Journal of Al-Azhar University Engineering Sector

Vol. 20, No. 75, April 2025, 582-594

FRAMEWORK AND GUIDELINES FOR THE DESIGN AND APPLICATION OF TRAFFIC CALMING MEASURES IN URBAN AREAS

Mahmoud Solyman[1], Hassan Salama[2*]

[1] Construction Engineering Department, Zagazig University, Egypt

[2]Civil & Environmental Engineering Department, Al Azhar University, Cairo, Egypt

***Correspondence:** hassansalama.14@azhar.edu.eg

Citation:

M. Solyman, H. Salama "Framework and Guidelines for the Design and Application of Traffic Calming Measures in Urban Areas", Journal of Al-Azhar University Engineering Sector, vol. 20, pp. 582-594, 2025.

Received: 04 January 2025
Revised: 16 February 2025
Accepted: 28 February 2025
Doi: 10.21608/auej.2025.354110.1758

ABSTRACT

This study evaluated 10,668 Traffic Calming Measures in Riyadh, Saudi Arabia, against current international and national standards. Data collection included the types of measures, construction materials, intended purposes, the presence of traffic safety features, and compliance with applicable standards. Vehicle speeds were analyzed before, at, and after encountering these measures, focusing on their types and heights. An assessment of existing construction procedures identified several shortcomings, prompting the development of a new approval process based on a point-scoring system informed by previous studies, local experiences, and international standards. The analysis demonstrated that traffic calming measures constructed according to standards improved driver and vehicle comfort while consistently reducing speeds to the target range. The study recommends implementing traffic calming measures through a systematic point-scoring method rather than citizen requests. This approach prioritizes locations with greater safety concerns and provides justification for the selection process to the public.

KEYWORDS: Traffic Calming Measures, Speed Bump, Speed Hump, Speed Table, Raised Intersection, point-scoring system

الإطار والمبادئ التوجيهية لتصميم وتطبيق إجراءات تهدئة حركة المرور في المناطق الحضرية

محمود سليمان[١]، حسن سلامة[٢*]

[١]قسم الهندسة الانشائية، جامعة الزقازيق، مصر

[٢]قسم الهندسة المدنيه، جامعة االازهر، القاهرة، مصر

البريد الالكترونى للباحث الرئيسى: hassansalama.14@azhar.edu.eg

الملخص

قامت هذه الدراسة بتقييم ١٠٦٦٨من إجراءات التهدئة المرورية في مدينة الرياض، المملكة العربية السعودية، وفقًا للمعايير الدولية والوطنية الحالية. شمل جمع البيانات أنواع إجراءات التهدئة المرورية ، ومواد بناءها، واالغرض المقصود من بناءها، ووجود وسائل السلامة المرورية بها، والامتثال للمعايير المطبقة. تم تحليل سرعات المركبات قبل وعند وبعد المرور بهذه الإجراءات ، مع التركيز على أنواعها وارتفاعاتها. كشف تقييم طرق البناء الحالية عن عدد من القصور، مما أدى إلى تطوير عملية توافقية جديدة تعتمد على نظام نقاط مستوحى من دراسات سابقة وخبرات محلية ومعايير دولية. أظهرت التحليلات أن إجراءات تهدئة حركة المرور المصممة وفقًا للمعايير تعمل على تحسين راحة السائق والمركبة مع تقليل السرعات باستمرار إلى النطاق المستهدف. توصي الدراسة بتطبيق إجراءات التهدئة المرورية من خلال نظام نقاط منهجي بدلاً من الاعتماد على طلبات المواطنين. يهدف هذا النهج إلى إعطاء الأولوية للمواقع ذات المخاطر الأكبر على السلامة وتبرير اختيارها للمواطنين.

الكلمات المفتاحية : إجراءات تهدئة حركة المرور، مطب السرعة، مطب تهدئة، منصة تهدئة السرعة، تقاطع مرتفع، نظام نقاط التقييم.

1. INTRODUCTION

In densely populated urban areas with high traffic volumes and pedestrian activity, enforcing traffic laws can be costly, making traffic calming measures (TCMs) a necessary feature to reduce vehicle speeds. TCMs should be considered at key locations within the urban road network, including intersections, places of worship, schools, hospitals, parks, public service facilities, and roads prone to car drifting and racing.

The design and implementation of TCMs, such as speed bumps, speed humps, speed tables, and raised pedestrian crossings are an essential aspect of managing traffic in urban areas. These measures are necessary to augment safety, manage the speed of vehicles, and ensure urban environments are habitable. Existing research into their design, optimization, behavioral impacts, and long-term performance has produced important information into the application and effectiveness of these measures.

Functional TCMs must consider speed reduction, safety, and comfort. Studies based on simulations have shown the importance of perfecting the geometry of the measure to reduce discomfort while also ensuring evident reduction of speed. For instance, an effective design for speed humps and dips focuses on decreasing health risks associated with whole-body vibration thresholds, while also ensuring functionality and effectiveness [1]. In similar fashion, flat-top speed humps have also been advanced to regulate peak vertical accelerations, which optimizes overall comfort and safety [2]. Improvements such as the K-pass, which is an adjusted speed bump design that targets the comfort of bicyclists, demonstrate the ability of TCMs to maintain their function while also accommodating vulnerable users [3]. The necessity of methods that are human-centered is emphasized by additional research, as they combine strategic placement and geometry of speed humps to ensure speed is consistently reduced [4]. Additionally, the assessments of speed tables on low-volume crosstown roads also highlight the importance of standardized designs and spacing for optimal safety [5].

In terms of the behavior impact and safety outcomes of TCMs, research shows that raised pedestrian crosswalks, when combined with speed humps, decrease speed of vehicles and enhance the compliance of drivers with yielding practices [6]. Yet the experience of various users differs. For instance, bicyclists experience greater discomfort than drivers of motorized two-wheeler vehicles when encountering traditional speed humps, which raises the demand for more inclusive designs [7]. Studies that emphasize on the attention patterns of drivers surrounding speed humps reveal that factors such as age and traffic conditions affect the focus and reaction times of users. This also indicates that the design of these measures should cater to the diversity of users [8]. Vertical deflections have also been shown to be successful in maintaining speed reduction when used in series in Tempo-30 zones [9]. Nonetheless, the aggressive nature of acceleration and deceleration practices near these TCMs highlight the need of inclusive strategies, such as refined signage, to enhance the physical strategies implemented and guarantee steady safety outcomes [10].

It is crucial to factor in environmental and long-term considerations when designing TCMs as well in order to assess the resilience of these measures. Long-term research conducted on natural cobble stones and concrete block-paved vertical TCMs indicate their durability and sustainability despite heavy traffic loads [11-12]. The results highlight the need to opt for materials that are longlasting while also ensuring consistent maintenance to uphold the effectiveness of the measures implemented. Building on this understanding, the current study investigates the material types used in TCMs to further understand their performance and suitability.

Technological and methodological advancements have a ripple effect as they are transforming the evaluation of TCMs over time. An emerging affordable alternative for collecting data with high accuracy at a large scale, discovered through research, is smartphone-based speed surveying [13]. Alternative improvements include advanced spectrum modeling, utilizing multi-sensor data, which enables precise observation of road features and reinforces approaches that are data-based for the design and implementation of TCMs [14]. These progressions underscore the ability of technology to augment both the application and continuous assessment of TCMs.

TCMs hold broader implications, beyond instant effects on road safety, such as urban habitability and economic performance. A study from Portland, Oregon, reveals the willingness of residents to pay for residence on streets with successful traffic calming programs [15]. This highlights the connection between controlled traffic and property values. The results of this research draws attention to the multiple functions of TCMs in both advancing safety and cultivating urban development.

In summary, existing research provides a solid foundation for the design and implementation of TCMs in urban areas. The integration of advanced designs with behavioral considerations, sustainable materials, and progressive monitoring techniques can enhance safety, habitability, and broader urban design objectives. Building on previous studies, all TCMs in Riyadh City, Kingdom of Saudi Arabia, were collected and evaluated against standard practices. Additionally, the effectiveness of these measures in reducing speed at their respective locations was assessed relative to the current speeds on the streets. The study operates on the assumption that the presence of TCMs will reduce speeds, regardless of their types and design, given the fact that the measures are physically apparent to drivers. If this assumption is correct, these TCMs should be designed and constructed in adherence to established standards to ensure the safety and comfort of both drivers and residents.

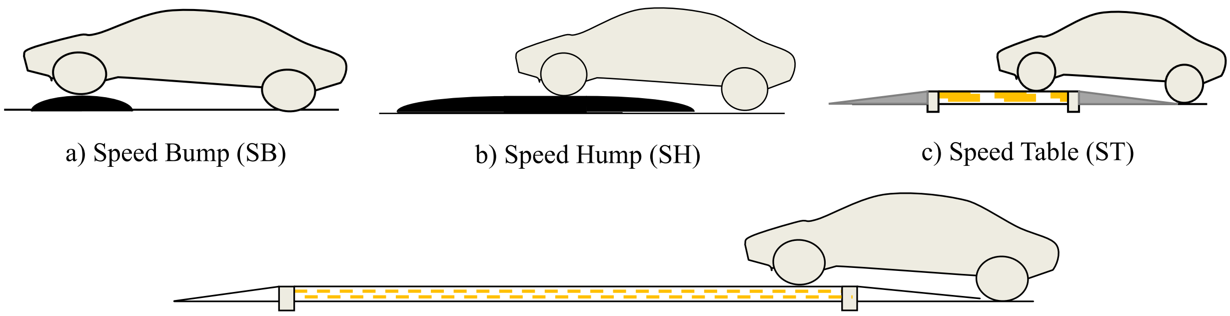
This study addresses the lack of objective, systematic steps for installing TCMs by developing a new approval process based on a point-scoring system informed by international standards and local experiences. By evaluating over 10,000 TCMs in Riyadh, the study examines their compliance with standards, effectiveness in reducing vehicle speeds, and impact on driver comfort. This approach emphasizes the importance of a standardized, data-driven framework for the design, implementation, and maintenance of these measures, moving away from unsystematic installations based on citizen requests.

2. DATA COLLECTIONS

This study collected data on various types of TCMs across Riyadh City (the study area), covering 10,653 installations distributed throughout the city's districts. The data included road classifications of where these measures were located, their types, construction materials, surrounding land use, presence of TCMs, and reasons for their implementation. The collected information was analyzed to evaluate existing guidelines and develop improved procedures and criteria for constructing TCMs. The following subsections highlight key aspects of the collected data.

2.1. Types of Traffic Calming Measures

The study area includes various types of TCMs, including Speed Bumps (SB), Speed Humps (SH), Speed Tables (ST), and Raised Intersections (RI). **Fig. 1** provides a schematic representation of these traffic calming types, while **Table 1** presents their respective quantities and percentages. The data indicate that speed bumps constitute the majority, representing over 80% of all TCMs, followed by speed tables and speed humps. Raised intersections are the least common, with only 14 instances, accounting for just 0.1% of the total.



a) Speed Bump (SB) b) Speed Hump (SH) c) Speed Table (ST)

d) Raised Intersection

Fig. 1: Types of Traffic Calming Measures

The collected data indicated that TCMs in the study area were constructed using various materials, including asphalt, interlock, concrete, and rubber. Asphalt TCMs were the most prevalent, with 10,332 units, representing 96.9% of the total. Interlock speed humps, numbering 254 (2.4%), were commonly used for both speed humps and raised intersections, particularly near pedestrian crossings. Concrete TCMs were rare, with only 67 units (0.6%), all of which were non-standard and built by residents. Rubber speed humps were the least common, with just 15 units (0.1% of the total). **Table 2** summarizes the number of TCMs by material type.

Table 1: Types and Percentage of Traffic Calming Measures in Riyadh City

Types	Numbers	Percentages
SB	8580	80.5%
SH	243	2.3%
ST	1816	17.0%
RI	14	0.1%
Total	10653	100

Table 2: Traffic Calming Measures Classification According to Material Types

Material Types	Asphalt	Interlock	Concrete	Rubber	Total
No. of traffic-calming measures	10332	254	67	15	10668

2.2. Purpose of Constructing Traffic Calming Measures

TCMs are implemented for various purposes, primarily to enhance pedestrian safety near high-foot-traffic areas such as schools, places of worship (mosques), hospitals, parks, and public service facilities, as well as to mitigate issues such as car drifting and racing. **Fig. 2** illustrates the different purposes for constructing these measures in the study area [16]. An analysis of the collected data revealed that the main reasons for installing TCMs were the need for speed reduction (22.1%), the presence of road intersections (22.1%), and proximity to schools (22.0%) or places of mosques (26.6%). Other facilities, including hospitals, parks, and public service centers, accounted for smaller percentages, ranging from 0.8% to 3.7%.

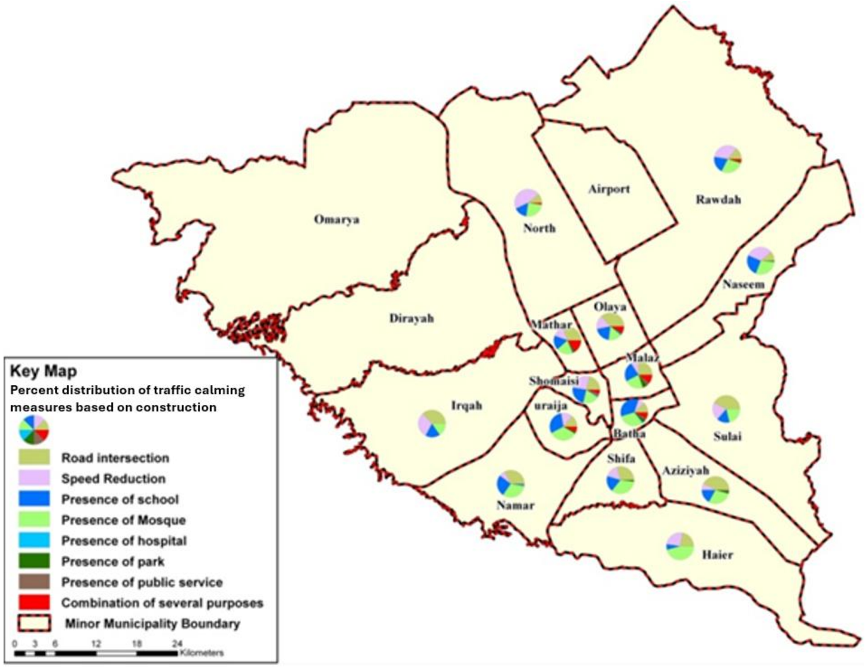


Fig. 2: Purposes of Constructing Traffic Calming Measures in the Study Area

2.3. Traffic Safety Elements at Existing Traffic Calming Locations

TCMs are effective tools for reducing vehicle speed in urban areas. However, it is crucial to implement appropriate traffic safety measures at these locations to inform drivers. Such measures include warning signs, pavement markings, and in some cases, flashing signals. The absence of these safety features can reduce the effectiveness of the speed calming measures, increase the risk of accidents, and cause noise disturbances for nearby residents. Data analysis revealed that 7,509 speed humps (70.4%) are equipped with safety measures, while 3,159 speed humps (29.6%) lack any such features.

3. EVALUATION OF EXISTING TRAFFIC CALMING MEASURES

Data on TCMs were collected, evaluated, and analysed. These measures were classified based on their compliance with standard criteria into two categories: standard and non-standard. Vehicle speeds before and after selected speed humps were measured to assess their impact on traffic speed. Additionally, the current procedures for constructing speed humps used by the municipality were reviewed, revealing several shortcomings.

3.1. Compliance of Traffic Calming Measures with Guidelines

Relevant guidelines from the literature were reviewed [16 – 20], and standard criteria were established based on previous studies and local experience. **Table 3** presents these criteria, detailing location, width, height, and ramp slope specifications for various types of speed humps.

Table 3: Standard Criteria for Traffic Calming Measures

Speed calming measure	Standard Criteria			
	Locations	Width	Height	Ramp slope
Speed Bump (SB)	Driveways and Parking lots	0.3 – 1.0 m	7-10 cm	N/A
Speed Hump (SH)	Residential local streets	Minimum 3.5 m	7 – 10 cm	N/A
Speed Table (ST)	Residential collector streets and emergency vehicle or transit routes if necessary	Minimum 6.6 m	7 – 10 cm	1:20 to 1:24
Raised Intersection (RI)	Local or collector streets in commercial areas	Width of intersected street	7 – 10 cm	1:20 to 1:24

In accordance with established criteria, all types of TCMs in the study area were evaluated for compliance with standard guidelines. The TCMs were classified as either "standard" or "non-standard." Standard TCMs meet the required specifications for width, height, and ramp slope, while non-standard TCMs fail to meet at least one of these criteria. **Table 4** presents a classification of the TCMs as either standard or non-standard. The results show that 4,395 speed humps, along with 10 speed tables, conform to the standard criteria, while the remaining measures violate at least one of the standard dimensions (width, height, or ramp slope). This indicates that only 41.3% of the measures meet the prescribed standards. **Fig. 3** provides a graphical representation of the different types of speed humps and their compliance with the standard criteria.

This section examines the effect of TCMs on vehicle speeds. Speed measurements were collected at 10 locations on collector roads, each featuring a variety of TCMs, including speed humps, speed tables, and speed bumps. These measures varied in type, height, and design. Vehicle speeds were recorded at three points: 80 meters before the measure, directly at the measure, and 80 meters after the measure.

Fig. 4 illustrates the average speeds recorded at these locations, revealing consistent trends across all measure types. Speeds at 80 meters before the measures were consistently higher than those recorded 80 meters after. On average, vehicle speeds decreased from 55 km/h before the measure to 28 km/h at the measure, aligning with the target range of 20–30 km/h at most locations, and then increased to 47 km/h 80 meters after the measure. A closer examination of **Fig. 4** reveals the following key observations:

Table 4: Classification of Traffic Calming Measures into Standard and Non-standard

Type	Standard	Non-standard				Total
		Width	Heights	Ramp Slope	All	
Speed Bump	0	1278	0	0	538	1816
Speed Hump	4395	283	3749	0	153	8580
Speed Table	10	0	0	233	0	243
Raised Intersection	0	0	0	14	0	14
Total	4405	1561	3749	247	691	691

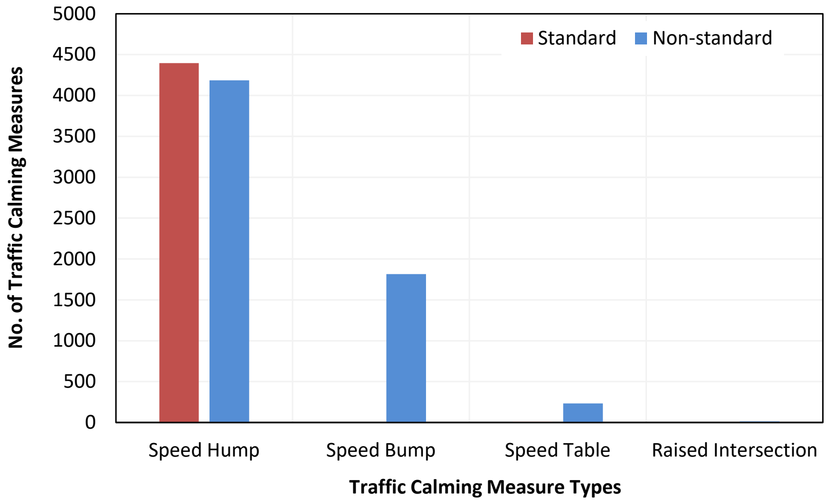


Fig. 3: Conformation of the Traffic Calming Measures with the Standards

3.2. Effect of Traffic Calming Measures on Speed

The analysis of speed data collected at various TCMs reveals key insights into their effectiveness. These findings highlight the variations in performance across different TCM designs and underscore the importance of adhering to established design standards. The following observations summarize the study's key results and their implications for improving speed control measures:

- Speeds dropped substantially from 55 km/h before the measures to 28 km/h at the measures, achieving the desired target speed range at most locations. Similar studies examining vehicle speeds before, at, and after speed humps and speed tables have reported consistent findings [8].
- The higher two lines in **Fig. 4**, representing speed hump designs of 3.5m – 7.5cm and 4.0m – 7.5cm, indicate speeds exceeding 30 km/h at the measure. These designs, particularly when approaching speeds exceed 60 km/h, fail to achieve adequate speed control. The reduced effectiveness is likely due to the lower height of 7.5 cm, which lacks the physical prominence necessary for significant deceleration.
- According to the Institute of Transportation Engineers (ITE) [17] and other guidelines, vertical TCMs should ensure speeds do not exceed 30 km/h at the measure. The 7.5 cm height of these speed humps may fall below recommended thresholds for effective speed reduction, especially on roads with higher traffic volumes or speeds. Enhancements such as warning signs and optical markings are recommended to improve their effectiveness.
- While most TCMs reduced speeds to within the target range, exceptions such as the 3.5m – 7.5cm and 4.0m – 7.5cm speed humps highlight the need for stricter adherence to design standards to ensure consistent performance across all measure types.
- The above results validate the study assumption that the presence of TCMs will reduce vehicle speeds, given the fact that the measures are physically apparent to drivers.

After excluding the 3.5m – 7.5cm and 4.0m – 7.5cm speed humps which consider outliers, the speed before, at and after the measures were averaged for each measure of speed hump, speed bump and speed table. **Fig. 5** illustrates the effect of types of TCMs on vehicle speed. The figure shows the following observations:

- Speed bump measures achieve the greatest reduction in vehicle speed, with average speeds dropping significantly at the measure and remaining lower compared to other measures. This reflects their higher effectiveness in enforcing deceleration due to their steep profile.
- Speed humps demonstrate a moderate reduction in speed at the measure, with average speeds higher than those observed for speed bumps but lower than speed tables. This indicates a balance between driver comfort and speed control.
- Speed tables exhibit the least reduction in speed, with average speeds at the measure being higher than those for speed humps and speed bumps. Their design, typically involving a flat surface, offers greater comfort for drivers, which may contribute to less significant speed reduction.

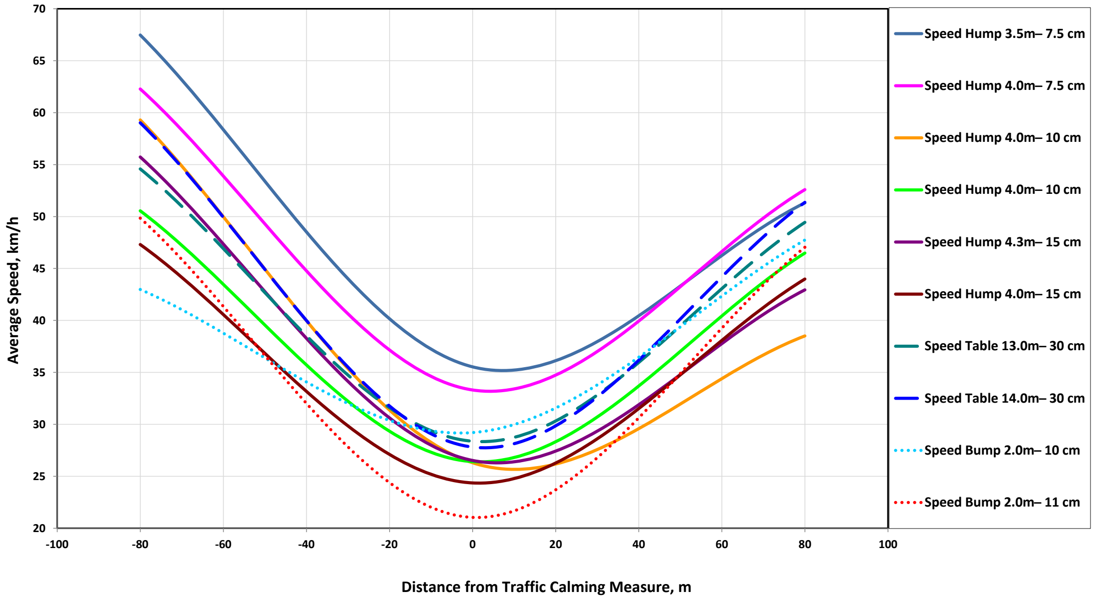


Fig. 4: Effect of Traffic Calming Measures of Different Types and Geometry on Vehicle Speed

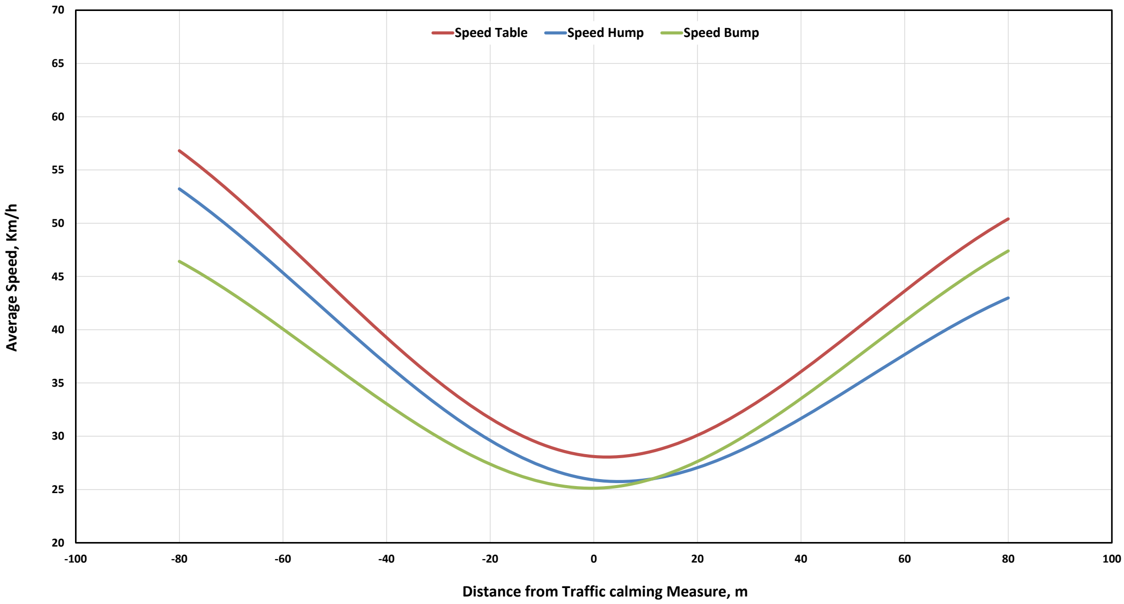


Fig. 5: Effect of Types of Traffic Calming Measures on Vehicle Speed

3.3. Procedures for Constructing New Traffic Calming Measures

Fig. 6 illustrates the workflow for constructing or removing TCMs in the study area. It should be noted that the current process and application for installing TCMs are only initiated by a request from citizens without any planning or suggestions made by the municipality. However, the appropriate process should begin with planning and evaluation by the municipality culminates in the final implementation. As part of the evaluation process for constructing TCMs, a comprehensive review of several specifications and guidelines [16–20] identified the following criteria.

3.3.1. Criteria for Speed Hump Installation

Speed hump installation is guided by specific criteria to ensure effective traffic calming and safety improvements. These measures are typically suitable for local and collector streets with moderate traffic volumes, low-speed limits, and proximity to pedestrian-attracting areas such as schools and parks. The following criterion:

- TCMs are generally not permitted on expressways or arterial roads, except under special safety circumstances.
- TCMs are appropriate for local and collector streets with a speed limit of 50 km/h.
- They are recommended near pedestrian-attracting land uses, such as schools, mosques, parks, and community centers.
- These measures can be implemented at non-controlled intersections where sight distance is inadequate.
- The street should carry a daily traffic volume of between 750 and 5,000 vehicles.
- The minimum street length should be 300 meters, though this requirement can be reduced to 200 meters near pedestrian-attracting areas.
- Streets regularly used by public transit or emergency vehicles are not suitable for TCMs.
- The longitudinal grade of the street should not exceed 8%.
- The 85th percentile speed should be at least 10 km/h higher than the posted speed limit.

3.3.2. Evaluation of Criteria Application

The evaluation of the criteria and their current implementation in the study area revealed the following deficiencies:

- Requests for TCMs are exclusively initiated by citizens, with no proactive assessments or planning conducted by the responsible authorities, such as the traffic department or municipality.
- Decisions are strictly based on whether all criteria are fully satisfied, without considering partial compliance or assessing the severity of deviations from individual criteria.
- Critical factors, such as speed-related accident rates, the presence or absence of sidewalks, and driveway spacing, are not incorporated into the evaluation criteria, limiting the comprehensiveness of the process.
- There is a lack of systematic measurement and analysis of the 85th percentile speed, which is a key indicator in assessing traffic calming needs.
- Traffic volumes were only measured in a small number of cases, undermining the reliability of the evaluations.
- The approval process relies heavily on subjective judgment rather than an objective, transparent, and data-driven evaluation framework, leading to inconsistencies in decision-making.

3.3.3. Recommendations for Improvement

To address the identified deficiencies and enhance the effectiveness of TCMs, several recommendations are proposed. These recommendations aim to establish a more proactive, comprehensive, and transparent evaluation process:

- Municipal authorities should take the initiative in identifying locations for TCMs, rather than relying solely on citizen requests.
- Introduce a scoring framework that accounts for partial compliance and the severity of deviations from specific criteria, ensuring a more nuanced decision-making process.
- Expand the evaluation criteria to include key factors such as accident history, sidewalk availability, and driveway spacing, which are crucial for safety and usability.
- Establish consistent methodologies for collecting critical data, such as traffic volumes and 85th percentile speeds, to ensure reliable and objective evaluations.
- Create a clear and objective decision-making framework that minimizes subjective judgments and increases accountability.

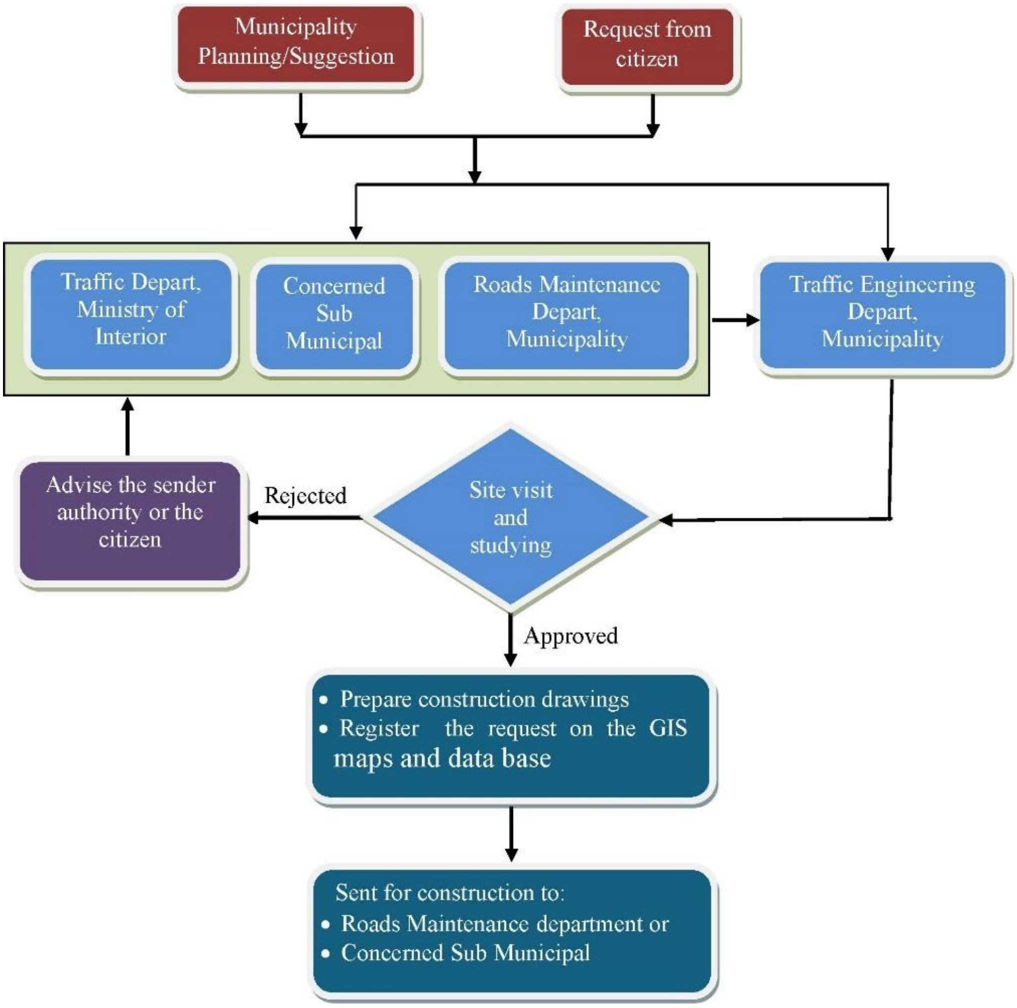


Fig. 6: Workflow for Constructing or Removing Traffic Calming Measures in Traffic Engineering Department

4. DEVELOPMENT DESIGN GUIDELINES AND PROCEDURE FOR CONSTRUCTION APPROVAL OF NEW TRAFFIC CALMING MEASURES

This section outlines the development of guidelines and procedures for approving the construction of new TCMs. It also introduces the primary design standards and approval criteria that guide their implementation.

4.1. Design Guidelines

The newly developed guidelines were established based on previous studies [16–20] and local experience in the study area. These guidelines are as follows:

- TCMs should not be installed within 60 meters of the nearest speed control point, such as a sharp horizontal curve, the start of a downgrade, or a stop sign.
- When multiple TCMs are required, the distance between consecutive measures should range from 80 to 120 meters.
- For street segments without other speed control measures, the recommended number of TCMs is:
  - One measure for street segments 90 to 150 meters long.
  - Two measures for street segments 150 to 300 meters long.
  - Three measures for street segments 300 to 450 meters long.
- TCMs should be installed perpendicular to the street's direction.

- Minimum sight distance to the measure should align with the design speed.
- TCMs are not recommended on streets with an 85th percentile speed of 70 km/h or higher.
- Avoid installing measures on horizontal curves with a radius of 90 meters or less.
- Speed humps should not be installed on streets with a longitudinal grade of 8% or greater [17].
- The minimum distance between a TCM and intersecting streets should be:
  - 6 meters from a residential local street.
  - 30 meters from a residential collector street.
  - 75 meters from a signalized intersection.
- The geometric design criteria for new speed humps are detailed in **Table 5**.

Table 5: Geometric Design Criteria for Traffic Calming Measures

Type	Location	Height, cm	Total width, m	Leveled width, m	Ramp width, m	Ramp slope
SH	Residential local streets	7 - 9	3.7 - 4.3	NA	NA	NA
ST	Residential collector streets and emergency vehicle or transit routes if necessary	7 - 9	6.6 – 7.0	3	1.8 -2.0	1:20 – 1:24
RI	Local or collector streets in commercial areas	7 - 9	Width of intersected street + width of ramps	Width of intersected street	1.8 -2.0	1:20 – 1:24

4.2. Construction Approval

To address the limitations of the current approval process for constructing TCMs − which relies heavily on subjective judgment rather than systematic quantitative criteria − a new point-scoring system was developed. This system provides an objective framework for approval, based on measurable factors. Key factors influencing the placement of TCMs were identified from previous studies, standards, and guidelines. These factors were evaluated by transportation safety experts, with relative scores assigned to each item. Additionally, several standards and guidelines [16–20] were reviewed to refine the final point allocation for each factor. **Table 6** outlines the specific points assigned to each evaluation criterion, establishing a priority-based system for implementing TCMs. This system is particularly beneficial for municipalities facing budget constraints, ensuring that resources are allocated efficiently based on quantified needs. The following list highlights the most important factors relevant to the study area.

- Posted speed: Prevailing speed on the road.
- Land use: Primarily residential areas.
- Road classification: Urban local and collector roads.
- Road alignment and length: Uninterrupted straight roads with lengths exceeding 300 m.
- Road cross-section: Two-lane, two-way roads.
- Traffic volume: Low traffic volume with an ADT (Average Daily Traffic) between 500 and 4,000 vehicles/day.
- Crash history: Number of crashes recorded in the past three years.
- Sidewalk availability: Presence of sidewalks on both sides of the road.
- Type of traffic: Streets serving local traffic versus a mix of local and through traffic.
- Adjacent activities: Land use and activities on both sides of the road.

Each item was assigned a score relative to the others, with items scoring less than 5 points excluded due to their minimal impact. The final list includes only the most effective items, with a total score of 100 points. Table 6 presents the final list of evaluation items along with their assigned scores. This table provides an objective, systematic framework for deciding where to implement traffic calming measures (TCMs) within the municipality's jurisdiction, minimizing potential biases arising from citizen requests. Once the necessary information for the items listed in **Table 6** is collected, each location can be evaluated, and a final score determined. The point-scoring method facilitates prioritizing locations with significant safety concerns, particularly when budget constraints exist, while also providing a transparent and justifiable basis for selecting locations to the public.

Table 6: Point-Scoring System for Traffic Calming Measures Warrant

Criterion	Points	Details
Severity of Speeding	Up to 40	4 points for every 1 km/h that the 85th percentile speed exceeds the limit.
Traffic Volume (ADT)	Up to 20	1 point per 200 vehicles over 1,000 vehicles/day.
Crash History	Up to 15	5 points per speed-related crash in the past three years.
Proximity to Schools, Parks, Places of Worship, Malls, or Hospitals	Up to 10	10 points: within 100 m.
Absence of Sidewalks	Up to 5	5 points if no continuous sidewalks exist on either side of the road.
Pedestrian Activity	Up to 5	5 points for high pedestrian volumes during peak hours.
Cut-Through Traffic	Up to 5	5 points if significant non-local traffic is present.

CONCLUSIONS

This study analyzed over 10,000 traffic calming measures in Riyadh, Saudi Arabia, and evaluated the current procedures for their construction. Key conclusions are as follows:

- Drivers consistently reduced their speeds at all visible traffic calming measures, regardless of type or height. Constructing these measures according to established standards enhances both driver and vehicle comfort.
- The placement of traffic calming measures should be informed by comprehensive studies of candidate locations rather than relying on citizen requests. Municipal oversight during construction is crucial to ensure adherence to standards, as many non-compliant measures resulted from unsupervised citizen-driven initiatives.
- New procedures and guidelines were developed using a point-scoring system informed by previous studies and local experiences. This framework can be adapted for use in other regions by tailoring the scoring criteria to local conditions.
- Traffic safety features must accompany traffic calming measures to improve functionality, reduce accidents, and minimize noise. Dedicated maintenance budgets are essential to ensure long-term operational efficiency.
- Future studies should incorporate data on accident rates, traffic speeds before and after installation, and traffic volumes to enable a more comprehensive evaluation.
- The developed point-scoring system and guidelines provide a systematic, objective method for identifying and prioritizing high-risk locations for traffic calming measures, ensuring transparency and justifying decisions to citizens.

The current study provides a comprehensive analysis of traffic calming measures in Riyadh City, Saudi Arabia, focusing specifically on vertical deflection methods. While the developed point-scoring system offers a systematic framework for prioritizing and implementing traffic calming measures, its applicability should be reevaluated for other residential areas to account for local conditions and variations. Furthermore, this study exclusively examined vertical deflection methods, such as speed humps and speed tables, while other traffic calming measures—such as horizontal deflection, road narrowing, and signage—were not included. Future research could explore these additional methods to develop a more holistic understanding of traffic calming strategies and their effectiveness across various contexts.

ACKNOWLEDGMENTS

The authors wish to express their sincere gratitude to Riyadh City, Kingdom of Saudi Arabia, for their invaluable support throughout this research. This study would not have been possible without the provision of high-quality data and the constructive feedback offered by the city's representatives.

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

[1] E. Khorshid, H. Awada, A.H. Falah, and A. Elkholy, "Optimal design of traffic calming devices using computer simulation," International Journal of Modelling and Simulation, vol. 40 no. 5, pp.375-393, 2020.

[2] T.R. Botha, P.S. Els, P.E. Uys, and R. Bester, R., "Profile optimization of table top speed hump for speed control," International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, vol. 54853, pp. 733-738, 2011.

[3] S. Chandra, R.S. Chalumuri, K. Gupta, and N. Chakrabarty, N., "Evaluation of fixation and reaction gaze points near speed humps on urban roads in India," Current Science (00113891), vol. 124 no. 2, 2023.

[4] N. Berloco, P. Colonna, P. Intini, G. Masi, and V. Ranieri, "Low-cost smartphone-based speed surveying methods in proximity to traffic calming devices," Procedia computer science, vol. 134, pp.415-420, 2018.

[5] R. Ziolkowski, "Influence of traffic calming measures on drivers' behaviour," Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE, vol. 9, Vilnius Gediminas Technical University, Department of Construction Economics & Property, 2014.

[6] V. Gitelman, R. Carmel, F. Pesahov, and S. Chen, "Changes in road-user behaviors following the installation of raised pedestrian crosswalks combined with preceding speed humps, on urban arterials," Transportation research part F: traffic psychology and behaviour, vol. 46, pp.356-372, 2017.

[7] V. Vasudevan, and T. Patel, "Comparison of discomfort caused by speed humps on bicyclists and riders of motorized two-wheelers," Sustainable cities and society, vol. 35, pp.669-676, 2017.

[8] H.A. Mahdy, "Speed calming using vertical deflections in road alignment," The 9th International Conference on Civil and Architecture Engineering, vol.9, pp. 1-10, Military Technical College, 2012.

[9] S. Polloni, "Traffic calming and neighborhood livability: Evidence from housing prices in Portland," Regional Science and Urban Economics, vol. 74, pp.18-37, 2019.

[10] G. Loprencipe, L. Moretti, A. Pantuso, and E. Banfi, "Raised pedestrian crossings: Analysis of their characteristics on a road network and geometric sizing proposal," Applied Sciences, 9(14), p.2844, 2019.

[11] L. Cygaite, I. Lingyte, and M. Strumskys, "Analysis of vertical traffic calming measures in impacts on road safety and environment in lithuania state roads" Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE, vol. 9, Vilnius Gediminas Technical University, Department of Construction Economics & Property, p. 1, 2014.

[12] A.T. Moreno, A. García, and M.A. Romero, "Speed table evaluation and speed modeling for low-volume crosstown roads," Transportation research record, vol. 2203, no. 1, pp.85-93, 2011.

[13] J.T.S. Al-Obaedi, Z.A.Z. Al-Salihy, and H. Ahmad Jasim, "The effect of speed humps on highways pavement condition" International Journal of Engineering, vol. 33, no. 5, pp.737-743, 2020.

[14] H. Lyu, Q. Zhong, D. Jiao, and J. Hua, "Bump feature detection based on spectrum modeling of discrete-sampled, non-homogeneous multi-sensor stream data," Applied Sciences, vol. 14, no. 15, p.6744. 2024

[15] K. Ambak, S. Jemari, B.D. Daniel, M.H. Othman, and M.N. Borhan, "The effectiveness of new 3D visual effect speed hump in speed reduction," MATEC Web of Conferences, vol. 250, EDP Sciences, p. 02001, 2018.

[16] "General Specifications of Urban Road Construction, Appendix 5 – Traffic Calming Bumps," Ministry of Municipal and Rural Affairs Riyadh, Saudi Arabia, 2005

[17] "Guidelines for The Design and Application of Speed Humps," Institute of Transportation Engineers, (ITE), Washington, DC, USA, 2007.

[18] "Standard procedure for managing speed on residential streets", The City of Santa Ana, California, USA.

[19] City of Lynwood speed hump installation policy, guidelines, and procedures. California, USA.

[20] Traffic calming guide for Toronto. Ontario, Canada.