Chapter 39
Smart Geometric Design of Highways Using HTML Programming for Sustainable and Climate Resilient Cities

Aditya Dhanuka, Aman Srivastava, Leena Khadke, and Nand Lal Kushwaha

Abstract Conventional practice for geometric highway design using engineering drawing techniques and mathematical approaches demands heavy iterative manual efforts amidst numerous calculations, which is cumbersome and time consuming. Consequently, it is challenging highway engineers to approach for a broader perspective on geometric design. Given rising trends for advancing intelligent transportation systems for smart, sustainable and climate-resilient cities, a need is felt for developing web application tools for swift and accurate highway design. To this end, present study aims at developing a computer-based conceptual geometric design model called Web Application Tool for Highway Design (WAT-HD) for highway projects using HTML web application-based programming. The software tool comprehensively accounts for designing highway cross-sectional elements, sight distance, horizontal alignment and vertical alignment, along with their detailed components. A comparative assessment of findings from the tool with manual calculations for a two-lane two-way National Highway indicates its high designing accuracy amidst minimal input requirements. The study concludes that computer-based programming approaches could be more efficient while designing highway geometry with ease to modify within economic and environmental parameters. Such applications become more

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U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_39

pronounced when pressure is more on achieving goals of smart city design, intelligent urban transportation and reduced vehicular-emission-based greenhouse gas release amidst changing climate.

Keywords Highway engineering · Intelligent transportation · Smart city planning · Climate change · Computer science · Computer-aided programming · Artificial intelligence · Machine learning

Introduction

One of the most pressing issues facing municipal and urban authorities since the twenty-first century is the rise in carbon dioxide (CO_2) and greenhouse gas (GHG) emissions. The reasons have been primarily attributed to traffic congestion, which results in longer travel times, delays and undesirable fuel consumption, even on national highways. Metropolitan transportation planning and management organisations at the district, state and central levels find it challenging to address congestion in urban regions due to the growing population, economic expansion and personal leisure (Bibri and Krogstie 2017; IPCC 2022; Lwasa et al. 2022). Recurrent traffic congestion on highways is frequently caused by a regional imbalance between excessive demand and insufficient capacity. In contrast, non-recurring congestion is impacted mainly by frequent traffic accidents and poor weather conditions (Afrin and Yodo 2020; Chang et al. 2020). There is a pressing recommendation for advancing intelligent transportation systems for sustainable city planning to enable more sophisticated control of traffic demand and a more effective selection of efficient traffic mitigation strategies (Chowhan et al. 2022; Saharan et al. 2020; Telang et al. 2021). One of the approaches to achieving intelligent transportation systems could rest on improving the procedures involved in the geometric design of highways.

Highway geometric design is an inherent theme for introductory transportation engineering (Cafiso et al. 2021; Kanellaidis and Vardaki 2011). A civil engineer or, more specifically, a highway engineer witnesses many challenges while designing essential highways such as National Highways connecting states or provinces. As the concerned engineer undertakes several design controls and criteria, it often happens that the engineer is supposed to go beyond regulatory design standards. Some challenges may include traffic alterations, vehicle changes, construction capital investment limits, critical road establishment locations and environmental and ecological attention (Janssen et al. 2022; Shaaban 2022). In general, a highway engineer is mandated to duly comply with safety issues amidst achieving optimal mobility without compromising the highways' quality and the environment therein. Apparently, it becomes imperative for the present study to investigate difficulties that exist while designing important highways for any nation.

The highway design accounts for drivers' expectations, optimises traffic operations and minimises construction costs and environmental impacts (Othman et al. 2019). The highway design fundamentally includes safe sight distance, overtaking sight distance, horizontal curve, transition curve and vertical curve, along with their detailed components (Garcia and Pastor-Serrano 2022; Justo et al. 2015). Engineering drawing techniques are one of the most widely used traditional approaches for designing highway geometry (mentioned above) over contour maps (Liao and Levinson 2013). However, engineering drawing techniques suffer from a significant limitation of being manual and iterative alongside cumbersome and time consuming. Several commercial software packages and modelling techniques have been developed to overcome the limitations of drawing techniques. These packages mainly employed active digital maps, three-dimensional design models, artificial intelligence (AI) and machine learning (ML) techniques and virtual reality walkthroughs to boost the geometric design of the highway processes (Das 2022; Goswami and Sarkar 2021; Liao and Levinson 2013). Nevertheless, these commercial packages are generally not user friendly (demanding in-depth expertise in computer-based coding), usually complicated and costly to purchase and install. Hence, a need is felt to develop a simple web application tool that essentially executes similar to commercial packages and accurately yields the geometric designs of the highway. Coherently, Liao and Levinson (2013) attempted in the past to improve the understanding of engineering students on geometric design principles of roadways by developing a new software tool called ROAD: Roadway Online Application for Design. However, such attempts to design highways remained limited, and a research gap still exists in using computer-aided programs to replace the cumbersome design processes. Nevertheless, as far as other fields of civil engineering are concerned, attempts to develop web application-based models and employ AI-ML-based approaches have risen in the recent decade (e.g. Chang et al. 2020; Elbeltagi et al. 2022, 2023; Pande et al. 2022; Ezhilarasi et al. 2020; Kumar et al. 2022; Moradi et al. 2019; Sarkar et al. 2020; Srivastava et al. 2021; 2022a, b; Zhang et al. 2020). Thus, these recent advancements in deploying web applications motivated the present study.

Coherently, a non-Internet-based geometric design application called Web Application Tool for Highway Design (WAT-HD) has been developed using HTML programming language with the purpose of reducing numerous cumbersome roadway planning and design calculations. WAT-HD assists in conducting geometric design on a computer screen with minimal numeric inputs. The tool will allow for a more effective and swift design of the geometry of a highway, thereby paving the scope for advancing intelligent transportation systems for future smart cities. The novelty of this work is the integration of computer-aided advancements with highway engineering principles, yielding more sophisticated designed outputs using the former than the traditional manual approach. The study contends that giving professionals or, as such, any user access to geometric design that uses online tools can allow them to explore and evaluate various cause-and-effect scenarios. Such attempts may enable professionals to comprehend better the possible effects of their highway geometric designs in the real world.

Materials and Methods

Development of Web Application Tool for Highway Design (WAT-HD)

Due to their success in fusing computer-aided assistance with practical execution, web-based apps have been increasingly used in education, business, industry and other sectors, as previously mentioned. Platform and location freedom are the benefits of web-based learning resources. Users may virtually access these online apps utilising computers at any time, wherever in the globe. To this end, this investigation attempted to abridge the research gap that indicated limited avenues for geometric highway design. With client-side logic programmed in JavaScript and jQuery, the WAT-HD is created using HyperText Markup Language (HTML) and Cascading Style Sheets (CSS) (an open-source framework of JavaScript). It is linked to a web server that gives clients or users static files (Fig. 39.1). It has access to a MySQL database-connected Application Programming Interface (API). The API was created using Lumen, a PHP (Hypertext Pre-processor) micro-framework, and its primary function is to save the results of WAT-HD computations (as a backup). Representation State Transfer Web Services are used to establish communication between the client and the API server (RESTful Web Services). Create, Read, Update or Delete (CRUD) requests sent by the client over the HTTP (HyperText Transfer Protocol) are answered by the API server. Figure 39.2 shows the output of this programming—WAT-HD's menu page depicting operational tools for conducting geometric highway design.

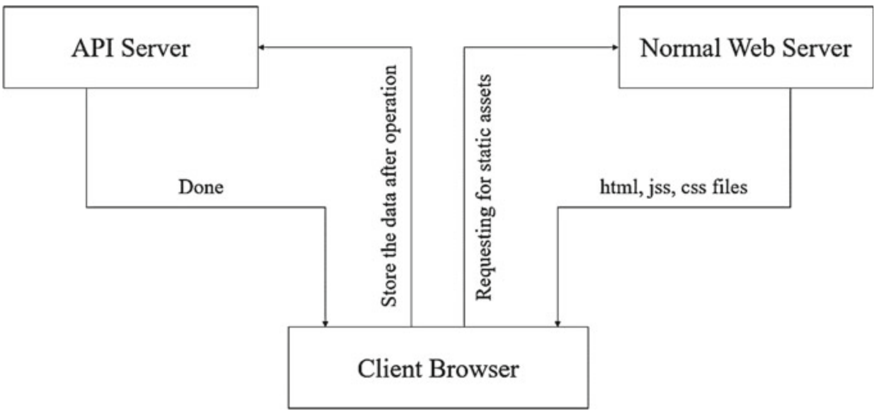

Fig. 39.1 Development of Web Application Tool for Highway Design (WAT-HD) (Methodological framework adapted from Srivastava et al. 2021)

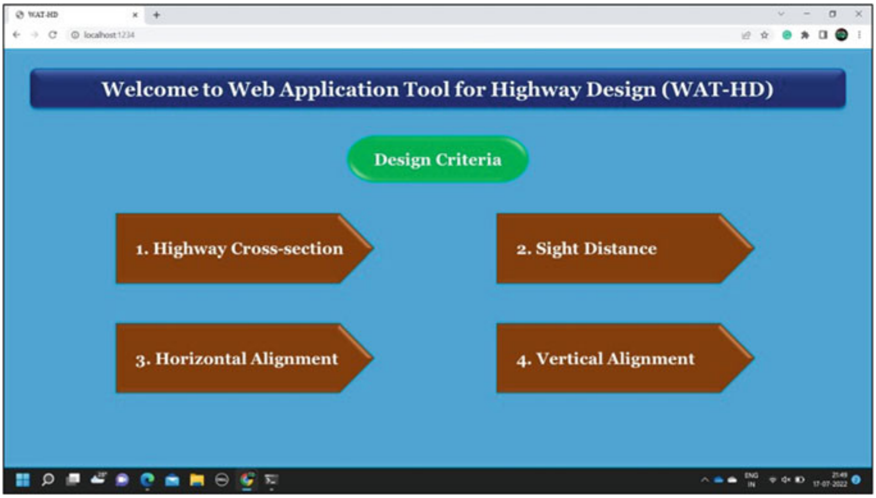

Fig. 39.2 Opening page of Web Application Tool for Highway Design (WAT-HD) showing basic operations

Geometric Highway Design Considerations in WAT-HD

The critical elements of highway geometric design include highway cross-sectional elements (Sect. "Highway Cross-sectional Design"), sight distance (Sect. "Sight Distance Design") and horizontal and vertical alignments (Sects. "Horizontal Alignment Design" and "Vertical Alignment Design") and are shown in Fig. 39.2. Careful consideration of their components allows for designing geometric characteristics of highways in the context of future traffic growth and for apparent road widening or upgrade. The factors influencing geometric design are design speed, topography, traffic, design hourly volume and capacity and environmental and economic factors. The considerations behind geometric highway design are discussed below and summarised in Table 39.1.

Highway Cross-sectional Design

The key cross-section elements include pavement surface characteristics, cross slope or camber, carriageway width, traffic separators, kerbs, road margins, formation width, right of way and land width. Pavement surface depends on pavement type and is characteristically determined through friction or skid resistance, unevenness, light reflecting characteristics and surface water drainage. As per the recommendation of the Indian Road Congress (IRC), the coefficient of longitudinal friction is between 0.35 and 0.40 for stopping distance calculations. At the same time, the lateral coefficient of friction is 0.15 for horizontal curve design. The unevenness index is low for good pavement surfaces, preferably less than 1500 mm per kilometres (mm/km),

Table 39.1 Geometric highway design consideration for developing Web Application Tool for Highway Design (WAT-HD)

Particulars	Web Application Tool for Highway Design (WAT-HD) control and criteria			
Design criteria	Highway cross-section	Sight distance	Horizontal alignment	Vertical alignment
Design components	Pavement surface characteristics	Stopping sight distance: reaction time, velocity, slope, braking efficiency, longitudinal friction factor	Design speed	Longitudinal gradient
	Camber: parabolic and straight line	Safe sight distance	Overturning and transverse skidding effect	Ruling, limiting, exceptional and minimum gradient
	Carriageway width	Overtaking sight distance: traffic-type, velocity, reaction time, distance, acceleration	Maximum and minimum superelevation: friction, horizontal curve radius, velocity	Grade compensation on horizontal curves
	Traffic separators	Absolute minimum sight distance	Pavement widening: mechanical and psychological	Vertical curves: summit curve depends on deviation angle, curve length, stopping sight distance, height of eye level and object
	Road margins: kerbs	Overtaking zones	Horizontal transition curves: Spiral, lemniscate and cubic parabola for plain and hilly terrains	Vertical curves: valley curve depends on deviation angle, stopping sight distance, velocity
	Roadway width and land width	Intermediate sight distance: traffic-type, velocity, reaction time, distance, acceleration	Setback distance: sight distance, length and radii of horizontal curve	
			Curve resistance: tractive force and horizontal curve angle	

Note Any standard highway engineering textbook can be referred to for equations and derivations of design consideration used here; some mathematical calculations are shown in Sect. "Performance Evaluation of WAT-HD and Its Scope in Smart City Planning" and Table 39.2

while for satisfactory pavement surfaces, a value of 2500 mm/km is taken. Regarding light reflectivity, a light-coloured (say white) pavement is considered for better night visibility.

Drainage and quick disposal of the rainwater, etc., is essential, for which cross slope or camber is provided. Usually, a flat camber, ranging from 1.7% to 2%, is usually preferred for relatively impervious pavement. For the width of the carriageway, influencing factors include the number of traffic lanes and each lane width, along with considering the width of the largest vehicle class and lateral clearance required therein. Comprehensively, the width of the carriageway is estimated averagely at around 3.5 m (m) per lane. Besides, traffic separators or medians are provided to prevent head-on collision, usually having a width of 8–14 m. The road margins such as footpaths are provided as kerbs which can be categorised as low kerb (100 mm above the pavement edge), semi-barrier type kerb (150 mm above) and barrier type kerb (200 mm above). Roadway width comprises the width of the carriageway, traffic separators and road margins. Furthermore, additional land is acquired along the road alignment called the land width (or right of way) to meet the future demand for the widening of highways.

Sight Distance Design

Highway design is objected to adopting safe and efficient design for smooth operations. For example, the road length to overcome the obstacle becomes essential when the obstruction becomes visible to the driver while driving on the highway. Knowledge of this road length paves the way for safe vehicle operation. Sight distance, which can be measured along the road surface, thus can be defined as road length ahead of the driver during any moment of the driver's journey. In the context of geometric design of highways and traffic control, sight distance can be categorised as absolute minimum sight distance (which is called stopping sight distance (SSD)], passing sight distance [also called safe overtaking sight distance (OSD)] and safe sight distance. Highway geometry generally demands safe stopping, safe overtaking and safety at an uncontrolled intersection. In the case of SSD, factors affecting the sight distance and the distance at which the driver can stop the vehicle include reaction time, speed, brake efficiency, friction between tyre and road and the road gradient. In contrast, for OSD, for safe overtaking, factors include the speed of overtaking vehicle, speed of an overtaken vehicle, the speed of the vehicle from the opposite direction; acceleration rate of overtaking vehicle, the distance between overtaken and overtaking vehicles, reaction time of the driver and road gradient. Besides, IRC defines two more categories of sight distance: intermediate sight distance (ISD) and headlight sight distance. The former is required when OSD cannot be provisioned in the geometric design, while the latter measures the distance visible to the driver under the illumination of vehicle headlights during night-time.

Horizontal Alignment Design

The obligatory points in the highway pathway (to be established) or the topographic challenges necessitate changes in the direction of highway alignment. Horizontal alignment ensures vehicles' safe and comfortable movement by not accounting in design for sudden turns on the road with sharp or reverse curves. Since horizontal alignment decides the design speed, therefore, while designing highways, the alignment must not provoke drivers to undergo abrupt speed changes, which may increase accident rates. Different design components influencing horizontal alignment include design speed, circular curve radius, transition curves type and length, superelevation, pavement widening on curves and setback distance. Design speed is the critical factor in geometric design, such that sight distance, other components of horizontal alignment and summit and valley curve lengths are dependent. Design speed is estimated based on the road class and terrain. Fundamentally, four types of terrain are considered in a geometric design of highways: plain, rolling, mountainous and steep. Furthermore, geometric designing is done mainly by considering the ruling design speed (and not the minimum design speed) because it is regarded as the guiding criterion. However, if the ruling design speed cannot be adopted for design, may be due to topographic restrictions, minimum design speed can be used for horizontal curve design. The horizontal curve in the highway provides directional change concerning the road's centre line. The vehicle negotiating a horizontal curve due to centrifugal force results in overturning and transverse skidding effects. To overcome the negative effect of centrifugal force alongside overturning and transverse skidding effects, superelevation is accounted for while designing highway geometry, wherein the outer edge is raised with reference to the inner edge.

Besides, when the horizontal curve is not of higher radii, pavement width is slightly widened while designing and is categorised as mechanical widening and psychological widening. Also, transition curves are introduced when it is required to introduce a smooth transition between a straight highway and a circular curve highway, which allows for controlling the adverse effects of centrifugal force. They are further categorised as spiral, lemniscate and cubic parabola transition curves. Regarding challenges for horizontal curves, the sight distance at the inner curve is needed to be considered while designing, such that either the obstacle is removed or alignment is redesigned to meet reasonable sight distance requirements. Designers are also supposed to consider curve resistance in the geometric design since the front wheels of the vehicle move but not the rear wheels, thereby generating additional tractive forces resulting in high friction.

Vertical Alignment Design

Since the vertical profile of the highway to be designed is challenging to be uniform, it instead comprises slopes of varying magnitudes along the profile. Thus, varying slopes demand deep cuttings or high embankments. The geometric design requires minimising high cutting and filling, for which knowledge of grades and vertical curves from the highway's vertical alignment is essential. Different variables, such as vehicle speed, acceleration, stopping distance, sight distance, comfort and economic aspects, are governed by the vertical alignment of highways. Grade or the gradient of the vertical alignment can be defined as the rate of fall or rise along the highway length. The gradient can be classified as ruling, limiting, exceptional and minimum. It is imperative to highlight that in horizontal curves, it is not only the tractive force due to the fixed rear wheel of the vehicle but also the gradient that may add in, thereby increasing the gross tractive force to cause discomfort while driving. To overcome this difficulty, the designer reduces the gradient to compensate for the loss of tractive effort due to a sharp horizontal curve. The reduction in gradient at the horizontal curve is defined as grade compensation. Given convexity and concavity in the highway alignment, information on vertical curves is also required. They are categorised as summit and valley curves.

Results and Discussion

Two-Lane Two-Way Geometric Highway Design Analysis Using Manual Approach

A two-lane two-way National Highway is geometrically designed via a manual approach and also executed by employing WAT-HD to validate the functionality and performance of WAT-HD against the manual procedure. Four problem statements, viz. design problem on highway cross-section elements, sight distance, horizontal curve and transition curve, are described step-wise, followed by its manual solution in Sect. "Two-Lane Two-Way Geometric Highway Design Analysis Using Manual Approach". Comparative assessment between manual estimations and WAT-HD output, thereby discussion on the user-friendliness of WAT-HD, are documented in Sect. "Performance Evaluation of WAT-HD and Its Scope in Smart City Planning". For uniformity, each design component's recommendations are based on IRC's prescribed values (https://morth.nic.in/sites/default/files/1-volume-1.pdf, accessed 17 July 2022).

Problem statement—1

In a district located in a high rainfall region having plain and rolling terrain, a two-lane ($n = 2$) National Highway is to be paved. Assuming the straight line camber with a bituminous concrete surface, design the height of the crown concerning the highway edges.

Solution—1: A two-lane National highway for plain and rolling terrain is recommended to have a roadway width of 12 m and a carriageway with raised kerbs of 7.5 m, while the road surface, having cement concrete and a high type bituminous surface, is recommended to attain camber in the range of 1 in 50 (or 2%) for heavy rainfall conditions.

- The rise of crown concerning highway edges is estimated as $= (7.5 \div 2) \times (1 \div 50) = 0.09$ m

Problem statement—2

Design the safe stopping sight distance (SSD), headlight sight distance and intermediate sight distance (ISD) for the same conditions as in problem statement—1, and if the designed speed (V) is 80 km/hours (or kmph; such that $v = 22.2$ m/s), two-way traffic prevails on the two-lane National Highway. Also, design safe overtaking sight distance (OSD) and a minimum and desirable length of overtaking zone: if the velocity of overtaking and overtaken vehicle (i.e. V_a and V_b) is 70 kmph ($v_a = 19.4$ m/s) and 40 kmph ($v_b = 11.1$ m/s), respectively. Following IRC recommendations, the coefficient of friction (f) is assumed to be 0.37, the driver's reaction time (t) is 2.5 s (s), the driver's overtaking reaction time (t_o) is 2 s, and the average overtaking vehicle acceleration (a) is 0.99 m/s^2.

Solution—2: The SSD for two-lane, given conditions mentioned above and acceleration due to gravity (g) as 9.81 m/s^2, is estimated as follows:

- $\text{SSD} = vt + \frac{v^2}{2gf} = (22.2 \times 2.5) + \frac{22.2^2}{2\times 9.81\times 0.37} = 123.5\,\text{m}$

While the headlight sight distance will be the same as SSD (=123.5 m) and ISD will be twice SSD (=247 m), OSD is estimated by incorporating the given values in the following equation:

- $$\begin{aligned}\text{OSD} &= (v_b \times t_0) + \left[\left(v_b\sqrt{\frac{4(0.7v_b+6)}{a}}\right) + 2(0.7v_b+6)\right] \\ &\quad + \left(v_a\sqrt{\frac{4(0.7v_b+6)}{a}}\right) = (11.1 \times 2) \\ &\quad + \left[\left(11.1\sqrt{\frac{4(0.7\times 11.1+6)}{0.99}}\right) + 2(0.7\times 11.1+6)\right] \\ &\quad + \left(19.4\sqrt{\frac{4(0.7\times 11.1+6)}{0.99}}\right) = 277.6\ \text{m}\end{aligned}$$

The minimum length of overtaking zone is three times OSD (=834 m), and the desired length of overtaking zone is five times OSD (=1390 m).

Problem statement—3

Following the information in problem statements—1 and 2, design the superelevation (e) rate for a mixed traffic condition having a horizontal curve radius (R) of 480 m. Also, determine by how much the outer edge should be raised against the inner edge of the highway. Besides, design the ruling minimum radius (R_r) of the horizontal curve if the design speed considered for the current highway design is the ruling design speed. Similarly, design the horizontal curve's absolute minimum radius (R_a)

if the current highway's minimum design speed ($V_{\min}$) is 60 kmph. For this horizontal curve ($R = 480$ m), design the extra widening (W_e) if the vehicle's most extended wheelbase (l) expected on this highway is 6.5 m. In addition, design the length of the transition curve (L_s) for this horizontal curve if the allowable rate of introduction of the superelevation (e_{rate}) is 1 in 150, such that the pavement is rotated about the inner edge (because the highway is located on heavy rainfall area where better drainage is required). For the minimum sight distance (S) of 240 m, assuming the length of the curve (L_c) to be greater than S, and considering extra widened road and other details as mentioned above, estimate setback distance (m).

Solution—3: As per the recommendation for mixed traffic conditions, the superelevation should counteract the centrifugal force for 75% of the design speed ($V = 80$ kmph). Therefore:

- The superelevation can be designed using: $e = V^2 \div (225R) = 80^2 \div (225 \times 480) = 0.059$

The superelevation of 0.059 may be adopted because it is lower than 0.07, which is considered safe for the given design speed and other conditions. Also, the carriageway width (B) for the present design is 7.5 m.

- Raising of outer edge w.r.t. the inner edge can be determined using $= B \times e = 7.5 \times 0.059 = 0.44$ m

For designing the ruling minimum radius (R_r) and absolute minimum radius (R_a) of the horizontal curve, IRC recommends the following equation:

- $R_r = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.059+0.37)} = 117.5\,\text{m}$ and $R_a = \frac{\text{V}_{\text{min}}^2}{127(e+f)} = \frac{60^2}{127(0.059+0.37)} = 66\,\text{m}$

Considering the mechanical (W_m) and psychological (W_p) widening of the two-lane National Highway, the total extra widening (W_e) can be designed using the following relations:

- $W_e = W_m + W_p = \frac{nl^2}{2R} + \frac{\text{V}}{9.5\sqrt{R}} = \frac{2\times 6.5^2}{2\times 480} + \frac{80}{9.5\sqrt{480}} = 0.088 + 0.384 = 0.47\,\text{m} \sim 0.5\,\text{m}$

After designing extra highway widening at the horizontal curve, the new carriageway width (B_n) is $= 7.5 + 0.5 = 8$ m. For this, the length of the transition curve can be designed using the following relation:

- $L_s = B_n \times e \times e_{\text{rate}} = 8 \times 0.059 \times 150 = 70.8\,\text{m}$

For estimating setback distance (m), the given condition is the length of the curve, $L_c > S$, $B_n = 8$ m, $R = 480$ m, and the highway is two-lane. Therefore, the distance between the centre line of the two-lane highway and the centre of the inner curve (d) $= B_n \div 4 = 8 \div 4 = 2$ m. The subtended angle and thereby m can be estimated by employing the following equation:

- $\frac{\alpha}{2} = \frac{180\text{S}}{2\Pi(R-d)} = \frac{180\times 240}{2\Pi(480-2)} = 14.4^\circ$ and $m = R - (R - d)\cos\frac{\alpha}{2} = 356\,\text{m}$

Problem statement—4

Considering all the conditions and design criteria estimated in the previous problem statements, determine grade compensation and compensated gradient for the horizontal curve (as designed in problem statement—3) if the ruling gradient (*RG*) in the highway location is 6%. Besides, design a summit curve at the intersection of two gradients, +3% and −5%, and a valley curve at the junction of descending grade of 1 in 25, meeting an ascending grade of 1 in 30.

Solution—4: Grade compensation (*GC*) and the maximum limit of grade compensation (GC_{max}) are estimated using the following relation. At the same time, the difference between the ruling gradient (provided) and GC_{max} yields compensated gradient (*CG*).

- $\mathrm{GC} = \frac{30+\mathrm{R}}{R} = \frac{30+480}{480} = 1.06\%$; $\mathrm{GC_{max}} = \frac{75}{R} = \frac{75}{480} = 0.16\%$; $\mathrm{CG} = \mathrm{RG} - \mathrm{GC_{max}} = 5.84\%$

For the design of the valley curve, there is a need to estimate SSD (estimated in problem statement—2 and estimated as 123.5 m), deviation angle (*N*), followed by summit curve length (L_{sum}), such that it is assumed that $L_{sum} > \mathrm{SSD}$, described below:

- $N = \text{Ascending gradient} - \text{Falling gradient} = 0.03 - (-0.05) = 0.08$
- $L_{\text{sum}} = \frac{N \times \mathrm{SSD}^2}{4.4} = \frac{0.08 \times 123.5^2}{4.4} = 277.3\ \mathrm{m}$

As per the IRC guidelines, the minimum summit curve length for $V = 80$ kmph should not be less than 50 m. Hence, the present value of $L = 277$ m suffices for the geometric design criteria. Similarly, for the design of the valley curve, there is a need to estimate *N*, valley curve length for the comfort condition (L_{val_com}), SSD, and valley curve length (L_{val}), such that it is assumed that $L_{val} > \mathrm{SSD}$ and centrifugal acceleration (*C*) is 0.6 m/s^2, while $v = 22.2$ m/s is already known; steps are described below:

- $N = -(1 \div 25) - (1 \div 30) = -(11 \div 150)$
- $L_{\text{val\_com}} = 2\left[\frac{\mathrm{N}v^3}{C}\right] = 2\left[\frac{11 \times 22.2^3}{150 \times 0.6}\right] = 73.1\ \mathrm{m}$
- $L_{\text{val}} = \frac{N \times \mathrm{SSD}^2}{(1.5 + 0.035\,\mathrm{SSD})} = \frac{11 \times 123.5^2}{150(1.5 + 0.035 \times 123.5)} = 192\ \mathrm{m}$

As per the guidelines, to accept L_{val}, it should be greater than L_{val_com}, which is the present case, and thus $L_{val} = 192$ m may be accepted in the geometric design.

Performance Evaluation of WAT-HD and Its Scope in Smart City Planning

All the design calculations conducted against each criterion and component of the two-lane two-way National Highway in the previous section are also performed using

WAT-HD. The findings of both manual analyses and the same obtained from WAT-HD are compared in Table 39.2. Results indicate that the values obtained from WAT-HD match the manual calculations. In fact, the load behind rigorous manual design calculations performed in Sect. "Two-Lane Two-Way Geometric Highway Design Analysis Using Manual Approach" is handled very conveniently using WAT-HD, so the design measures are obtained with minimal input and less duration. For example, concerning Table 39.2 and Fig. 39.3, for sight distance design, with minimal inputs like design speed, different velocities of the vehicle and its acceleration, reaction time and friction coefficient, WAT-HD can design SSD, ISD, OSD and minimum and desirable overtaking zones. Similar frameworks can be observed for designing horizontal and vertical alignments.

To summarise, applying computer science applications in core civil engineering sectors such as transportation and, more specifically, highway engineering can do wonders when handling cumbersome and tediously long mathematical calculations. Such applications then become more pertinent when there is a pressing demand for bringing down traffic congestion, road accidents and rising GHG emissions amidst climate change (Bibri and Krogstie 2017; IPCC 2022; Lwasa et al. 2022; Srivastava et al. 2022c). Besides, sustained transit is one of the critical engines of growth and a long-standing phenomenon. Effective transportation networks must be established to ensure sustainable development in smart cities (Chowhan et al. 2022; Saharan et al. 2020; Telang et al. 2021). Imperatively, modern advancements in computer science and engineering, given laying down platforms of web application software development and other approaches such as AI, ML and Internet of Things (ToT), have revolutionised transportation engineering in general and highway geometric design

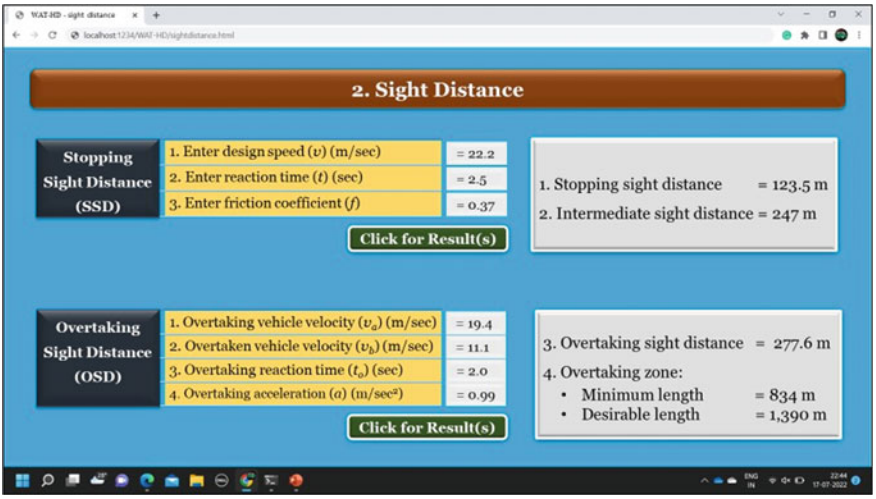

Fig. 39.3 Web Application Tool for Highway Design (WAT-HD) demonstrating sight distance design for two-lane two-way National Highway as per the guidelines of Indian Road Congress (IRC)

Table 39.2 Comparative assessment of manual calculations with Web Application Tool for Highway Design (WAT-HD) for a two-lane two-way Geometric Highway Design by following the considerations of Indian Road Congress (IRC)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
Highway cross-section design					
• Straight line camber: to estimate a rise of crown w.r.t. the edges	Rainfall conditions	Heavy	2% camber	0.09 m	0.09 m
	Road surface type	High-type bituminous surface			
	Lane width	3.75 m	7.5 m		
	Number of lanes (n)	2			
Sight distance design					
• Stopping sight distance (SSD)	Design speed (V or v) or vehicle velocity	80 kmph or 22.2 m/s	$= vt + \frac{v^2}{2gf}$	123.5 m	123.5 m
	Reaction time (t)	2.5 s			
	Friction coefficient (f)	0.37			
• Intermediate sight distance (ISD)	Stopping sight distance (SSD)	123.5 m	$= 2 \times \text{SSD}$	247 m	
• Overtaking sight distance (OSD)	Overtaking vehicle velocity (v_a)	19.4 m/s	$= (v_b \times t_0) + \left[\left(v_b\sqrt{\frac{4(0.7v_b+6)}{a}}\right) + 2(0.7v_b + 6)\right] + \left(v_a\sqrt{\frac{4(0.7v_b+6)}{a}}\right)$	277.6 m	277.6 m
	Overtaken vehicle velocity (v_b)	11.1 m/s			
	Overtaking reaction time (t_o)	2 s			
	Overtaking acceleration (a)	0.99/s^2			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
• Overtaking zone	Overtaking sight distance (OSD)	Minimum length	$= 3 \times$ OSD	834 m	834 m
	Overtaking sight distance (OSD)	Desirable length	$= 5 \times$ OSD	1390 m	1390 m
Horizontal alignment design					
• Superelevation (e)	Traffic conditions	Mixed traffic	Counteract centrifugal force for 75% of V	0.059	0.059
	Horizontal curve radius (R)	480 m	$= V^2 \div (225R)$		
	Design speed (V)	80 mph			
• Raising of outer edge w.r.t. the inner edge	Carriageway width (B)	7.5 m	$= B \times e$	0.44 m	0.44 m
	Superelevation (e)	0.059			
• Ruling minimum radius (R_r)	Ruling design speed (V)	80 kmph	$= \frac{V^2}{127(e+f)}$	117.5 m	117.5 m
	Superelevation (e)	0.059			
	Friction coefficient (f)	0.37			
• Absolute minimum radius (R_a)	Minimum design speed (V)	60 kmph	$= \frac{V_{\min}^2}{127(e+f)}$	66 m	66 m
	Superelevation (e)	0.059			
	Friction coefficient (f)	0.37			
• Mechanical widening of the highway (W_m)	Number of lanes (n)	2	$= \frac{nl^2}{2R}$	0.088 m	0.088 m
	Length of wheelbase (l)	6.5 m			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
	Horizontal curve radius (R)	480 m			
• Psychological widening of the highway (W_p)	Design speed (V)	80 kmph	$= \frac{V}{9.5\sqrt{R}}$	0.384 m	0.384 m
	Horizontal curve radius (R)	480 m			
• Extra widening (W_e)	Mechanical widening of the highway (W_m)	0.088 m	$= W_m + W_p$	0.47 m or ~0.5 m	0.47 m or ~0.5 m
	Psychological widening of the highway (W_p)	0.384 m			
• Transition curve length (L_s)	Carriageway width (B)	New carriageway width (B_n) = 8 m	$= B_n \times e \times e_{\text{rate}}$	70.8 m	70.8 m
	Extra widening (W_e)				
	Superelevation (e)	0.059			
	Superelevation induction rate (e_{rate})	150			
• Setback distance (m)	Is $m > SSD$?	Yes	$\frac{\alpha}{2} = \frac{180S}{2\Pi(R-d)} = 14.4°$ $m = R - (R - d)\cos\frac{\alpha}{2}$	356 m	356 m
	New carriageway width (B_n) = 8 m	Centre of the inner curve (d) = $\frac{B_n}{4}$ = 2 m			
	Number of lanes (n) = 2				
	Horizontal curve radius (R)	480 m			
	Horizontal curve sight distance (S)	240 m			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
Vertical alignment design					
• Grade compensation (GC)	Horizontal curve radius (R)	480 m	$= \frac{30+R}{R}$	1.06%	1.06%
• Maximum limit of grade compensation (GC_{max})	Horizontal curve radius (R)	480 m	$= \frac{75}{R}$	0.16%	0.16%
• Compensated gradient (CG)	Ruling gradient (RG)	6%	$= \mathrm{RG} - \mathrm{GC}_{\max}$	5.84%	5.84%
	Maximum limit of grade compensation (GC_{max})	0.16%			
• Length of summit curve (L_{sum})	Is $L_{sum} > SSD$?	Yes	$N = G_a - G_d$ $L_{\mathrm{sum}} = \frac{N \times \mathrm{SSD}^2}{4.4}$	277.3 m	277.3 m
	Stopping sight distance (SSD)	123.5 m			
	Ascending gradient (G_a)	0.03			
	Descending gradient (G_d)	0.05			
• Length of valley curve for comfort condition (L_{val_com})	Descending gradient (G_d)	0.04	$N = G_d - G_a$ $L_{\mathrm{val\_com}} = 2\left[\frac{Nv^3}{C}\right]$	73.1 m	73.1 m
	Ascending gradient (G_a)	0.03			
	Centrifugal acceleration (C)	0.6 m/s^2			
	Design speed (v)	22.2 m/s			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
• Length of valley curve (L_{val})	Is L_{val} > SSD?	Yes	$\mathrm{N} = G_d - G_a$ $L_{\text{val}} = \frac{N \times \text{SSD}^2}{(1.5+0.035\,\text{SSD})}$	192 m	192 m
	Descending gradient (G_d)	0.04			
	Ascending gradient (G_a)	0.03			
	Stopping sight distance (SSD)	123.5 m			

in the recent decade. Furthermore, the driving force behind creating smart cities is to warrant the link between social capital, infrastructure and human capital in order to promote higher economic growth and high quality of life for the residents of these regions. The future scope of making transportation systems resilient to climate disasters such as floods and earthquakes is significant and essential for ensuring sustainable and safe mobility in the face of climate change (IPCC 2022; Srivastava et al. 2022c; Khadke and Pattnaik 2021). It requires a comprehensive and integrated approach involving infrastructure design, technology implementation, emergency response systems, and green transportation strategies. Therefore, one of the factors advancing smart cities is sustainable transportation. There is a need to exploit sustainability in innovation, science and technology for highway design to result in local and global prosperity through the constant movement of capital.

Conclusions

This research introduces and assesses the use of the Web Application Tool for Highway Design (WAT-HD) in executing the geometric design of highways. As observed from the present findings, WAT-HD comprehensively accounted for safe sight distance, overtaking sight distance, horizontal curve, transition curve and vertical curve, along with their detailed components. For each unit, the tool yielded precisely the same output as the manual calculations when employed for designing a two-lane two-way National Highway. The execution of the WAT-HD allowed overcoming limitations of conventional practice for geometric highway design; for example, engineering drawing techniques, when employed for highway design, are found iterative, manual, cumbersome and time consuming. Nevertheless, the aim of augmenting WAT-HD into practice is not to overlook the essence of equations and calculations behind the geometric design; instead, to sensitise the challenges that exist for highway engineers. Coherently, introducing computer-aided programs in highway engineering could drastically speed the design process with more flexible options, such as modifying within economic and environmental parameters. Through the backing of WAT-HD, the concerned stakeholders, such as transportation engineering students and professional highway engineers, can better understand the procedures behind geometric highway design. Software tools like WAT-HD pave the scope for exploring different geometric designs that can satisfy given design constraints and requirements in real-world applications. In fact, such applications become more pronounced when pressure is more on achieving goals of smart city design, intelligent urban transportation and reduced vehicular-emission-based greenhouse gas release amidst changing climate.

Declaration

Acknowledgements The authors thank Mr. Sandeep R. Mahajan's Lead India Jalgaon Group for providing the research infrastructure to conduct this research.

Technical assistance provided by Mr. Ankush Patil in developing the web application tool is highly acknowledged. Thanks to Vijay Motamwar and Sushant Shinde for sharing their comments on the first draft of this research.

Authorship Contribution AD and AS collected the data and developed the web application tool, while LK contributed to the study's conception and design. NLK guided the material preparation, data collection and analysis. The first draft of the manuscript was written by AS, while all authors commented on previous versions of the manuscript. AD and AS contributed equally to this work and shared the first authorship. All authors read and approved the final manuscript.

Conflict of Interest The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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