrian clearance times were also compared against field-collected benchmarks.

2.4 Performance Matrix

2.4.1 Vehicle Flow Performance

Intersection capacity, delay, and queue lengths were analyzed using Equations 2, 3, and 4.

(2) $$C = \frac{(S \cdot g)}{C_T} \times N$$

where:
C = Approach capacity (vehicles per hour)
S = Saturation flow rate (vehicles per hour per lane)
g = Effective green time (seconds)
C_T = Cycle length (seconds)
N = Number of lanes on the approach

(3) $$d = d_1 + d_2 + d_3$$

where:
d = total delay (seconds/ vehicle)
d_1 = uniform delay (seconds/ vehicle)
d_2 = incremental delay due to traffic interactions (seconds/ vehicle)
d_3 = additional delay due to oversaturation (seconds/ vehicle)

(4) $$Q = \frac{\lambda 2}{\mu(\mu - \lambda)}$$

where:
Q = average queue length (feet)
λ = arrival rate (vehicles per second)
μ = service rate (vehicles per second)

2.4.2 Pedestrian Safety Metrics

Pedestrian safety improvements were evaluated via exposure time reduction (as noted in Section 2.2.2).

Comparisons were made between baseline and proposed pedestrian delays, with attention to improvements achieved through concurrent signal phasing and reduced crossing widths. The ultimate goal of the modeling effort involved using digital twin technology to leverage real-time data and simulations to reduce waiting times (Shahriar et al., 2024). Overall, digital twins can potentially improve existing traffic management strategies (Zhang et al., 2022).

2.5 Limitations and Assumptions

This study assumes a constant saturation flow rate of 1,800 veh/hr/lane across all approaches, consistent with urban arterial standards. While this assumption simplifies calibration, it may not fully capture driver behavior variability, particularly under adverse weather or non-ideal visibility conditions. Additionally, pedestrian behavior was modeled using uniform walking speeds, which may not reflect demographic differences. The simulation framework, while robust, cannot account for all real-world stochastic events such as double parking or emergency vehicle interruptions.

3. RESULTS AND DISCUSSIONS

3.1 Baseline and Current Conditions

3.1.1 Traffic Volume and Turning Movement Patterns

The evaluation of existing traffic conditions is critical in assessing the impacts of the proposed road diet and requires a detailed understanding of traffic volumes, turning patterns, and signal timing (Stoker et al., 2015). Congestion limited direct volume observations to select movements; therefore, a saturated flow rate of 1,800 veh/hr/lane was applied broadly to estimate capacities, following established standards for urban arterials (Sheffi, 1986) (Table 1). At City Square, a significant southbound movement of 744 veh/hr was recorded toward the Washington Bridge, while Keany Square exhibited a northbound flow of 359 veh/hr in the same direction, both emphasizing the corridor's key role in urban connectivity (Loganayagan et al., 2020) (Figure 2). These dominant through movements at both intersections substantiate their importance in intervention strategies focused on enhancing mobility and safety. As previous studies suggest, well-implemented road diets can reduce delays and improve safety across modes (Bared et al., 2005).

Intersection	Movements	No. of Lanes	Volume/Lane	Total Volume
City Square	SB	4	1,800	7,200
	NB	4	n/a	n/a
	WB	3	1,800	5,400
Keany Square	SB	4	n/a	n/a
	NB	1	1,800	1,800
	NWB	1	37	37
	WB	2	1,800	3,600
	EB	3	66,7	200

Table 1. Traffic volume

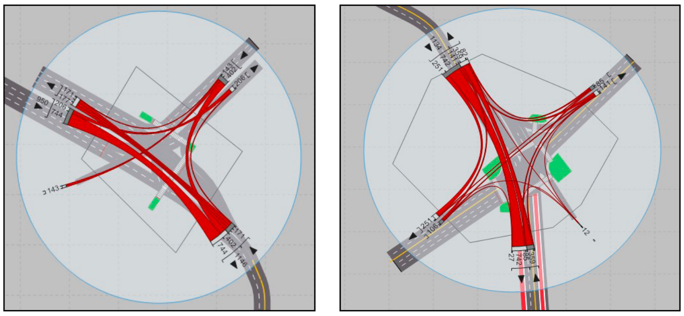


Figure 2. Turning volume at City Square (left) and Keany Square (right).

3.1.2. Signal Timing Configuration and Inefficiencies

The current signal timing at City Square consists of a coordinated-actuated control with a 140-second cycle and an actuated pedestrian-only phase (Figure 3). While prioritizing pedestrian access, this design introduces limitations during peak vehicle demand. Keany Square, also using coordinated-actuated control, operates with a 175-second cycle and a conditionally activated Phase 4 triggered by detector demand, providing greater adaptivity (Chiabaut et al., 2018) (Figure 4). Advanced signal management using vehicular networks has shown potential to reduce delays by dynamically adjusting to real-time flow (Cai et al., 2019).

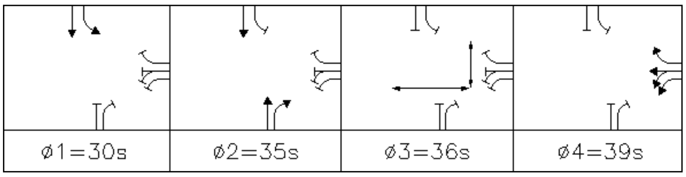


Figure 3. City Square signal timing under the current conditions.

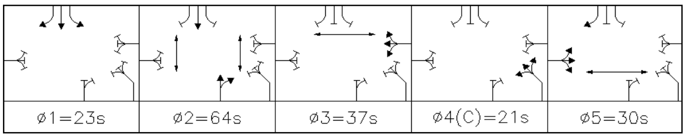


Figure 4. Keany Square signal timing under the current conditions.

Despite their adaptive components, both intersections suffer from inefficiencies under variable conditions, leading to elevated delays. Conventional control systems often fail to respond to fluctuating traffic volumes, highlighting the need for real-time, autonomous signal optimization (Jing et al., 2017; Qasim et al., 2024). Integrating multisource traffic data into centralized platforms can enable more responsive traffic signal strategies (Manikonda et al., 2011).

Cloud-based data integration and vehicle telemetry support real-time routing and efficient traffic resource allocation, essential for mitigating urban congestion. Balancing safety and flow through optimized signal design remains a foundational goal in traffic engineering (Wang et al., 2021). Addressing timing inefficiencies and optimizing intersection geometry within the proposed road diet framework aims to improve vehicular throughput and pedestrian experience simultaneously.

3.1.3. Intersection Delays

City Square exhibited an average intersection delay of 171.97 vehicle-seconds (veh-s), reflecting severe peak-hour congestion (Loganayagan et al., 2020) (Table 2). Specific movements were

Intersection	Movements	d (veh-s)	Avg. d (veh-s)	Avg. Queue Length (ft)	c (veh/hr)	Total c (veh/hr)
City Sq.	SBT	107.80	171.97	n/a	745	2,148
	SBL	230.30		n/a	206	
	NBR	237.05		1,677.33	58	
	NBT	240.13		1,677.33	518	
	WBR	159.30		n/a	40	
	WBTL	114.61		n/a	376	
	WBL	114.61		n/a	205	
Keany Sq.	SBR	174.62	146.60	1,812.88	251	2,049
	SBT	99.99		1,812.88	742	
	SBL	189.12		1,812.88	141	
	NBT	151.68		n/a	377	
	NBR	37.72		n/a	66	
	NWB	91.05		n/a	35	
	WBR	396.11		n/a	85	
	WBTL	188.44		n/a	151	
	EBL	98.74		n/a	48	
	EBT	70.74		n/a	94	
	EBTR	71.62		n/a	59	

Table 2. Delays, queue lengths, and capacities under the current conditions

more impacted: Southbound Left at 230.3 veh-s, Northbound Through at 240.13 veh-s, and Northbound Right at 237.05 veh-s, indicating signal phasing imbalances and reduced throughput (Kafy, 2018). At Keany Square, although the average delay was slightly lower at 146.60 veh-s (Labib et al., 2019), significant delays were noted for specific movements: Westbound Right at 396.11 veh-s, Westbound Through at 188.44 veh-s, and Eastbound Through-Right at 71.62 veh-s, suggesting local bottlenecks likely due to geometric or timing deficiencies.

3.1.4. Queue Lengths

As in Table 2, queue lengths affirmed the severity of congestion, with the Northbound approach at City Square reaching 1,677.33 ft and the Southbound approach at Keany Square extending to 1,812.88 ft. These lengths hindered local flow, induced upstream spillback, and increased network-level delays (Comert et al., 2020). Such conditions endanger pedestrian safety, particularly where queues overlap with crosswalks (Yang & Zhong-ke, 2017). At Crossing 2 in City Square, pedestrians face a 118.62-ft crossing requiring 33.89 seconds of exposure time, heightening risk.

3.1.5. Pedestrian Safety Metrics

Crossing two at City Square is 118.62 ft long, causing a pedestrian exposure time of 33.89 seconds (Figure 5 and Table 3). Variability in pedestrian green times, with some exceeding 64 seconds at Keany Square, compounds safety concerns, especially for vulnerable users like the elderly (Zheng et al., 2016). These patterns highlight the urgent need for interventions that balance flow efficiency with pedestrian protection (Hamid & Arora, 2021).

Intersection	Crossing	Length (ft)	Exposure Time (s)	Green Time (s)
City Square	1	76.4	21.83	36
	2	118.62	33.89	36
Keany Square	3	77.57	22.16	30
	4	57.97	16.56	64
	5	82.69	23.63	37
	6	40.04	11.44	64
	7	23.72	6.77	64

Table 3. Crossing length, pedestrian exposure time, and pedestrian green time under the current condition

3.1.6 Intersection Capacity Estimates

Despite theoretical capacities of 2,148 veh/hr at City Square and 2,049 veh/hr at Keany Square—supporting up to 745 veh/hr Southbound Through and 518 veh/hr Northbound Through at City Square—the high delays and queues suggest poor utilization (Parr et al., 2020) (Table 2). Inefficient green time allocation likely exacerbates congestion. Addressing these inefficiencies demands pedestrian-focused infrastructure enhancements (Rukmana et al., 2023; Erlangga et al., 2021) and a better understanding of pedestrian risk factors (Ulak et al., 2020; Mukherjee & Mitra, 2020; Chaudhari et al., 2020). Optimizing signal phasing and design is key to balancing safety and mobility under urban density pressures (Pandey & Agarwal, 2020).

3.2 Proposed Condition (Road Diet Implementation and Signal Timing Adjustments)

3.2.1 Road Diet and Geometric Changes

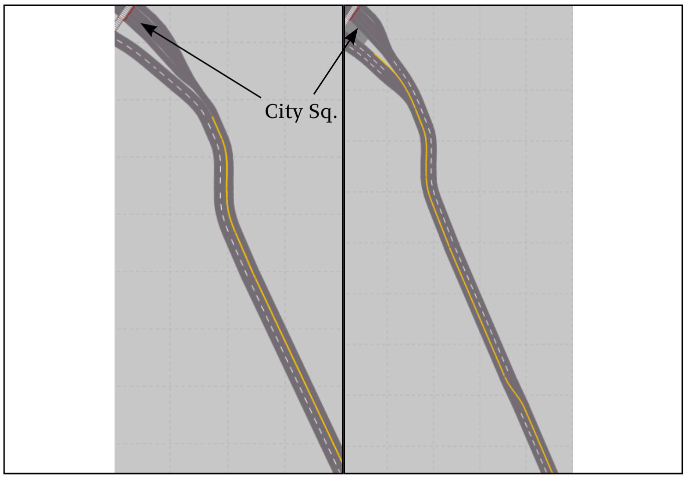


Figure 6. Additional northbound lane approaching City Sq. was added by eliminating one southbound lane, leaving the intersection. The current lane configuration is presented on the left, and the proposed one on the right.

The proposed intervention, involving a road diet coupled with signal timing adjustments, introduces significant geometric modifications to the study area to optimize traffic flow and enhance pedestrian safety. Specifically, a northbound approaching lane, extending approximately 785 feet (Figure 6), was strategically added to the Washington Bridge to alleviate congestion and improve throughput capacity (Friedman et al., 2024). Complementing this addition, a southbound lane reduction was implemented at a point approximately 151 feet south of City Square, intended to streamline traffic movement and create opportunities for pedestrian-oriented improvements. These physical design alterations, as visually depicted in Figure 7, also incorporated the splitting of existing pedestrian crossings and the narrowing of receiving lanes, calculated to shorten pedestrian exposure times within the crosswalk and reduce vehicle speeds in proximity to pedes-

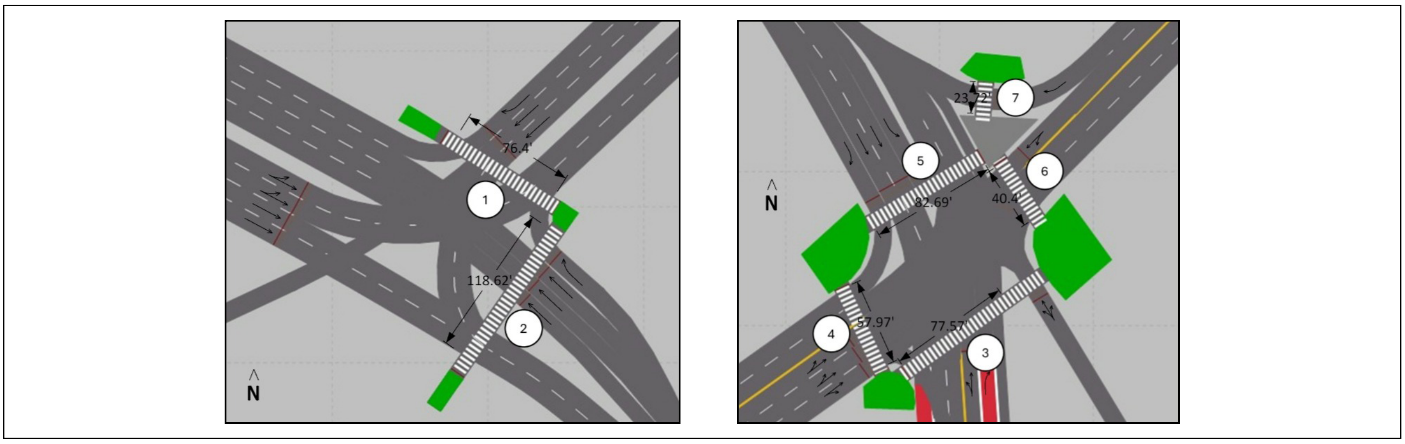


Figure 5. Pedestrian crossings at City Square (left) and Keany Square (right) under the current conditions.

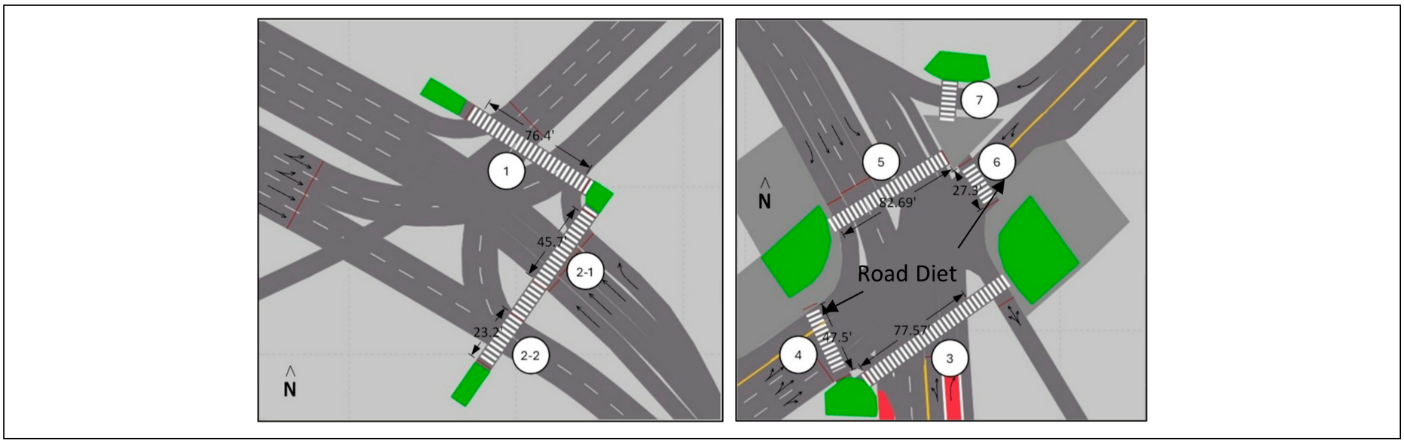


Figure 7. Pedestrian Crossings at City Square (left) and Keany Square (right) under the proposed conditions.

trian zones (Bared et al., 2005). Such geometric refinements represent a proactive approach to balancing vehicular mobility with pedestrian safety, creating a more harmonious and efficient transportation ecosystem.

3.2.2. Pedestrian Safety Improvements

The implementation of the road diet strategy, incorporating both geometric changes and signal timing adjustments, demonstrates notable improvements in pedestrian safety, particularly at key intersections such as City Square and Keany Square, as detailed in Figures 8–9. At City Square, Crossing 2 was strategically divided into two distinct segments: Crossing 2-1, spanning 45.7 feet with an associated pedestrian exposure time of 13.06 seconds, and Crossing 2-2, covering 23.2 feet with a reduced exposure time of 6.63 seconds. Similarly, at Keany Square, Crossing 4 was shortened to 47.5 feet, resulting in a pedestrian exposure time of 13.57 seconds, while Crossing 6 was reduced to just 27.3 feet, yielding an even shorter exposure time of 7.8 seconds. These reductions in crossing distances and exposure times are critical in minimizing pedestrian vulnerability to vehicle conflicts, ultimately contributing to a safer and more walkable environment (Chaudhari et al., 2020). The strategic reconfiguration of pedestrian crossings, coupled with optimized signal timing, reflects a comprehensive approach to pedestrian safety, aligning with the principles of sustainable urban design and prioritizing the well-being of vulnerable road users.

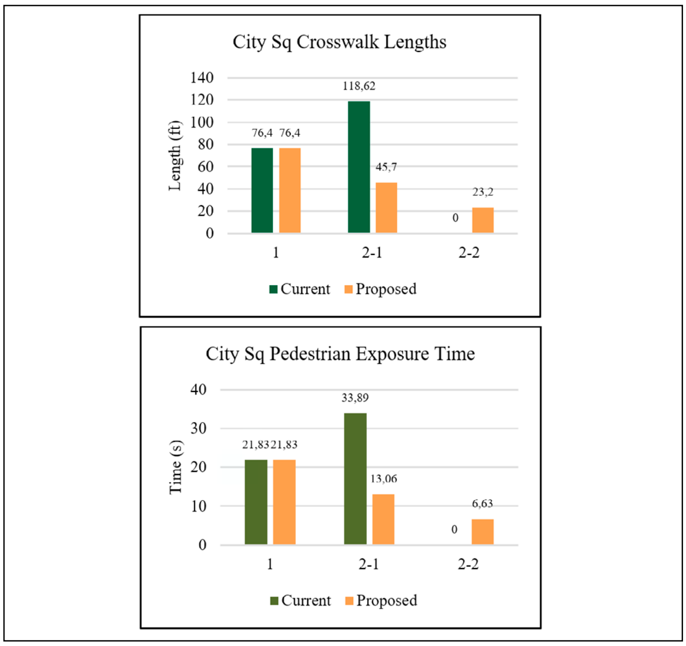


Figure 8. City Square crosswalk lengths and pedestrian exposure time.

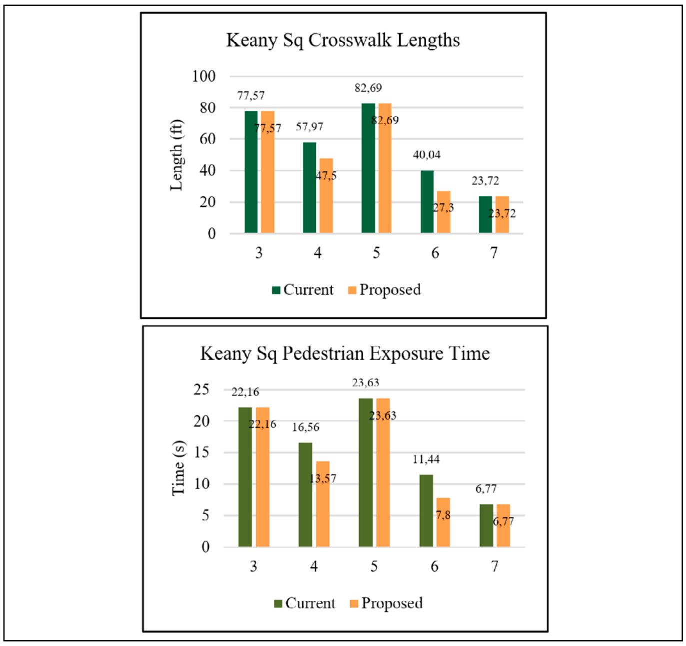


Figure 9. Keany Square crosswalk lengths and pedestrian exposure time.

The integration of road diets and optimized signal timing is instrumental in mitigating conflict situations between vehicular traffic and pedestrian flows while simultaneously fostering environmental enhancements such as landscaping and reductions in noise and air pollution (Burilo et al., 2023). The road diet approach contributes to pedestrian safety by decreasing crossing distances and reducing the number of lanes pedestrians must traverse (Stoker et al., 2015). The strategic design and operation of traffic signals at intersections necessitates careful consideration of elements that may engender trade-offs between safety and mobility, which suggests that well-planned signal timing can play a significant role in managing these trade-offs (Wang et al., 2021). The comprehensive restructuring of road infrastructure and traffic management strategies leads to tangible benefits for both pedestrian safety and the overall quality of the urban environment (Zegeer, 1983). The presence of well-designed pedestrian zones, complemented by amenities that cater to pedestrian comfort and convenience, encourages increased foot traffic and fosters a sense of community (Hahm et al., 2019) (Sunarti et al., 2019).

While the geometric interventions significantly reduced pedestrian crossing distances and exposure times, enhancing safety, they also introduced longer maximum pedestrian waiting times at certain crossings due to revised signal coordination. Notably, the waiting time at Crossing 2 (City Square, west to east) increased from 104 to 176 seconds, and the combined delay for diagonal movement across Crossings 6 and 3 (Keany Square) rose from 169 to 310 seconds. These extended wait times reflect the introduction of split phases and the prioritization of vehicle throughput in high-demand directions.

Although pedestrian crossing comfort may be reduced due to longer waits, this trade-off must be considered in the context of overall intersection performance and safety. Reducing crossing lengths, shorter exposure times (e.g., from 33.89 s to 13.06 s), and the use of refuge islands enhance safety outcomes. From a policy perspective, such trade-offs may be acceptable within urban contexts that prioritize network fluidity — especially when pedestrian safety is simultaneously improved (Wang et al., 2021).

However, to ensure that pedestrian levels of service remain within acceptable limits, future designs may consider adaptive signal control or pedestrian-actuated recalls to minimize perceived waiting times. These approaches could help reconcile vehicle mobility with pedestrian comfort more effectively.

3.2.3. Signal Timing Adjustments

Implementing the proposed condition yields significant improvements in traffic flow and pedestrian safety, demonstrating the synergistic effects of these combined strategies. Specifically, at City Square, the signal timing was strategically modified from a coordinated-actuated system to a fully coordinated system, accompanied by a reduction in the cycle length from 140 seconds to 134 seconds as presented in Figure 10, optimizing signal progression and minimizing unnecessary delays (Lü et al., 2015). Similarly, at Keany Square, the signal timing remained coordinated-actuated, but the maximum cycle length was reduced to 160 seconds (Figure 11)—a critical adjustment aimed at enhancing responsiveness to fluctuating traffic demands. A key element of the signal timing adjustments involved the strategic reallocation of pedestrian green times through phase splitting. This innovative approach allowed for the creation of second green intervals for critical vehicular movements, effectively reclaiming time from pedestrian phases that were previously consolidated (Jin et al., 2019). The split pedestrian phases resulted in reduced green times, varying from 36 seconds to 19, 25, and 29 seconds depending on the specific crossing, carefully calibrated to balance pedestrian needs with vehicular flow requirements.

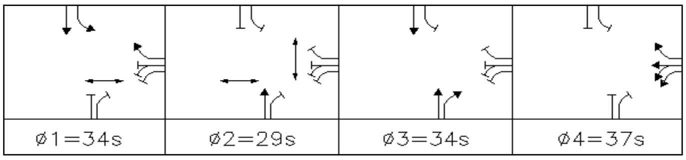


Figure 10. City Square signal timing under the proposed conditions.

3.2.4. Delay Reductions

One of the most notable outcomes of the proposed condition is the substantial reduction in average delay experienced by vehicles at both key intersections. At City Square, the average delay plummeted from a baseline of 171.97 vehicle-seconds to a significantly improved 31.12 vehicle-seconds, marking a substantial enhancement in traffic efficiency (Figure 12). Likewise, at Keany Square, the average delay decreased from 146.60 vehicle-seconds to 64.88 vehicle-seconds, reflecting a considerable improvement in traffic throughput (Figure 13). These delay reductions can be attributed to several factors, including the optimized signal coordination, which facilitates smoother traffic progression, and the improved phasing strategies that prioritize critical vehicular movements, preventing unnecessary stops and starts. The pre-determined traffic light control management system should also be considered in the reduction of average delay experienced by vehicles (Ramadhan et al., 2021).

3.2.5. Queue Length Improvements

Further supporting the effectiveness of the proposed condition are the marked improvements in queue lengths observed at critical approaches to both intersections. Specifically, at City Square, the queue length on the northbound approach was reduced from 1,677.33 feet to 899.4 feet, al-

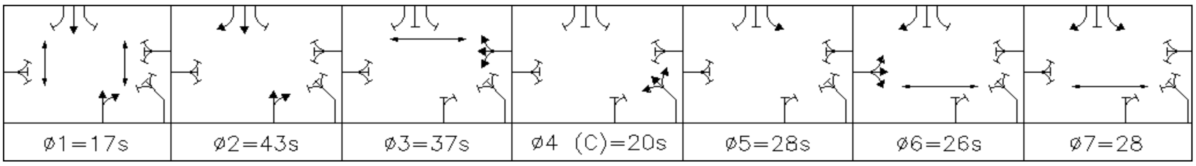
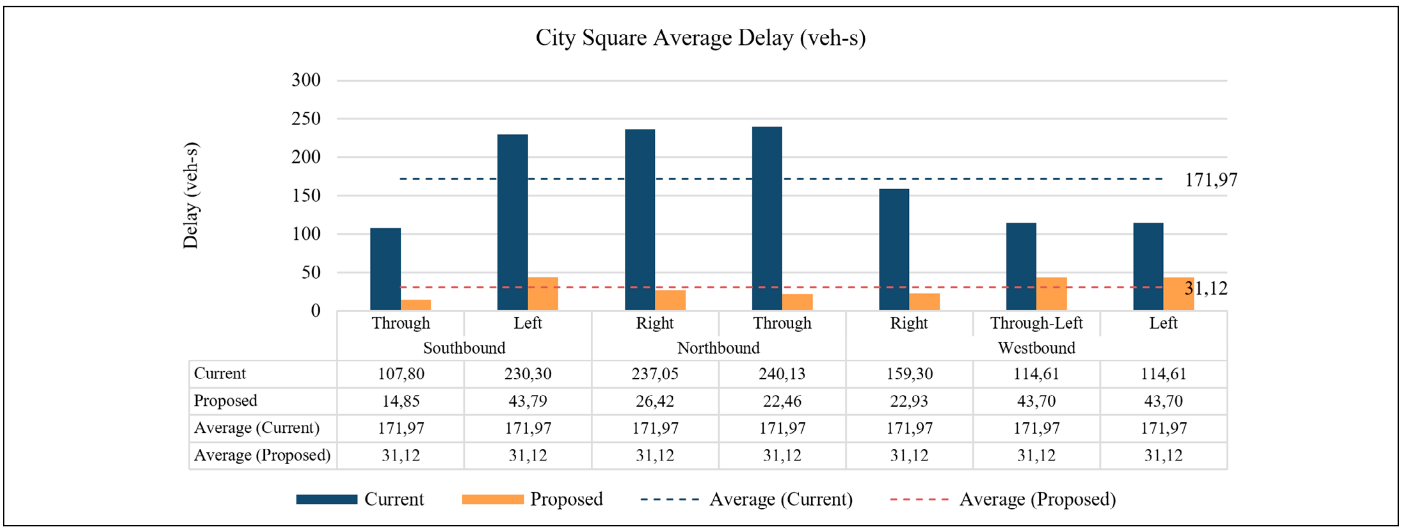
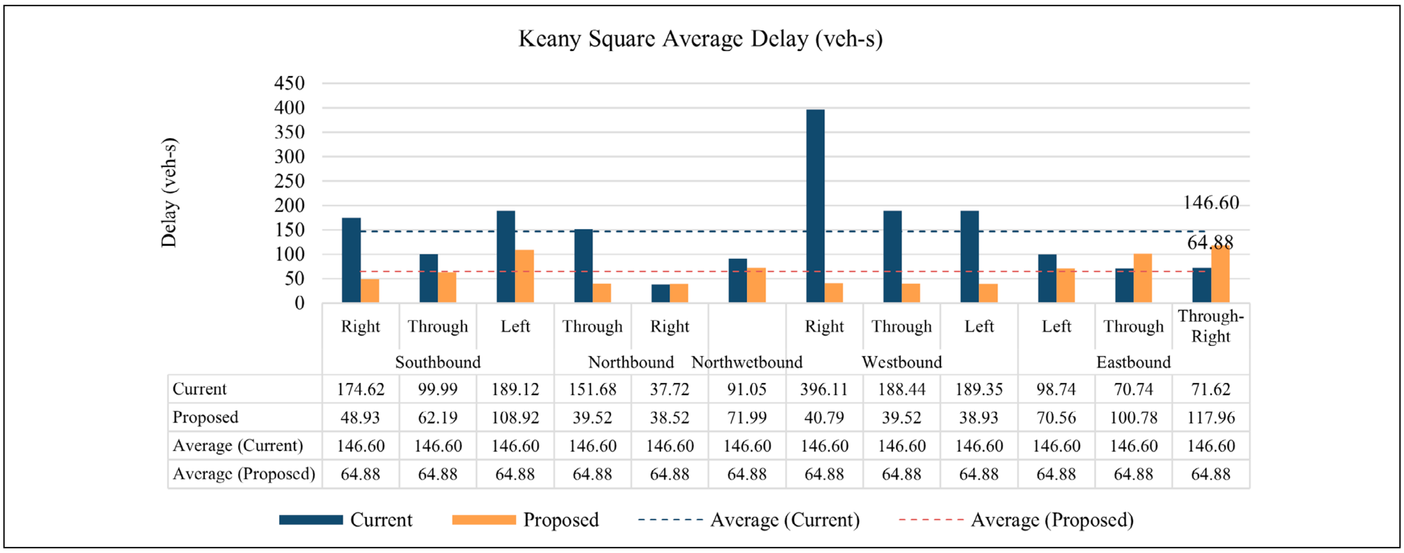


Figure 11. Keany Square signal timing under the proposed conditions.



	Southbound Through	Southbound Left	Northbound Right	Northbound Through	Westbound Right	Westbound Through-Left	Westbound Left
Current	107,80	230,30	237,05	240,13	159,30	114,61	114,61
Proposed	14,85	43,79	26,42	22,46	22,93	43,70	43,70
Average (Current)	171,97	171,97	171,97	171,97	171,97	171,97	171,97
Average (Proposed)	31,12	31,12	31,12	31,12	31,12	31,12	31,12

Figure 12. Comparison of delays at City Square under the current and proposed conditions.



	Southbound Right	Southbound Through	Southbound Left	Northbound Through	Northbound Right	Northwetbound	Westbound Right	Westbound Through	Westbound Left	Eastbound Left	Eastbound Through	Eastbound Through-Right
Current	174.62	99.99	189.12	151.68	37.72	91.05	396.11	188.44	189.35	98.74	70.74	71.62
Proposed	48.93	62.19	108.92	39.52	38.52	71.99	40.79	39.52	38.93	70.56	100.78	117.96
Average (Current)	146.60	146.60	146.60	146.60	146.60	146.60	146.60	146.60	146.60	146.60	146.60	146.60
Average (Proposed)	64.88	64.88	64.88	64.88	64.88	64.88	64.88	64.88	64.88	64.88	64.88	64.88

Figure 13. Comparison of delays at Keany Square under the current and proposed conditions.

leviating congestion and minimizing the risk of spillback into upstream intersections (Bared et al., 2005) (Figure 14). Similarly, at Keany Square, the queue length on the southbound approach decreased from 1,812.88 feet to 769.25 feet, significantly mitigating congestion and enhancing overall network flow. The optimization of traffic signal parameters can lead to maintaining free-flow states within a targeted area (Chiabaut et al., 2018). The reduction in queue lengths is of paramount importance, particularly in dense urban environments where spillback can have cascading effects on traffic flow and network performance. The observed reduction in queue lengths and average delay, coupled with the strategic signal timing adjustments, collectively contribute to a more efficient and safer transportation network (Goyal et al., 2019).

The improvements in queue length, as detailed in Table 8 and visually represented in Figure 14, underscore the effectiveness of the proposed interventions in mitigating congestion. The results obtained from the proposed condition demonstrate a significant enhancement in urban mobility through the strategic combination of road diet measures and signal timing adjustments, showcasing the potential for integrated transportation planning to address complex urban challenges.

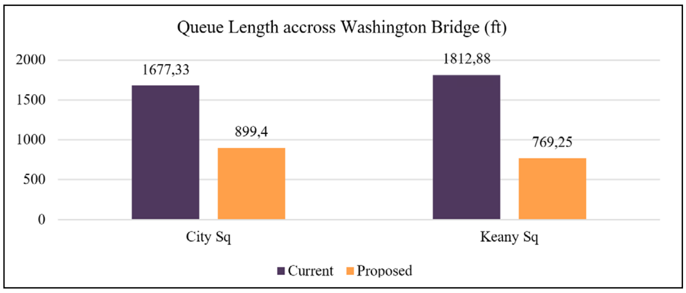


Figure 14. Comparison of the queue lengths across Washington Bridge under the current and proposed conditions.

3.2.6. Capacity Improvement

The implementation of the proposed road diet yielded significant enhancements in traffic capacity at both City Square and Keany Square, as illustrated in Figures 15–16. Specifically, the total capacity at City Square surged from 2,148 vehicles per hour (veh/hr) to 2,891 veh/hr, marking a substantial increase of 34.59%, this notable improvement underscores the potential of road diets, when combined with strategic signal timing, to optimize traffic flow in urban environments (Zegeer, 1983). Similarly, Keany Square experienced a considerable capacity boost, rising from 2,049 veh/hr to 2,561 veh/hr, which translates to a 24.98% increase, this further validates the effectiveness of the proposed intervention in enhancing traffic throughput at different locations with varying geometric and traffic characteristics. Analyzing movement-specific improvements reveals that the Northbound approach at City Square benefited the most, with an increase of 498 veh/hr (86.46%), which demonstrates the ability of the road diet to alleviate congestion and improve traffic progression along specific corridors. The Southbound approach at City Square also saw a capacity increase of 222 veh/hr, indicating a more balanced distribution of traffic flow across different directions. Likewise, at Keany Square, the Northbound approach experienced a significant capacity gain of 334 veh/hr, further emphasizing the positive impact of the road diet on North-South traffic movement, the Southbound approach at Keany Square also benefited, with an increase of 150 veh/hr, contributing to the overall improvement in traffic flow at the intersection.

However, it is important to note that some specific movements experienced slight reductions in capacity, for instance, the Westbound Through-Left and Westbound Left movements at City Square, as well as the Eastbound Through-Left movement at Keany Square, saw minor decreases, these reductions can be attributed to the redistribution of right-of-way and the prioritization of certain movements to optimize overall intersection performance, such trade-offs are inherent in road diet implementations, where the goal is to maximize overall network efficiency rather than uniformly increasing capacity for all movements.

3.2.7. Implications

The observed capacity enhancements, despite the perception of road diets as capacity-reducing measures, can be attributed to several factors (Polus & Shmueli, 1997). The optimized signal timing, in conjunction with the narrowed lane widths and the introduction of pedestrian refuge islands, facilitated shorter delays and safer conditions for both vehicles and pedestrians (Bared et al., 2005). The enhanced phasing strategies enable a better allocation of green time to critical movements, while the narrowed lanes encourage drivers to maintain lower speeds, leading to reduced crash rates and improved safety, the pedestrian refuge islands provide safe crossing opportunities for pedestrians, further enhancing

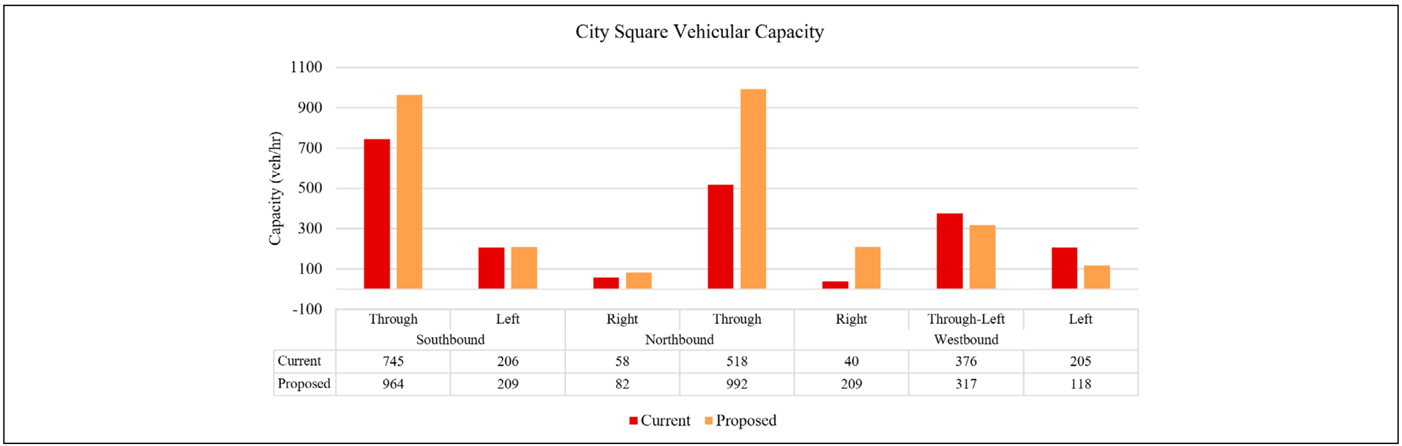


Figure 15. Comparison of City Square vehicular capacity under the current and proposed conditions.

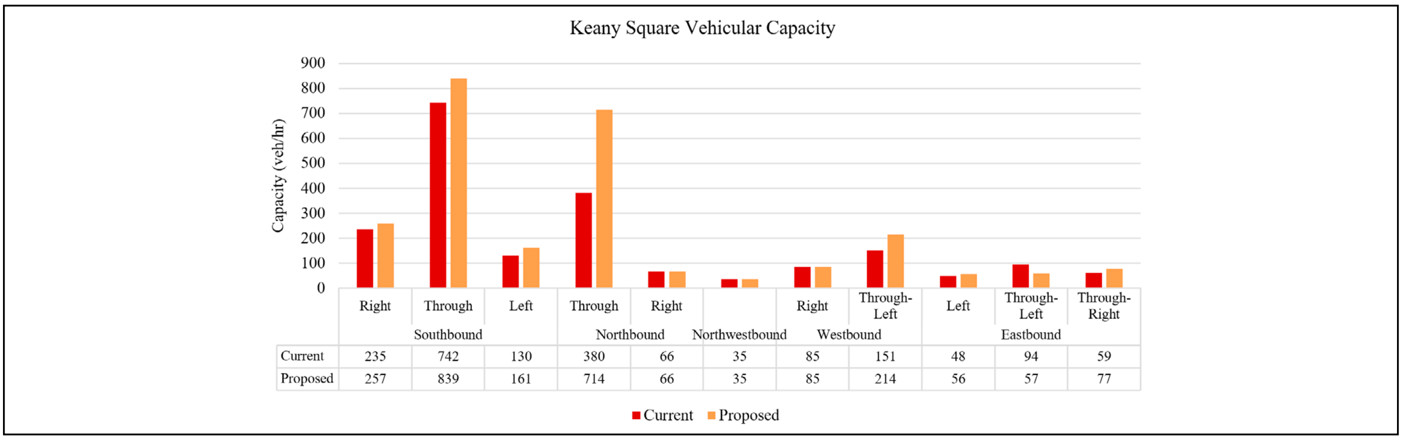


Figure 16. Comparison of Keany Square vehicular capacity under the current and proposed conditions.

the overall safety and accessibility of the roadway. The implementation of flexible signal logic, particularly at Keany Square, played a crucial role in sustaining performance without imposing rigid timing plans (Goyal et al., 2019). The capacity calculation was carried out, to determine the maximum limit of the available spaces (Dewi et al., 2022). This adaptive approach allowed the signal timing to adjust dynamically based on real-time traffic conditions, ensuring that the intersection operated efficiently under varying demand patterns, in essence, the road diet, combined with strategic signal timing adjustments, created a more balanced and efficient transportation system that prioritizes both mobility and safety. Urban intersection design seeks to optimize the safety and convenience of various users, including vehicles, pedestrians, and cyclists (Fitzpatrick et al., 2005). Flexible signal timings can reduce the severity of crashes (Wang et al., 2021).

4. CONCLUSION

This study provides empirical evidence that road diet implementation, coupled with signal timing optimization, can significantly enhance both traffic capacity and pedestrian safety at high-volume urban intersections. The intervention at City Square and Keany Square in Boston demonstrated substantial improvements across all performance metrics. Average vehicle delays decreased dramatically—from 171.97 to 31.12 veh-s at City Square and from 146.60 to 64.88 veh-s at Keany Square. Queue lengths also declined, with the northbound approach at City Square reduced from 1,677 ft to 899 ft, and the southbound approach at Keany Square from 1,812 ft to 769 ft. Pedestrian exposure times were substantially lowered due to split crossings and narrowed lanes, notably reducing the vulnerability of pedestrians at long, signalized intersections. Contrary to the belief that lane reductions compromise capacity, total intersection capacity increased by 34.59% at City Square and 24.98% at Keany Square, with the northbound approach at City Square gaining 498 veh/hr. These results underscore the efficacy of combining geometric redesign with coordinated signal control. The study advances the understanding of road diet applicability in congested urban contexts and reinforces the value of people-centric design in transportation engineering. Future research may expand this framework by examining long-term safety impacts, multimodal integration, and scalability to other high-density corridors.

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