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Usage and impacts of speed humps on vehicles: A review

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ABSTRACT

Traffic calming plays a vivacious role for the sustainability of traffic management system. Vertical and horizontal calming devices are used globally to decrease speeds at acceptable levels for the execution of laws with ease. Various types of retarders are used to calm the speeds such as speed breakers, which are installed for the safety of users, can impose detrimental effects on vehicles and environment as well. If installed improperly, or the design is ineffective without the use of prior guidelines then they become vehicle breakers actually. Current review chiefly discusses some work and investigations carried out from 1985 to 2015 for traffic management and impact analysis. To cope up with related issues this review also highlights some investigations related to impacts on vehicles and environment at a glance, which will help governmental agencies and researchers to improve the designs of humps and vehicles, which will ultimately lead the system towards proficient use with minimal impacts.

1 Introduction

Road accidents and injuries are becoming major fatality accelerators in developing as well as developed countries. Consequently, traffic calming is a need of today's roads. There is a need of various solid strategies to make roads for sure safe for users, vehicles and environment. Speed retarding measures are to be made in connection with the safety of vehicles and environment. But if these designs and structures are implemented without the use of approved guidelines, then they could become havoc and pose significant impacts on users, vehicles and environment. Hence, there is a need to identify these problems with quick eradication i.e., if designs are improper then they should be removed and substituted with new ones having proper dimensions, which will help in the reduction of traffic related problems.

Research conducted in the fields of traffic management, traffic calming, speed humps with their associated impacts were reviewed and analyzed thoroughly for this review. These papers, which are

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mentioned in this review cover a duration of 30 years i.e., from 1985 to 2015. Over speeding, careless behavior of driver, underestimation of legislations are some factors which evoke us to move towards special revised standards and designs for the safety of everything associated with stakeholders, roads and streets. A number of strategies can be implemented for speed reduction and traffic management like sign boards, chicanes, speed breakers, driver education, raised intersections, roundabouts and traffic circles. Fig. 1 shows various horizontal and vertical measures used for flow retardation, which are as follows [1]:

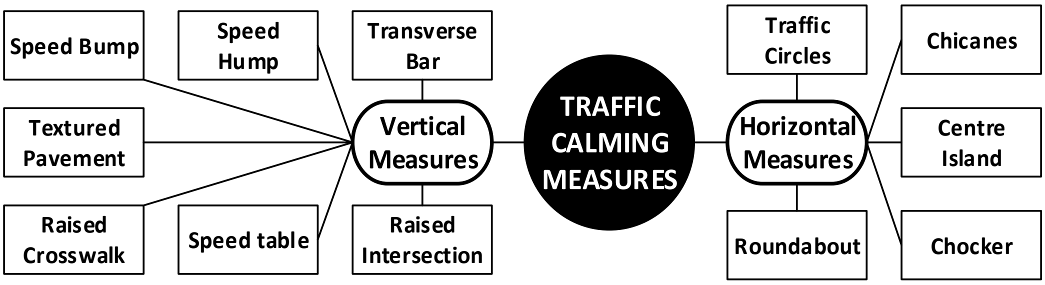

Fig. 1. Various traffic calming measures [1]

In this paper, core focus is on speed breakers or speed humps which are used for traffic calming and strategy used for the minimization of traffic injuries. Speed breakers if installed with negligence and without using prior guidelines can impose serious threats on vehicles. Speed breakers are being underestimated in two ways: Firstly, they are being installed improperly without approved design usage; secondly they are being installed at inappropriate places repeatedly, where there is no need of them. Vehicles considered by previous researchers were all types of rides like cars, trucks, buses, tractors, bikes and rickshaws. These undulations on the roads cause excessive Whole-Body Vibration (WBV) with vehicle damage [2-4]. Vehicle is deteriorated either by wear and tear of brakes and tyres or by damage of internal suspension components with more fuel consumption.

Environment is also affected either due to emissions or increase in noise levels. If the design is improper and there is no space for drainage system then rain water may become stagnant at various points, which may cause the germination of bacteria and mosquitoes. These problems in turn affect residents and environment with impaired aesthetics. When vehicle bottom comes in contact with speed breakers then friction is generated which cause destruction of shoulders and hump itself. Therefore, while deceleration and acceleration of vehicle Particulate Matter (PM_{10}), carbon oxides (CO_2, CO) and nitrogen oxides (NO_x) are emitted in excess, which cause breathing problems for locals and users [5].

2. Literature review

Emphasis on various related aspects is made by the help of small segments in literature, where each section articulates the wok done for speed breakers in different years. Worthy attempts were carried out by various researchers for the identification of major impacts.

2.1 Impacts on vehicles

Vehicle is mainly deteriorated due to bottom damage, wear and tear of brakes and tyres, suspension and internal component damage. Figure 2 shows the impacts associated with speed humps on vehicle. Network diagram shown in Figure 2 is molded by the help of extensive literature review related to impacts on vehicle and guidelines used for design and installation of speed humps.

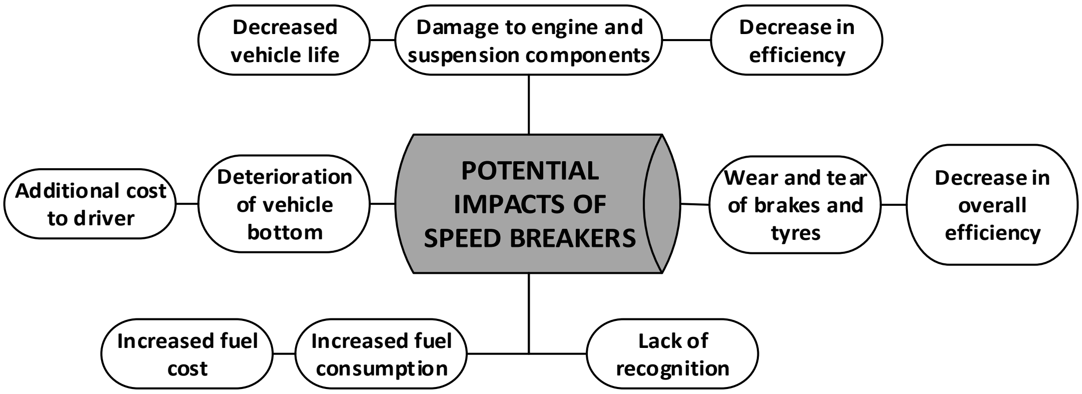

Fig. 2. Potential impacts of speed breakers on vehicle

2.2 State-of-the-art guidelines

A study was carried out to assess the performance of traffic management system by the help of various traffic control devices for residential streets [6]. In 1985, a drill was carried out by Bureau of Traffic Services, Department of Public Works, Washington, D.C to quantify issues and opinions related to road bumps. It was mentioned that most of the traffic officials are against the use of speed bumps due to deterrence. It was also forecasted that future is for road humps instead of road bumps for smooth flow of traffic without huge impacts. Commonly used approaches like public awareness and engineering approaches were discussed [7]. Conclusions supported that speed bumps work as the way users use them i.e., if agencies install bumps with inappropriate designs then they will serve as evil cause. Authors also recommended that Institution of Transportation Engineers (ITE) and American Association of State Highway and Transportation Officials (AASHTO) should not remain calm for this aspect [7]. Several investigations revealed that speed humps are efficient enough to decrease vehicle speed, while taking care of driver and vehicle safety under specific scenarios [8-11].

2.3 Speed management and community acceptance

In 1992, a research was probed for road humps as speed moderators in urban areas on the basis of literature review and survey, in which community acceptance was evaluated and influencing factors were identified. Survey methodology was used in community for the valuation of speed hump experience. Issues identified due to road humps were vehicle control, discomfort, noise and vibration. Potential difficulties for emergency vehicles were identified such as discomfort, damage, access and delay [12].

2.4 Institute of Traffic Engineers and Traffic Calming

In September 1996, Institute of Traffic Engineers (ITE) Annual Meeting was held in Minneapolis, Minnesota to debate traffic calming. The purpose of meeting was to discuss how ITE could contribute to traffic calming. According to this traffic calming is essentially related to physical measures that reduce adverse effects of motor use and changing driver behaviour with improvisation in conditions for non-motorized users [13].

2.5 Designs and speed behaviour

In 1997 an investigation was carried out by University of Leeds to quantify the effect of road design on speed behaviour. In this literature efficacy of various speeds reducing measures were estimated. The foremost focus of this research was on the factors, which pose impacts on the driver's behaviour indirectly [14].

In 2000, geometric standards for speed humps were deliberated in ITE journal, where contribution of new designs were evaluated as main agenda for users of different countries, where environment, vehicle characteristics and motorist expectations vary. The induced vertical acceleration induced is decreased due to shock absorbers in suspension system [15]. It was emphasized that length of speed hump should be more because if it will be then there will be more linear dynamic effects and length was considered as critical design parameter [16, 17]. In first phase, radar gun was used to record speeds. In second phase, off-road experiments were conducted and discomfort associated with vibrations were measured, while taking Root Sum of Square (RSS) equal to discomfort criteria for each type of vehicle. Results signposted that sample size should be more for defining discomfort criteria. Future studies should be for different ramp slopes because Watts and Seminole profile humps have same heights and have same ramp slopes [15].

In 1992, it was outlined that in developed countries like UK most common traffic calming devices were flat-topped tables, humps, raised junctions, cushions and chicanes [18]. In 2000, research was published under Transportation Research segment, in which a model was presented for traffic calming with an emphasis on the analysis of different combinations of calming measures on the speed of unimpeded vehicles. Data regarding driver's behaviour was collected at pre-determined points with traffic calmed points. Regression was used for the estimation of variables in the model. It was concluded that greatest impact on speeds is due to speed tables, followed by speed humps, chicanes and cushions with a need of in-depth analysis for chicane's design [19].

2.6 Passive speed control strategies

According to Research laboratory (UK) Vertical undulations on roads were used for speed reduction in 1970s and this became a common passive method for speed reduction in many countries [20]. Researchers have focused on the undulations used for traffic calming and speed reduction up to 85^{th} and 50^{th} percentile of speeds [11, 21-25]. In 2001, Italian experience was inspected for speed bumps to decrease speed and to limit fatalities in urban areas. It was also mentioned that benefits taken by the help of speed humps in terms of decrease in accidents and pedestrian safety are more as compared to other costs like car damage.

A relationship was developed between lane width and speed at both bumped and free sections by linear regression analysis. ANOVA was used to evaluate the worth of speed variations. It was suggested that speed variation depends upon geometries rather than types of traffic calming devices used. Results also deduced that speed bumps provoke no decisive reaction from drivers approaching a crosswalk [26].

Various researchers have worked in determining the range of speeds in the areas where different types of traffic calmers as undulations were employed. Some of the investigations carried out are mentioned below in Table 1 [26]:

Table 1
Range of observed speeds for different calming measures [26]

Sr. No	Investigator	Device	Range of speed observed (85%) (km/h)
1	[11]	Humps	35.2 – 43.7
2	[21]	Humps	22.4 – 32.6
3	[27]	Humps	30.4 -38.4
4	[28]	Humps	20.8 – 41.6
5	[29]	Humps	18 – 20
6	[22]	Humps	25
7	[25]	Humps	32 – 45.3
8	[25]	Cushions	35.7
9	[23]	Cushions	24.8 – 50.9

To limit fatalities, pedestrian and traffic injuries Italy used speed bumps at a large scale in 1990 [26]. Road bumps which were used to limit accidents actually became user and vehicle breakers due their more heights and impacts. This investigation suggested that bumps should be modified with other traffic calming measures and there is a need to move toward speed hump and cushions [26].

2.7 World Health Organization and fatality rates

World Health Organization (WHO) published a report to estimate the distribution of mortality rates among different income groups, which showed that 1170694 people died due to traffic accidents in 1998 [30]. A study indicated that economic loss due to road injuries range from 1-2 % of Gross Domestic Product (GDP) for all the nations in the world, which was more for high-income countries than for less-motorized countries [31]. Studies emphasized that patients occupy 30-70% orthopedic beds in hospitals for less-motorized countries [32]. Safety and design standards for cars are decided in high-income countries and low-income countries with less expertise are neglected in this regard [33]. In 2002, a review highlighted future concerns regarding road safety in less-motorized areas. Future directions referred to the priorities that cannot be global with an emphasis on vehicle standards, road factors with blackspot and speed control. It was concluded that issues of low-motorized countries are not experienced by high-income countries. Therefore, transportation planning with exposure control and separation of non-motorized traffic will play a vital role in less-income countries [33]. Acceleration and deceleration cause the spread of particulate matter in air. In 2014, a review article was published to assess the settlement of air borne particles, airflow distributions and their effect on nearby hospitals [34].

2.8 Vibration Dose Value (VDV) and Seat Effective Amplitude Transmissibility (SEAT) value

The isolation efficiency of seats in vehicles can be calculated by the help of Seat Effective Amplitude Transmissibility (SEAT) value [3, 35, 36] and this value is calculated by Vibration Dose Value (VDV) [2, 37]. In 2002, a study was carried out to estimate the effect of seating on Whole-Body Vibration (WBV) exposure in vehicles in which Seat Effective Amplitude Transmissibility (SEAT) values were identified for 14 vehicle types and with total 100 work vehicles. It was concluded that severity of WBV exposures can be reduced by improvement in seating dynamics [4]. ISO 10326-1 was used for the measurement of seat vibration by conforming equipment [3]. For analysis frequency weightings, Root Mean Square (r.m.s) vibration magnitudes, VDV and SEAT values were evaluated which directly have link with vehicle deterioration in terms of internal structure and suspension damage. Results and findings indicated that 75% vehicles had SEAT values less than 100% with large variation in values within vehicle categories [4].

Speed humps, employed for speed reduction are actually road features, preferred over other calming devices because of reduction in collisions and speeds [38]. These humps pose significant impacts on vehicles and users, so there should be a design factor of user's health like old people with backache [39]. The performance and safety related to speed hump is related to their contingent design with appropriate place of installation, in which choice depends on need of traffic management system [40]. There are various researchers who have worked for the safety of vehicle and driver's comfort [7, 20, 40, 41] such as circular humps were used worldwide [15, 17, 20, 36, 40, 42], parabolic designs were used in United Kingdom [20] and sinusoidal profile was used in Netherlands [43].

2.9 Optimal designs of speed humps

In 2004, a numerical study was carried out in Kuwait University, for optimal design of speed humps by sequential quadratic programming method. Dynamic behaviour of vehicle and driver body components was investigated in different road conditions for Watts, flat-topped and polynomial humps. The proposed design was for the reduction of excessive shocks experienced by vehicle and driver by keeping Comfort Criteria (CC) and Critical Speed (CS) under consideration. It was also found that best design among all designs was of polynomial hump due to its profile flexibility. Length of hump is proportional to its optimal design. Results showed that hump design showed robustness for the safety of suspension system, mass, inertia, seat, cushion and tyre properties [44].

Speed humps can be used in one-way or two-way streets [45]. These are not recommended for emergency vehicle routes or on lanes leading to hospitals and emergency services [46]. Speed humps and tables are used as traffic calming techniques that are used to facilitate bicyclists and improve safety as well [47]. In 2007, guidelines were recommended in annual meeting of ITE for design of speed humps. It was noted that speed hump installation and design varies between jurisdictions and meet resistance from stakeholders. State-of-the-art guidelines were made by the help of extensive literature review and that knowledge was supported by online survey to fill the gap supported by a framework. Split speed tables are mainly built for emergency routes and transit agencies. It was stated that before the construction of humps stakeholders, residents, business owners, property owners, emergency services, schools, hospitals, medical centers, transit operators, road maintenance workers, snow plow operators and waste collection agencies should be consulted [45]. Results indicated that reduction in traffic speeds and volumes were seen after the installation of speed humps. A framework was developed by the help of various agencies to follow speed humps and tables in their jurisdictions with community involvement [48].

Speed humps are effective and efficient way for decreasing the speeds of vehicles in residential areas for the reduction of accidents [40]. According to Saadoon, speed bumps are found to be ineffective in controlling speed limits at desired values [39]. Cross and Wasters concluded that jarring effect of shocks is a main cause of 36% of back injuries for moving equipment operators [49]. In 2007, a study was carried out for the evaluation of WBV caused due to Speed Control Humps (SCHs) in different ergonomic conditions in which hump geometry was the main factor in altering the shocks caused due to these undulations and were evaluated by seat pad accelerometer to identify the health hazards. Factors taken were vehicle type, passenger location, speed and hump geometry. Results showed that circular humps are more dangerous and two new humps were proposed with improved performance. This current study has directed towards the removal of damaged structures and to move towards redesigning of new ones [50].

2.10 Safety and Quality-of-Life (QoL)

Traffic calming helps in the improvement of safety and quality-of-life by the reduction of speeds and volumes [51]. Several traffic calming techniques have been implemented by the help of minor and major modifications in streets for the safety of vehicles and users [52]. Traffic calming measures helps in the reduction of fatal injuries and accidents, when implemented may cause problems for emergency services, vehicles and higher emissions due to repeated acceleration and deceleration [53, 54].

[55] concluded that if driving is in low gear with smooth and low speed, then traffic calming implementation results in low emissions, which will ultimately work for the betterment of air quality. Increase in emissions is caused due to increase in number of stops [56]. In another study, six sigma technique was applied for the estimation of safety performance at transport logistics industry [57].

2.11 Environment and Energy Impacts

In 2009, a field inquiry was carried out for the estimation of environment and energy impacts due to traffic calming by Global positioning data and emission models. Computer-based micro simulation software was used for the simulation of vehicle trajectories. It was identified that traffic calming has a negative impact on vehicle safety and its fuel consumption rate. Results indicated that extra fuel consumption may occur due to newly installed humps and stop signs. It was also concluded that by the reduction of sharp acceleration areas heavy energy and emission savings can be achieved by the help of driver education and awareness [58]. A standard note was published in 2010 for the investigation of traffic calming on roads, whose main purpose was the implementation of traffic calming measures and enforcement of laws, which are necessary for traffic calming [59]. Proper procedures were outlined for the installation and consultation with stakeholders like fire and ambulance services [60].

2.12 Digital Image Processing (DIP) and Speed Breaker

In 2011, a research was carried out in India, in which Digital Image Processing (DIP) technique and AVI software tool was used for the ultimatum of speed breaker coming in the way of driver by the help of voice and display. The motivation behind this research was the problem of jerk and damage to suspension system and chassis of vehicle caused due to excessive speeds. Results concluded that if the vehicle is automated then output of Digital Speed Processor (DSP) can be given to automation control directly. It was mentioned that DIP proves to be more accurate, precise and effective than using a sensor to detect speed breaker [61].

Statistics provided by Ministry of Road Transport and Highways, India for the year 2002 and 2004 showed 58.8 and 72.7 million vehicles running on Indian roads, with an annual growth rate of 10% [62, 63]. In 2012 a research was carried out in YIT Jaipur, India, in which energy loss over speed breakers was investigated. It was suggested that this energy can be utilized for useful purposes like repairing punctured tube and cleaning tools. Results indicated that efficiency can be improved by multiple compressors [64].

2.13 Timeline of work done regarding impacts on vehicles

Work done by various researchers is highlighted below in Figure 3 by the help of timeline. This timeline shows a time span of 30 years i.e., from 1985 to 2015 with a reference of major 21 articles.

Duration of first 15 years i.e., from 1985 to 2000 shows that less work is done specially in prior span. With time cognizance was developed among masses. Due to the severe need of traffic management system with traffic calming and to reduce vehicle damage most of the research was carried out in later 15 years.

When a vehicle approaches a speed breaker with a speed greater than limits then risk of accident is obvious. Low visibility conditions such as night, rain, snow and fog make speed breakers inconspicuous for human eye which may lead to accident causing damage to humans and vehicles. This problem is particularly obvious in low-income or developing countries where there speed breakers so not accompany warning signs [12, 65]. Traffic calming techniques are of special purpose in countries, where warning signs have no value for drivers due to shortage of traffic laws [66]. Therefore, these speed breakers are ever-present in many countries like India, China, and Pakistan. [67]. In 2014, MS Rashidi and coworkers investigated for assessing the criteria for sustainable construction with the implementation of Environmental Management Plan (EMP) [68].

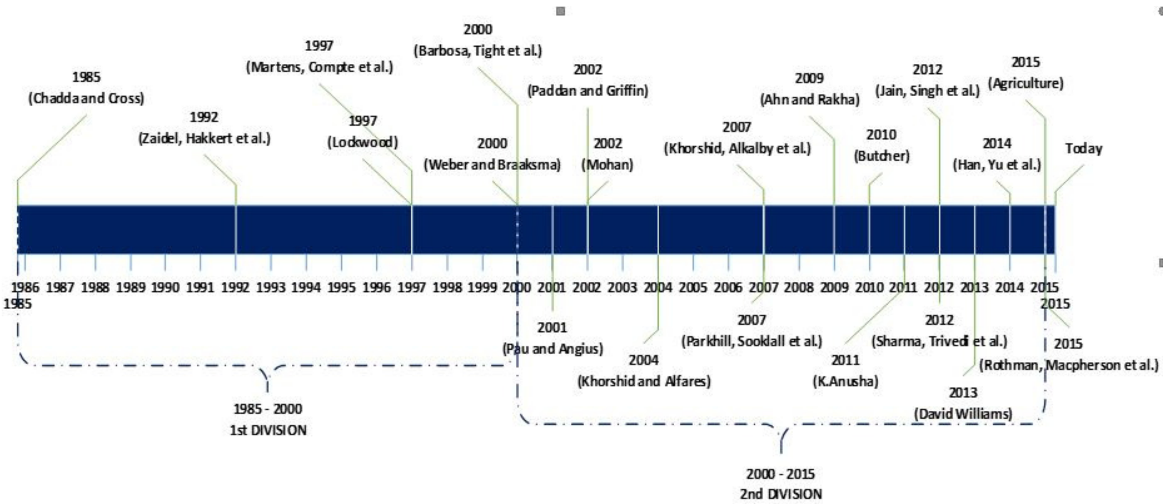

Fig. 3. Timeline of work done for speed breakers

2.14 Warning and Smartphone based technology

Logistics costs are increased, when vehicles cross the speed breakers at speeds higher than recommended values by damaging vehicles and goods in transit e.g., apples in bins get bruised due to higher vibrations [69]. Bhoraskar proposed a method for the detection of vehicle braking and road humps [70]. In 2012, a research was carried out for the use of speed breaker as early warning system in which smartphone based technology was used to alert the driver before vehicle approaches a speed breaker, with no accelerometer reorientation as strength. Conclusions presented promising results which can be improved further by the combination of reports from different smartphones. Results indicated that Speed-breaker early Warning System (SWAS) should be optimized to reduce overall battery consumption. It was also indicted that detector show good performance when smartphone is in car or in an auto-rickshaw but if there is motorcycle or cycle-rickshaw then performance was not satisfactory [65].

A study was carried out by Transport and Environmental Analysis Group, Imperial College London for the estimation of vehicle emissions at 20mph speed. In this study environmental impacts in connection with impacts on vehicles were outlined. Emissions from brake and tyre wear were also investigated. Analysis of Instantaneous Road Emissions (AIRE) model was used to determine the emissions associated with other parameters like fuel type and engine size. It was mentioned that changes in brake and tyre wear are directly connected with demand for power of vehicle. It was found that tyre and brake wear are linked to vehicle type due to influence of weight. It was recommended that in future more work can be done for tyre and brake wear [5].

To analyze complex urban traffic flows smartphone based applications are becoming more popular for intelligent driving experiences [71, 72], with increase in driver's safety [73, 74], better driver's behavior [75, 76] and better transportation network system [77, 78]. In 2014, SenSpeed in relation with driving conditions to estimate speeds in urban environments were studied by smartphone based sensors and GPS system for the estimation of vehicle speed. SenSpeed actually sense natural driving conditions like turns, uneven road surfaces. Results concluded that vehicle speed estimation system called SenSpeed is established at three useful references i.e., at making turns, vehicle stopping and uneven road surfaces [79].

An exploratory analysis was supported for speed control in developing countries by Afukaar [80]. In ITE, Schroll elaborated that traffic calming is the combination of concrete measures that reduce negative impacts on vehicle, driver's behaviour and non-motorized users [81]. In 2002, impact of temporary humps and speed tables on speed profiles were evaluated for collector streets in USA [82]. In 2000, effects of bumps were evaluated with respect to change in speed because speed plays a vital role in the maintenance of vehicle and safety of driver. In this study bump was taken as limiting factor of speed and sudden force on car due to bump as a upheaval [83].

In 2015 a study was carried out in Ilorin to check the effectiveness of speed bumps as speed reducers. Questionnaires were used for data collection. Descriptive and statistical data techniques were used for the analysis of collected data. Results indicated that road bump, its height and distance between speed bumps is directly related with speed reduction. Author has recommended further work on improved design of humps as alternative speed control method for the reduction of vehicle damage and driver injuries [84].

Traffic calming includes physical measures, optical measures, residential measures and environmental measures [85]. Road traffic injuries are responsible for 1.24 million deaths in 2010 [86]. These injuries cause 47% increase in annual death rates since 1990 [87]. Injuries caused due to roads are predicted to be fifth leading cause of deaths worldwide and seventh leading cause of disability by 2030 [88-90]. Speeds plays a crucial role in saving one's life or in injury severity [91, 92] e.g., if collision speed is ≥45km/h then there is 50% chance of survival but if speed is ≤30km/h then there is 90% chance of survival [92, 93]. Therefore, to reduce these problems speed humps are effective [45, 94] with a significant decrease in motor-vehicle collisions [95-97].

2.15 Speed humps and motor-vehicle collisions

In 2015, a quasi-experimental study was carried out in Toronto, Canada in connection with speed humps as reduction in motor-vehicle collision rate. Pre and post analysis was done by Poisson regression keeping in view season and roadway characteristics. Stratified analysis was done by the help of study between age group and injury severity. Results showed a significant decrease in accidents after the installation of speed humps. It was concluded that humps can be installed on roads with an intention to decrease child and pedestrian injuries. For future area-wide analysis is needed to determine the contribution of humps as injury reducer. Results of pre and post analysis showed that after the installation of humps accident rate has been decreased up to remarkable levels [98]. On contrary some problems are also caused because of speed humps such as delays for emergency vehicles, damage and effect on transit routes with discomfort for occupants [12, 98, 99]. Therefore, to reduce these problems other traffic calming services like medians, road narrowing were also proposed [100-102].

2.16 Direct/ indirect impacts with reactive measures

Impacts associated with speed breakers on vehicles, whether they are direct or in direct are shown below in Figure 4. If these impacts prevail then there is a severe need to change the scenario either by new installations or by the removal of unnecessary existing structures.

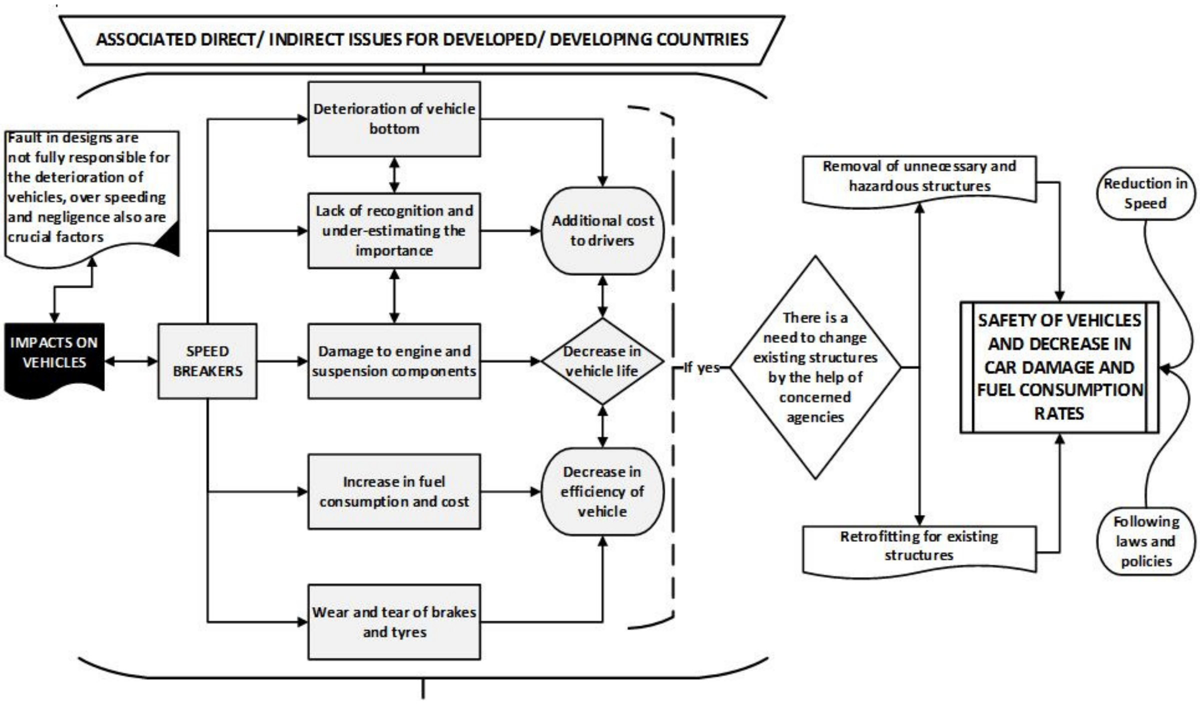

Fig. 4. Criteria to change speed breaker structure w.r.t impacts on vehicles

Figure 4 evidently illustrates that if such impacts prevails with speed breakers and over speeding, then there is an urgent need of implementation of laws and installation of new approved designs. Those designs will not only improve the safety conditions for vehicle but also will help in the reduction of costs in terms of damage and fuel consumption. Table 2 given below highlights some inquiries carried out for speed breakers and their associated impacts on vehicles.

Table 2
Literature review for impact analysis on vehicles in different conditions

Sr. No.	Work Done	Author and Year	Place & Sample Size	Impacts On: Vehicle	Impacts On: Users/ drivers	Impacts On: Environ ment	Technique and Software Used	Effectives + Comments
1	An evaluation of the estimated impacts on vehicle emissions of a 20mph speed restriction in central London Transport and Environmental analysis Group	[5]	London (6 routes)	✓	✓	✓	U-blox ANTARIS GPS module, non-parametric hypothesis test, Mann-Whitney U test, Analysis of Instantaneous Road Emissions (AIRE) model for emissions	Brake and tyre wear, Driving Style, from petrol and diesel (PM_{10}, NOx, CO_2)
2	Breaking the speed breakers using image processing	[61]	Andhra Pradesh, India	✓	✓		MATLAB simulation program, AVI software tool for images	Digital Signal Processor (DSP) and image processing, damage to suspension and chassis of vehicle, driver's discomfort
3	Towards a North American Geometric Design Standard for Speed Humps	[15]	North America (6 on-road humps)	✓	✓	✓	Radar gun for vehicle speed, experiments with Watts and Seminole profile humps, accelerometer for human vibrations, multiple regression model	Speed hump geometric design standards, environmental conditions, motorist expectations and vehicle characteristics
4	Development of speed breaker device for generation of compressed air on highways in remote areas	[64]	India	✓		✓	Reciprocating air compressors,	Energy lost, mechanism to generate and store compressed air, this air can be used for repairing the puncture of tube of tyre and cleaning of machines with pressurized air.
5	Do speed bumps really decrease traffic speed? An Italian experience	[26]	Italy (23 speed bumps)	✓	✓		Speed bump installation, Laser Traffic Counter for speed data, ANOVA, Linear regression for analytical relationship between speed and lane width	Pedestrian fatalities, Emergency vehicles, speed bumps that are in the routes of emergency vehicles are forbidden, car damage, speed for both bump and free sections
6	A field evaluation case study of the environmental and energy impacts of traffic calming	[58]	USA (3 roads and 9 vehicles)	✓	✓	✓	GPS data (in-field), pre and post traffic calming measures, Mathematical VT-Micro model for fuel usage and energy retes, MATLAB simulations for speed, Portable Emissions Measurement System (PEMS),	Vehicle fuel consumption and emission rates, CO emitters, changing driver's behavior, serious injury accidents, delay in emergency vehicles, energy and environmental impact,
7	Guidelines For the Design of Off Street Car Parking Facilities	[103]	Bahrain	✓			Standards and guidelines, Speed limit, hump warning, steep grade signs	Pedestrians and people with disabilities
8	Installation of speed humps and pedestrian-motor vehicle collisions in Toronto, Canada: a quasi-experimental study	[98]	Canada (409 roadways)	✓	✓	✓	Quasi-experimental pre and post analysis, Poisson regression model, Stratified analysis, Statistical analysis by SAS V.9.3 and STATA V.12.1, binomial modeling,	Pedestrian injuries, speed humps and Pedestrian-Motor Vehicle Collisions (PMVC), age group and injury severity, school
9	Road safety in less-motorized environments: future concerns	[33]	New Delhi, India (Review)	✓	✓		Literature review, guidelines and standards	Traffic crash fatalities and injuries, high, low and middle income countries, new policies and designs, age-wise data, pedestrians, bicyclists, motorized two-wheeler drivers
10	ITE traffic calming definition	[13]	Minnesota	✓		✓	Legislation and guidelines	Environmental, safety and severance impacts of vehicles on individual and society
11	Roads: traffic calming	[59]	UK	✓	✓	✓	Legislation and guidance, Transport Act 1981, Traffic Calming Act 1992, Road Safety Act 2006, London Ambulance Service (LAS)	Road accidents, emergency services (police, fire, ambulance), residential areas, patient discomfort, vehicle delay and damage by London Ambulance Service (LAS), swamp guards for vehicles
12	Updated Guidelines for the Design and Application of Speed Humps	[48]	Canada (300 responses)	✓	✓		Recommended practice by ITC (Institute of Transportation Engineers), framework	Public consultation, Speed humps vs Speed bumps, driver discomfort, parking lots and private roadways, pedestrians, bicyclists, emergency vehicles

13	The use of road humps for moderating speeds on urban streets	**[12]**	Israel (23 respondents)	✓	✓	✓	Literature review, International survey, Questionnaire survey and analysis, Attention getting devices, channelization devices, speed moderation devices, drastic speed control devices,	Residential streets, intersection, pedestrians crosswalks, public transport, trucks, emergency vehicles, legal status of device, Noise and vibration
14	Speed (road) bumps: Issues and opinions	**[7]**	Washington D.C, US (18 locations)	✓	✓	✓	Literature review, pre and post analysis of speed, Institute of Transportation Engineers (ITE) and American Association of State Highway and Transportation Officials (AASHTO)	Speeding on Urban residential streets, motorists and vehicle performance, delays, noise
15	SenSpeed: Sensing Driving Conditions to Estimate Vehicle Speed in Urban Environments	**[79]**	China, USA	✓	✓		Smartphone sensors for vehicle speed, algorithm, SenSpeed (Vehicle speed estimation system), phone's accelerometer	Urban environment, turns, stopping, uneven road surfaces, driving safety
16	Effect of seating on exposures to Whole-Body Vibration in vehicles	**[4]**	England (100 vehicles, 14 categories)	✓	✓		Seat Effective Amplitude Transmissibility (SEAT) value, Piezoresistive full-bridge accelerometers, ISO 10326-1, HV-Lab (version 3.81), BS 6841,	Cars, vans, lift trucks, lorries, tractors, buses, dumpers, excavators, helicopters, armored vehicles, mobile cranes, glass rollers, mowers and milk floats, seated persons
17	Measurement of whole-body vibration exposure from speed control humps	**[50]**	Kuwait (7 hump types)	✓	✓		Triaxial Seat pad accelerometer, BS 6841 and ISO/DIS 2631-5, different types and dimensions of humps to make an ideal hump, MATLAB software,	Shocks and WBV, cars, low back pain, occupational diseases, vehicle type, passenger location, speed, geometry, residential areas, zero vertical acceleration for ideal hump, micro or macro-trauma to vertebrae, spine tissue and neck,
18	A numerical study on the optimal geometric design of speed control humps	**[44]**	Kuwait (5 profiles)	✓	✓		Sequential quadratic programming method (non-linear), vehicle-driver model, CC by driver's head acceleration	Optimum geometric design, body and vehicle components, Comfort Criteria(CC) and Critical Speed (CS), accident rate, residential area, geometry,
19	The Effects of Road Design on Speed Behaviour: A Literature Review	**[14]**	UK, Netherland	✓	✓	✓	Literature review, law enforcement, standards and design procedures	Accident occurrence, increase in fuel consumption, residents, fire, ambulance service, noise, damage to grass
20	A model of speed profiles for traffic calmed roads	**[19]**	Brazil, UK (16 data points, 3 survey sites)	✓	✓		Empirical model using multiple regression technique, Case study, observers and video camera, literature, correlation tests, Regression analysis, The model curve fit	Speed of vehicles, passing time as a function of input speed and distance b/w measures, driver behavior, cars, vans
21	Speed-Breaker Early Warning System	**[65]**	India (22 drivers, 5 vehicles)	✓	✓		Smartphone based application, Speed Breaker Early Warning System (SWAS), Android based smartphones	Accidents and injury, visibility conditions (night, fog, rain, snow), warning signs, algorithm, 3-axis accelerometer data, magnetometer data, different speed breakers, battery consumption
	TOTAL			**21**	**18**	**10**		

3. Conclusion and outlook

This exhaustive literature will be helpful for researchers, analysts and government bodies, who are working for the minimization of impacts on vehicles due to speed breakers like bottom deterioration, internal damage and increase in fuel consumption. Strategies adopted by various researchers are outlined succinctly in this review with appropriate reactive and preventive measures.

Current review paper covers all the investigations carried out from 1985 to 2015. From these studies it is identified that no work has been done for Pakistan in connection of impacts on vehicles related to speed breakers so far. Author has also identified that in a single paper only one type of impacts is discussed but no study has been done with all the impacts associated, in one research.

There is an imperative need to study the effects of speed humps on qingqi and its users because it is a public transport most commonly used in emerging countries like Pakistan. Till now no work has been investigated for comparison between different socio-economic groups, different income groups, between developing and developed countries. Hence there is a need of proper designs and legislations regarding the structure of speed humps, proper planning is needed for their installation at specific places. So that, in return, speed humps could help the human beings, being a life saver instead of vehicle and back breaker. These few gaps can be utilized as the basis of research in future.

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