Model for sight distance calculation and three-dimensional alignment evaluation in divided and undivided highways

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Submitted to the 3rd International Conference on Road Safety and Simulation, September 14-16, 2011, Indianapolis, USA

ABSTRACT

The assessment of spatial road design and of visibility conditions along the alignment constitutes a procedure of great importance that should begin with preliminary design. This paper describes a tool for evaluating the three-dimensional alignment with the aid of the minimum required stopping (SSD) and passing (PSD) sight distance. The H11 System is a road design software -entirely developed at the National Technical University of Athens- that has the capability to generate perspective images from the driver's successive viewpoints along the road. These perspective views, whose creation is based on the basic principles of Perspective Geometry, allow the designer to detect and localize possible deficiencies of the spatial design, with respect to road safety and esthetics. Moreover, by picturing a vehicle in front of the driver at the SSD and a vehicle at the opposite traffic flow at the PSD –if it's about a two-lane, two-way highway-, they allow him to visually and directly check the availability of the two sight distances, providing him with an additional, quantitative aid to the procedure of the assessment of the road consistency and safety. The SSD and the PSD are calculated from the software for every station along the roadway, by means of the mathematical models used in current design practices. This tool is, nowadays, used for educational purposes in undergraduate classes at the Department of Transportation Engineering of School of Civil Engineers in NTUA. Some Highway Design Agencies and Consultant firms use it as well.

Key words: three-dimensional alignment, road design software, perspective images, sight distances.

INTRODUCTION

Driving safety is a value of growing importance to modern societies and it is widely recognized that, in order to promote highway safety conditions, it is essential to improve the geometric design consistency (Bella 2005). Highly inconsistent design that produces a sudden change in the characteristic of the roadway can lead to human errors and subsequently collisions. Design consistency implies that the design of a road does not violate either the driver's expectation or his ability to guide and control the vehicle in a safe manner (Easa and Wenlong 2006). Gibreel et al. (1999) refer to a consistent highway design "as one that ensures that successive geometric elements are coordinated in a manner to produce harmonious driver performance without surprising events".

The amount of information drivers have to process in relation to the time available for such analysis is known as mental workload. Naturally, mental workload is heavier as the geometry of the road is more complex or less predictable. Sudden changes in operating speeds or vehicle trajectories are usual signs of intense mental workload forced by alignment inconsistencies (Altamira et al. 2010).

An important reason for driving errors is the misjudgement of road users concerning the real course of the road. This misjudgement results from the overlapping of elements of the horizontal and vertical alignment which can be due to an unfavourable, in other words an inconsistent, spatial road alignment and leads to the perception of confusing visual cues by the driver. Thus, the optimization of the spatial road alignment is an important criterion for road design that should not be left to chance but should begin with preliminary design, during which stage adjustments can readily be made (AASHTO 2004). However, until recently, it was hardly taken into account in day-to-day design practice due to the lack of evaluation criteria (Zimmermann and Roos 2005). As far as current highway design guidelines are concerned, they provide indications and principles for spatial road design, as well as illustrations and descriptions of the three-dimensional alignment phenomena that designers have to avoid. However, they do not proceed to precise numerical suggestions regarding to design parameters, apart from very few cases, but they rest on the designer's judgement and on his capability to imagine the road in three dimensions.

As aforementioned, during the interaction among the driver, the vehicle and the road which is involved in the driving task, one must recognize the importance of visual cues as about 90% of the driver's required information is obtained visually. However, although the visual cues are a function of road esthetics and alignment coordination, the interpretation of these visual cues is a function of the driver's experience, physiology and psychological characteristics. Even if the road alignment is designed properly, there may still be situations in which the road alignment and features would cause drivers to experience optical illusions which could have a negative effect on road safety (Bidulka et al. 2002). It is therefore very important that road design engineers learn to see the highway in the eyes of the ordinary driver and that designing with the user in mind is reflected in highway geometric design guidelines (Kanellaidis 1996).

According to the current German highway design guidelines (RAA 2008), the only satisfactory procedure for the thorough check and evaluation of the spatial road alignment is the creation of perspective images for the respective road section. In fact, the only perspective depiction that is really useful is the one from the driver's eye position on the carriageway. By studying a perspective depiction of the road as seen from on high (bird's eye view), the designer can not always perceive the distorted perspective and the visibility problems that the driver encounters (Smith and Lamn 1993). However, the analysis of these images is qualitative and subjective.

A calculable parameter which can be related and constitute a basic criterion with regard to the above procedure is provided by the concept of sight distance. It is defined as the length of the carriageway that is exposed to the driver's field of view every single moment and its strong relationship with road safety has been pointed out by several researches. It is the most easily comprehensible aspect of the concept of visibility conditions, while partial road disappearance, sight distortion, erroneous perception of geometric elements and insufficient recognisability of curves ahead are aspects equally important. Any roadway should offer the driver at least some minimum sight distances in order to enable him to perform safely driving manoeuvres such as braking and overtaking, among others. Insufficient sight distances reduce the amount of information about the characteristics of the road and its surroundings that are exposed to the drivers, thus intensifying their mental workload and providing them with inadequate time to adapt their behavior to poor and inconsistent alignment, thus increasing their chances of being involved in accidents (Altamira et al. 2010; Moreno et al. 2010) Therefore, current design practices require highway designers to provide motorists with sufficient sight distances in order to enable them to perceive and react to any hazardous situation, with a low mental workload.

HIGHWAY ESTHETICS

It is worth to mention that, nowadays, the approach to the planning of transportation facilities is under evolution. There is a renewed effort towards ensuring that the design of a project enhances the cultural, social, historical and, of course, the natural environment. This trend demands that engineers be trained to balance factors such as environmental fit and esthetics with the more traditional design objectives of efficiency, safety and cost (Janikula and Garrick 2002).

According to Smith and Lamm (1993), the formal study of the esthetics of highways had already begun in Germany in the 1930's, with the work of Fritz Heller, Hans Lorenz and others. The Germans engineers went to considerable trouble and expense to eliminate or modify combinations of vertical and horizontal curvature which looked awkward when viewed in perspective from a low angle. Furthermore, they point out that although safety benefits of aesthetically pleasing highways have not been well-quantified, in "Practical Highway Esthetics" (1977) it is stated that there is a subtle interrelationship between highway esthetics and highway safety. Measures that make a highway beautiful, not only make it actually safer, but also make it appear safer to the driver, which reinforces his enjoyment and comfort while driving.

However, the issue of esthetics has traditionally been assigned a relatively low priority in the highway design process. There is a broad general awareness of the design factors that affect the esthetics of transportation facilities. The challenge is how to integrate these factors into the curriculum and how best to develop esthetic awareness in students. Given the nature and scale of highways, three-dimensional (3-D) visualization techniques are needed to effectively study the visual implications of various design choices (Janikula and Garrick 2002).

The current highway design guidelines, take into account the importance of the issue of esthetics when treating the coordination of horizontal and vertical alignment. Especially Austroads 2009, distinguish their indications in those that promote highway safety and those that promote highway esthetics.

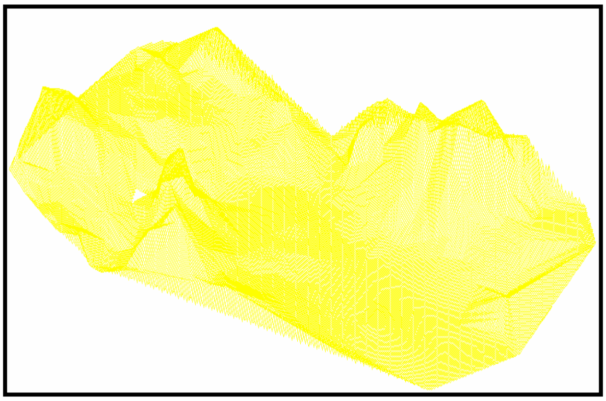
THE H11 SYSTEM

Road design engineers, usually use perspective views of the road from the driver's eye successive positions in order to evaluate the three-dimensional alignment and visibility diagrams in order to check the sufficiency of Stopping (SSD) and Passing (PSD) Sight Distance. This paper describes a tool that uses the minimum required sight distances in order to evaluate the spatial highway alignment.

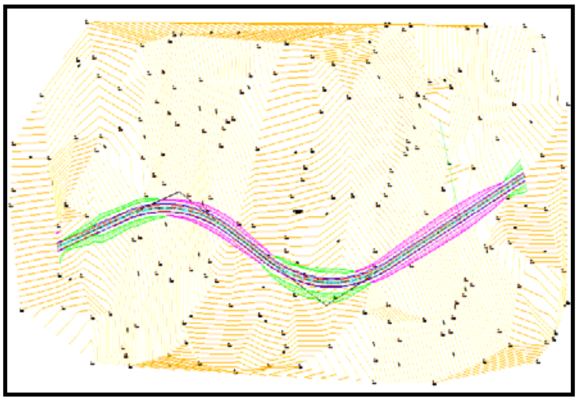
The H11 System is a road design software -entirely developed at the National Technical University of Athens- that has the capability to perform all the tasks related to highway geometric design (graphical analysis of terrain model, full definition of horizontal and vertical geometry, full definition of cross sections, construction of superelevation diagram, construction of visibility diagram, construction of operating speed diagram, optimization of earth work) and to create the respective drawings, both for a new design or an existing road. The software in question allows the system operator to perform the analyses on road layouts under the current German (RAA 2008), American (AASHTO 2004), Australian (Austroads 2009) and Greek (OMOE 2001) guidelines and under customizable settings. However, it is noted that mostly Greek and German guidelines are useful for Greek engineers, as they approximate better country's data. Figure 1 shows some of the graphical capabilities of the H11 System.

One of the most useful features of this system -the one that the paper aims to show off- is the possibility of observing the final design in continuous perspective views, seen from the driver's position or from any point of the space selected by the operator. The whole length of the road can be "traveled" at any "speed" chosen by the designer. These perspective views allow him to detect possible deficiencies of the three-dimensional alignment, with respect to road safety and esthetics. Moreover, they allow him to directly check the availability of stopping sight distance along the road, providing him with an additional aid to the procedure of the assessment of the road consistency, thus of the road safety.

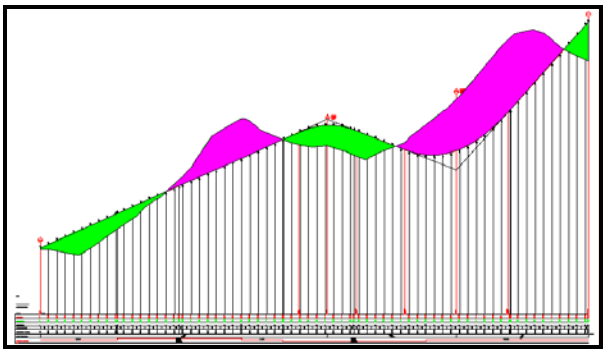
In the following paragraphs, the operating speed and the visibility diagrams that the H11 System extracts are also presented and briefly described as they are considered to contribute to the assessment of the alignment consistency.



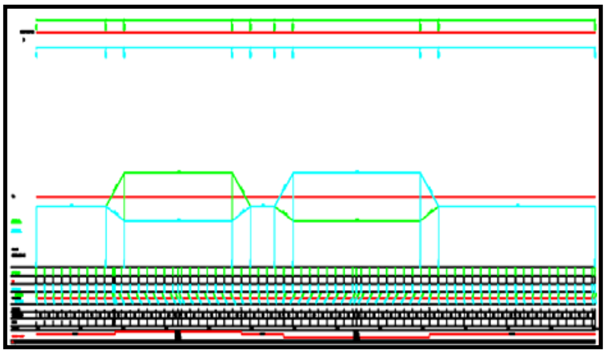
a) Terrain model



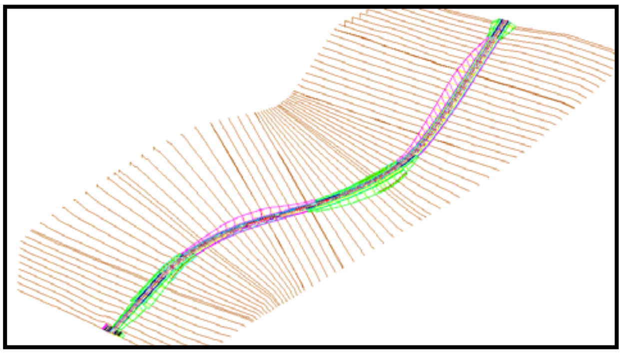
b) Final horizontal alignment on contour lines



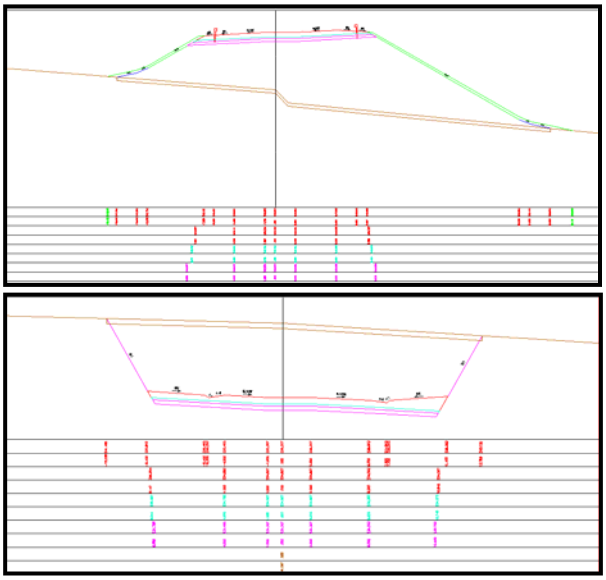
c) Final vertical alignment design



d) Superelevation diagram



e) 3D road final design



f) Typical cross sections

Figure 1 H11 graphical capabilities

Operating Speed Diagram

In literature there are various criteria to evaluate design consistency. They may be based on the analysis of alignment indices or on the quantification of mental workload of the driver, but the most commonly used method is the analysis of the operating speed profile (Bella 2005). Operating speed is defined as the speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds (V_{85}) is the most frequently used measure of the operating speed associated with a particular location or geometric feature (AASHTO 2004).

The evaluation of the design consistency through the analysis of the operating speed profile consists of the following two steps:

- The estimation-calculation of V_{85} profile of the road section under evaluation
- The check and limitation of the difference between the design (V_e) and the operating speed on each design element as well as the variation of the operating speed between successive elements of the alignment in order to avoid surprising events.

The second of the aforementioned steps is based on two quantitative safety criteria (Criteria I and II) that Lamm et al. (1999) developed for the evaluation of design on three levels (good, fair and poor) as seen in Table 1. These safety criteria have been introduced in Greek guidelines as well. A third safety criterion (Criterion III) refers to the adequacy of the safety dynamics provided (it is based on vehicle stability on horizontal curves) and aims to limit the difference between side-friction assumed for curve design (f_{RA}) and side friction demand (f_{RD}) for design at the operating speed.

Table 1 Quantitative safety criteria for undivided highways

	Design evaluation		
Safety Criterion	**Good**	**Fair**	**Poor**
I	$\lvert V_{85i}-V_{ei}\rvert \leq 10$km/h	10km/h $< \lvert V_{85i}-V_{ei}\rvert \leq 20$km/h	$\lvert V_{85i}-V_{ei}\rvert > 20$km/h
II	$\lvert V_{85i}-V_{85i+1}\rvert \leq 10$km/h	10 km/h $< \lvert V_{85i}-V_{85i+1}\rvert \leq 20$km/h	$\lvert V_{85i}-V_{85i+1}\rvert > 20$km/h

Researchers have found that the operating speed is a function of the geometric features and that it must be calculated for every single geometric element (horizontal curve or tangent) of the road. The H11 System calculates the values of V_{85} all along the roadway, based on the indications and by means of the equations included in Greek guidelines. Then, it extracts the operating speed diagram, an example of which is seen in Figure 2, by means of which the designer is able to evaluate the road alignment consistency according to safety Criteria I and II. Note that under the graph, the elements of the road's horizontal geometry are displayed.

The aforementioned diagram, in other words the determination of the value of V_{85} at every station along the road axis, is also necessary for the designer in order to calculate the SSD and PSD at every position of the driver according to current German, Australian and Greek highway design guidelines.

Apart from the diagram, H11 also generates a file where all the calculated values of V_{85} and the chainages of the corresponding stations are documented.

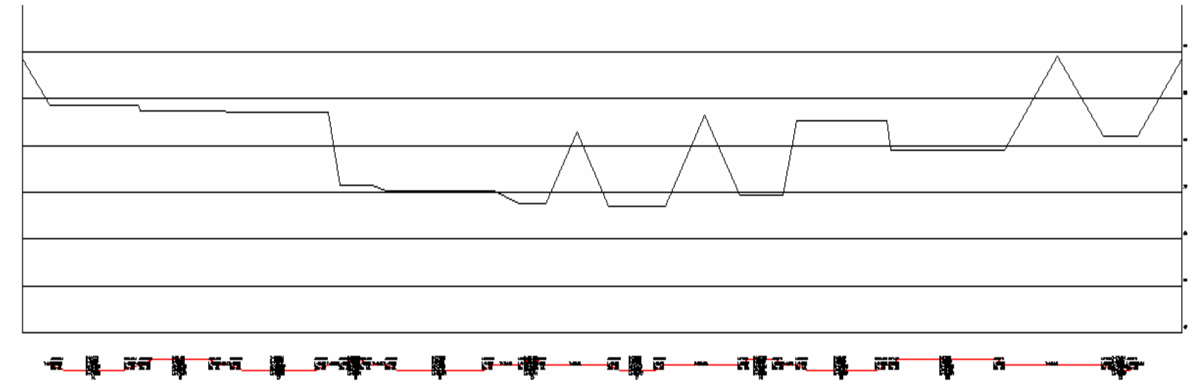


Figure 2 Operating speed diagram

Visibility Diagram

The H11 System has the capability to calculate the required SSD and PSD as well as the Available Stopping Sight Distance (ASSD) and the Available Passing Sight Distance (APSD) at any station along the roadway. The calculations process is repeated at any desired interval along the driver's roadline, in both directions of travel. Moreover, it takes into consideration both horizontal and vertical alignment of the road, as well as the characteristics of the environment, thus allowing a three-dimensional visibility analysis, both for a new design or an existing road. As a result of the process above, H11 extracts a diagram concerning either the ASSD (Figures 3 and 4) or the APSD (Figure 5).

The diagram displayed is composed of several parts. The graph constitutes its main part. Referring to Figures 3 and 4, the dark blue line indicates the SSD and the green line the ASSD. As far as Figure 5 is concerned, the dark blue line indicates the PSD and the green one the APSD. In Figures 3 and 4, the light blue line is the speed diagram (the left edge of the graph constitutes the sight distance axis, while the right edge constitutes the speed axis). From Figure 5 this line has been removed. The horizontal axis indicates the project's length.

The lower part of the diagram displays the longitudinal terrain profile (green color) and the corresponding vertical alignment (red color), as well as the project's horizontal geometrical features.

The left part of the diagram provides some useful information for the easier comprehension of the graph: the guidelines based on which the sight distances are calculated, the parameters' values that these guidelines assume, the direction of travel and the correspondence of each color displayed.

Apart from the diagram, H11 also generates files where the calculated values of required and available sight distances at all the stations along the driver's roadline, as well as the corresponding parameters needed for the SSD and PSD determination, are documented.

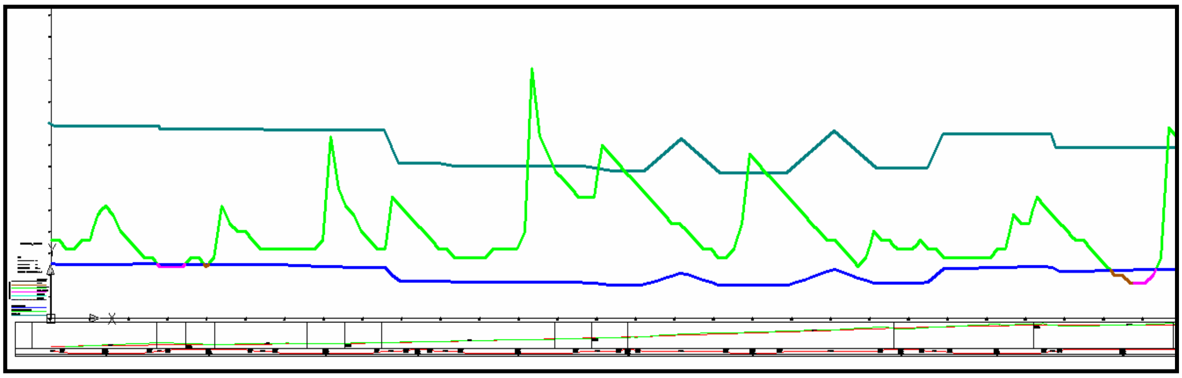


Figure 3 ASSD diagram for an undivided highway

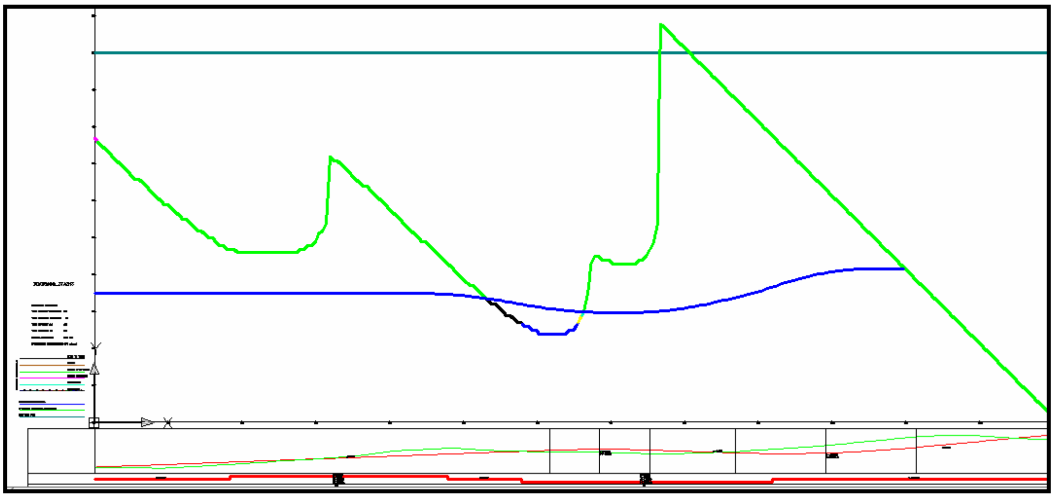


Figure 4 ASSD diagram for a divided highway

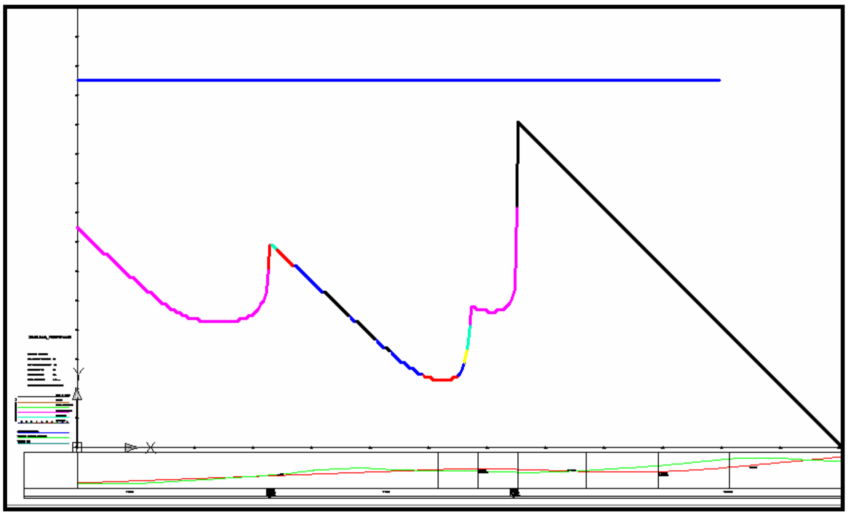


Figure 5 APSD diagram

Stopping Sight Distance (SSD)

The SSD is the distance to enable a normally alert driver, traveling on wet pavement, to perceive, react and brake to a full and safe stop before reaching a hazard that appears unexpectedly on the road ahead (Austroads 2009). Its calculation procedure can be performed either by following computational approach, where additional parameters from the vehicle, road or tire point of view are involved, such as ABS vehicle supply (Mavromatis et al. 2005), or by applying the traditional point mass model found in the current design policies. H11 is flexible in adopting any procedure. When the traditional methodology is applied, the following equations are utilized:

$$SSD = S_1 + S_2 \quad (1)$$

$$S_1 = \frac{V}{3,6} \times t_R = 0,278 \times V \times t_R \quad (2)$$

$$S_2 = \frac{(V/3,6)^2}{2 \times g \times \left(f_T + \frac{s}{100} \right)} = \frac{V^2}{254\left(\frac{a}{9,81} \pm \frac{s}{100} \right)} = \frac{V^2}{254\left(d \pm 0,01 \times s \right)} \quad (3)$$

where:

S_1 (m): the distance traveled during the total driver's reaction time

S_2 (m): the distance traveled from the instant brake application begins to fully stop

V (km/h): design speed according to AASHTO or operating speed according to RAA, Austroads and Greek guidelines.

t_R (sec): reaction time (from the instant the driver sights an object necessitating a stop to the instant the brakes are applied), which is assumed to be:
- 2.5 sec according to AASHTO 2004
- 2.5 sec, 2 sec or 1.5 sec, depending on the road conditions, according to Austroads 2009
- 2 sec according to RAA 2008 and Greek guidelines (2001)

α (m/s^2): deceleration rate during the braking time, which is assumed to be:
- 3,4 m/s^2 according to AASHTO 2004
- 3,7 m/s^2 (braking without ABS) according to RAA 2008

f_T (-): longitudinal friction coefficient ($f_T = \alpha/g$)

d (m/s^2): coefficient of deceleration (longitudinal friction factor) for which specific values are given depending on V_{85} (OMOE 2001) or on driver/road capability (Austroads 2009)

s (%): longitudinal grade (+ for upgrades and – for downgrades)

g (m/s^2): gravity acceleration (9,81 m/s^2)

Note that the values above refer to usual passenger cars. As far as trucks are concerned, the different guidelines take them into account in different ways which are not included in H11 considerations, therefore neither in the present paper.

Available Stopping Sight Distance (ASSD)

ASSD can be described with the aid of a line of vision between the driver's eye and the object that restricts his visibility. It is the distance along a roadway throughout which an object of specified height is continuously visible to driver and is dependent on the height of the driver's eye above the road surface, the specified object height above the road surface, and the height and lateral position of sight obstructions within the driver's line of sight (AASHTO 2004). Differnet design guidelines assume different values for driver's eye and object height.

It is noted that driver's visibility may be restricted by the surface of the road three-dimensional digital model itself (crest vertical curves), by the excavation planes in cuts, by the road environment natural terrain, by the central median (New Jersey) if the highway is divided, but also by roadside features such as barriers, buildings e.t.c. Therefore, the computational system must generate the digital model of all the aforementioned features related to the project.

In order to calculate ASSD, H11 bases on the generation of the full three-dimensional model of the project, as aforementioned, where each feature is rendered as a cluster of triangles. Moreover, the system uses equations of analytical geometry in order to describe lines of vision begun from the driver's eye and to determine the points of intersection of these lines both with objects assumed on the roadway and the triangles that form all the features that may restrict driver's visibility. ASSD is defined as the distance between the driver's eye and the point of intersection of his line of vision with the first triangle that hides an object assumed at the same cross section.

At any station along the driver's roadline, ASSD must not be shorter than SSD. In fact, it is preferred to be greater than SSD at a large proportion of the road's total length (RAA 2008, OMOE 2001). Where in the graph the green line is above the dark blue line, the ASSD is greater than SSD, in other words it is adequate. Figures 3 and 4 correspond to highways with fairly adequate ASSD. ASSD is shorter than SSD only for a few meters in both Figures, while almost all along the two projects, it is much greater as it should be. Figure 4 corresponds to a section of a divided highway with constant design speed; therefore V_{85} profile is simply a straight line. Note that the sections of the ASSD lines which are under the SSD lines have various different colors. These colors indicate the elements that at any single station restrict driver's visibility, thus giving the designer a first but full idea of the deficiency, before even look at the corresponding perspective images. For example, in Figure 3, the magenta color indicates that driver's visibility is restricted due to a plane of cut, while the brown color indicates that the problem is the environment terrain.

<u>Passing Sight Distance (PSD)</u>

Passing maneuvers in which faster vehicles move ahead of slower vehicles are accomplished on lanes regularly used by opposite traffic and concern only two-lane, two-way undivided highways. PSD is the distance required for the driver of a vehicle to safely complete the pass of a slower moving vehicle without interfering with the speed of an oncoming vehicle but also to have the time to return safely to his lane without completing the pass if he sees that opposing traffic is too close (AASHTO 2004, Austroads 2009). PSD is measured between the passing driver's eye and the oncoming vehicle of the opposite traffic lane. For H11, the oncoming vehicle is particularly assumed to be on the corresponding to the passing driver's roadline of the opposite traffic lane.

It is mentioned that the desirable frequency and length of the road sections which provide sufficient PSD is related to the design or the operating speed (depending on the guidelines

used), traffic volume and composition, terrain and construction cost, and the different design guidelines follow different general rules.
The precise and analytical calculation of PSD is difficult and time-consuming for the designers as there are a lot of entering factors. Therefore, highway design guidelines propose some standard minimum values for PSD, related to the design speed (AASHTO 2004) or the operating speed (RAS-L1995, Austroads 2009, OMOE 2001) of the passing vehicle. H11 uses these values in order to form the PSD line of the visibility diagram.

Note that RAA 2008 concern only divided highways, so they do not refer at all to PSD. Thus, H11 uses the corresponding values proposed by the older German guidelines RAS-L 1995.

Available Passing Sight Distance (APSD)

Similarly to ASSD, APSD is defined as the distance between the driver's eye and the point of intersection of his line of vision with the first triangle that hides an oncoming vehicle assumed at the same cross section but at the opposite traffic lane and at the corresponding distance from the road axis.

Depending on the guidelines used, the designer has to ensure that there are sufficient sections along the driver's roadline where APSD is greater than the minimum required. Referring to the visibility diagram, he must ensure that there are adequate sections where the green line is above the dark blue line. Figure 5 corresponds to a highway along which there is no station with sufficient APSD; consequently, the designer has to take appropriate measures. Note that, in fact, the APSD line is not green but has several colors which indicate the elements that restrict driver's visibitily for overtaking at every station along the project.

Perspective images

For any station along the driver's roadline, H11 generates a perspective image of the road and its environment, from the driver's point of view. Apart from the road surface and the roadside natural and possible artificial features, each perspective view displays the back image of a vehicle traveling in front of the driver, at the end of the SSD, and the front image of a vehicle traveling in the opposite traffic lane, at the end of the PSD. It is clear that, if the project under design is to warrant safety and comfort during driving, H11 must extract no image where the vehicle at the SSD is not seen, as well as several images where the vehicle at the PSD is also seen. Note that the vehicle at the PSD is depicted and taken into account with regard to road safety only when the road under design is a two-lane two-way undivided highway.

In order to create these perspective images H11 uses the principles of Perspective Geometry through their expression with the aid of analytical friction models. The 3D visualization of an object corresponds, to a certain approximation, to what the human eye perceives. It conveys the apparent changes in the size and shape of an object caused by its location and the distance from the viewer. This is due to the fact that the process of vision is geometrically identical with the method of central projection (Taiganidis and Kanellaidis 1999). Thus, the creation of the perspective images is based on the central projection of a large number of points, which approximately form the features of the project's spatial layout and whose spatial Cartesian coordinates X, Y, Z are known from previous operations of H11, on a vertical projection plane in front of the driver, with the driver's eye as center of projection. Analytical models are used in order to transform the spatial coordinates X, Z into x, z coordinates of the

corresponding points of the perspective-view plane (The y-axis constitutes the view axis and is assumed to be tangent to driver's roadline).
The perspective images from the driver's point of view that H11 extracts give the designer the capability to recognize and localize in time the errors or problems in the coordination of horizontal and vertical alignment, as well as the optical deficiencies resulting from them. Moreover, they enable him to localize visibility problems that may occur due to planes of cuts or to other factors that have been aforementioned (such as central medians New Jersey if it is about divided highways) and to take appropriate measures. The perspective images are generated for all the positions of the driver along the roadway, at any desired step, and the successive images are placed the one above the other. Thus, the designer can directly supervise the whole length of the road, while moving quickly from one image to the other has the feeling of movement. Moreover, H11 has the capability to "travel" in both directions of the road and not only from the driver's point of view but also from any point of the space around the station under consideration, thus generating bird's eye views which, however, are not very useful for the evaluation of the spatial layout of the road. The end of driver's vision, in other words the length of the road ahead that is displayed, is decided by the system's operator. Next to each image the chainage of the center of projection (usually the driver's eye) and the travel's direction are displayed. Finally, H11 has the capability to extract perspective images both for divided and undivided highways, based on the data imported by the system's operator.

It is noted that the eyes of a driver in motion are concentrated within the limits of a comparatively small space angle. In composed and confident driving and with the driver seated comfortably, without strain, his line of vision does not extend beyond the limits of the "rectangle of clear visibility", 10x16 cm in size, arranged at a distance of 50 cm from his eyes (the location of the windshield). For drawing the perspective view of a highway, within the rectangle of clear visibility, the view angle α is assumed to be between 20 and 30º, its vertex being the driver's eye (Taiganidis and Kanellaidis 1999). Moreover, the higher the vehicle's speed, the narrower is the driver's field of view (Road Safety Manual 2003). For simplicity, when creating any perspective image, H11 assumes that α is 30º.

Figure 6 corresponds to a station of a two-way two-lane highway where ASSD and APSD are sufficient. As it can be seen, both vehicles are visible. In the contrary, Figure 7 corresponds to a station of a two-way two-lane undivided highway where only the ASSD is sufficient. The oncoming vehicle at the opposite traffic lane can not be seen due to a plane of cut at a right horizontal curve. In that Figure, the triangles that form the road surface and and the planes of cuts are filled with color in order to better depict that the oncoming vehicle is not visible. Figure 8 corresponds to a station of a divided highway, therefore only the vehicle at the SSD is displayed. The central median is a New Jersey of 1 m height and it's the only feature in the image that is filled with color, so that the image observer can easily distinguish the elements that it actually hides. The driver is at a right horizontal curve, therefore there is no visibility restriction due to the central median. The vehicle at the SSD is visible. Finally, Figure 9 displays some usual cases of optical deficiencies resulting from unsuccessful three-dimensional design that a designer may be needed to recognize. In order to facilitate the focus on these specific problems, all the features except the road surface have been removed.

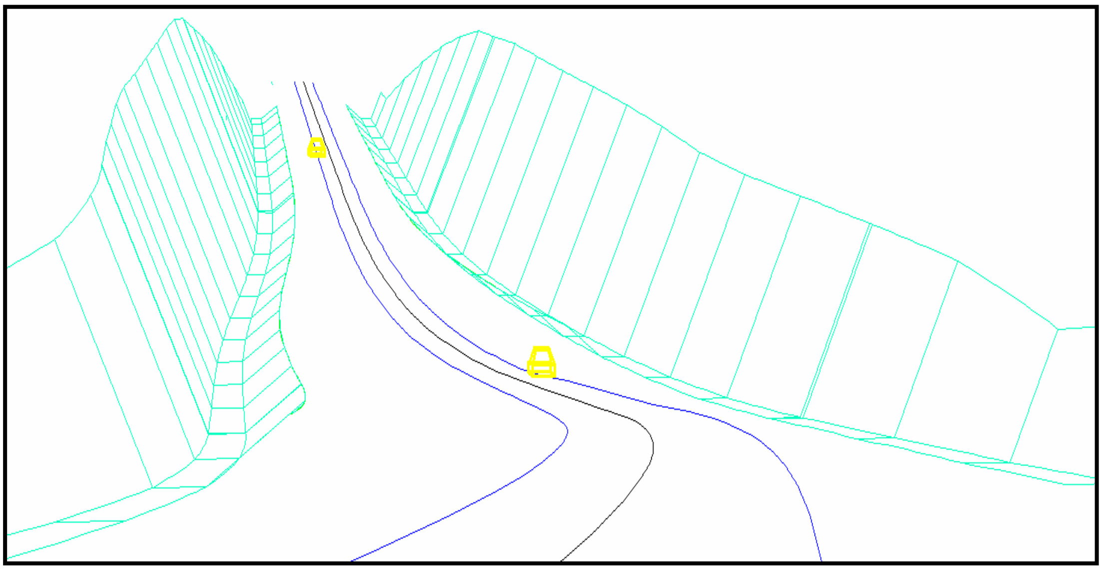


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Figure 6 Perspective view from a station of a two-way two-lane undivided highway where both ASSD and APSD are adequate

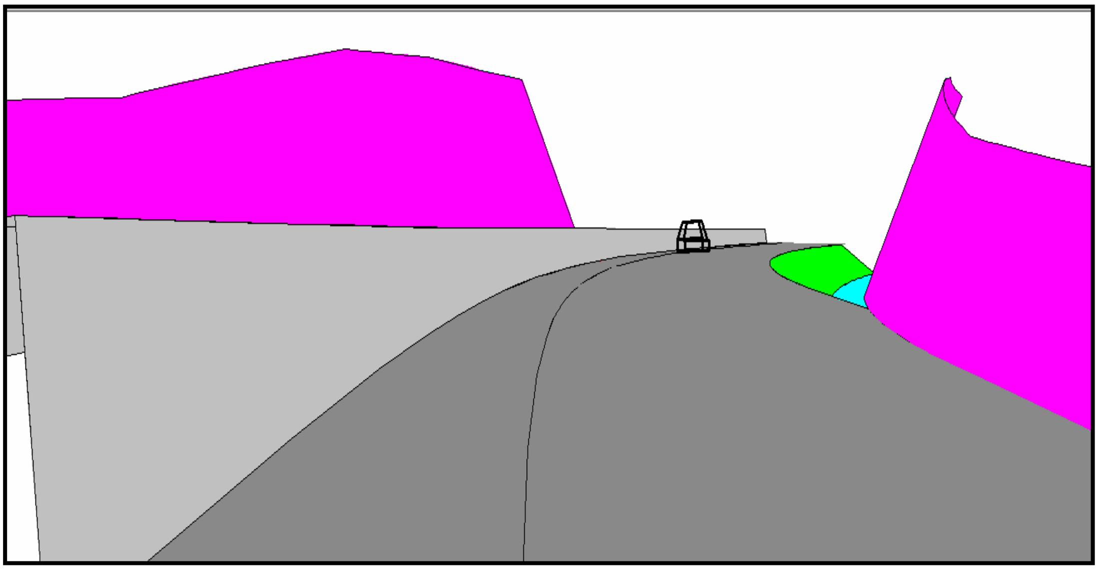

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Figure 7 Perspective view from a station of a two-way two-lane undivided highway where there is adequate ASSD but not APSD

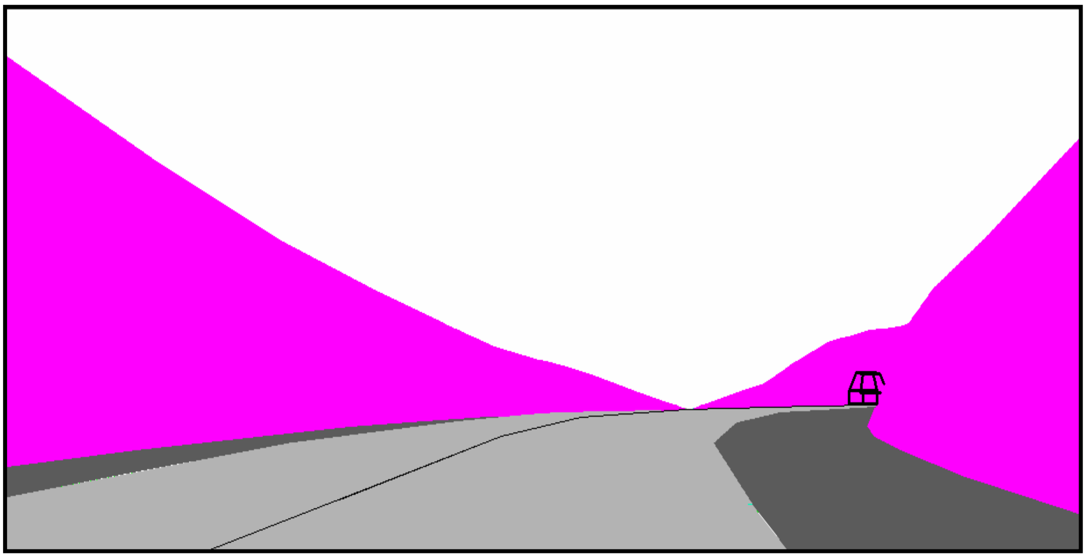

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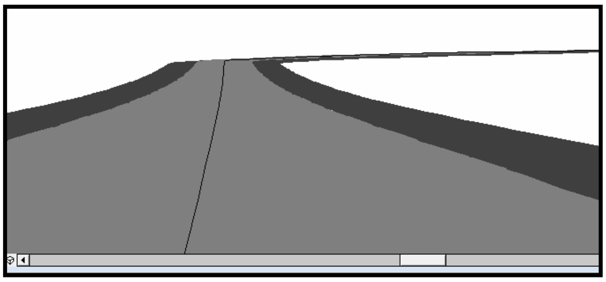
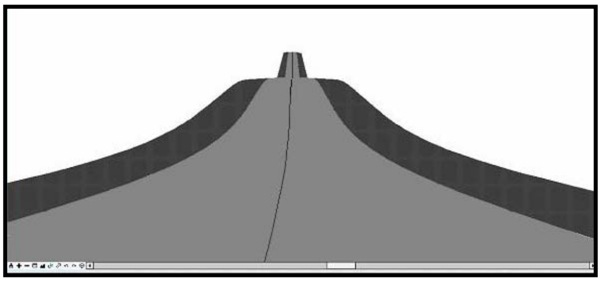
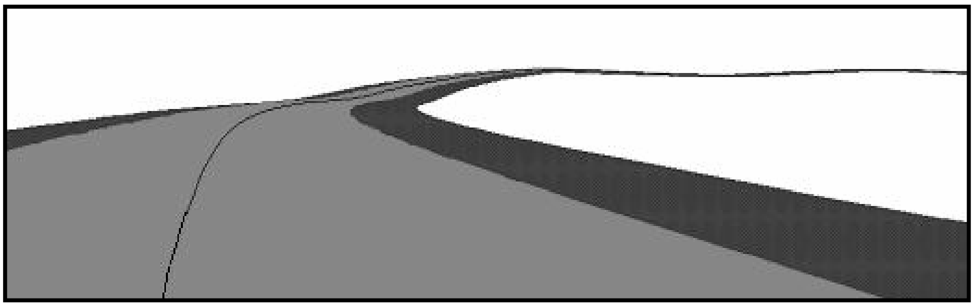
Figure 8 Perspective view from a station of a divided highway where ASSD is adequate



a) Optical alignment breakage due to small horizontal curvature



b) Hidden dip at horizontal tangent



c) Flutter at horizontal curve

Figure 9 Examples of optical deficiencies due to unadequate 3D design

CONCLUSIONS

The perspectives images generated by the H11 system constitute a valuable tool for a designer to evaluate the spatial alignment, the consistency and the visibility conditions that a new project provides, during the preliminary design when adjustments can still be made. The system operator has the capability to check visual continuity, to localize, analyse and fix optical deficiencies resulting from inadequate coordination of the horizontal and vertical alignment but also to evaluate highway esthetics.
All the existing softwares have the capability to generate perspective images, even videos that simulate the procedure of driving along the road under design. However, for most of them, the evaluation of spatial design is eventually subjective. The depiction of the back image of a vehicle at the end of SSD and of the front image of a vehicle at the end of PSD at the opposite traffic lane into H11 system's perspective views provides the system operator with a quantitative criterion for the evaluation of the perspective images. Moreover, he has the capability to directly localize the element that restricts driver's visibility, thus to take the appropriate measures. The visibility diagrams that H11 extracts provide the designer with an additional tool in order to evaluate the available sight distances al along the new project.

The authors recognize that H11 has room for improvement. They are working in order to insert into the perspective images more roadside features that may influence driver's comfort, visibility, mental workload and safety such as safety barriers, buildings or traffic signs. Moreover, they intend to make the perspective views photorealistic by representing, for example, the sunlight. However, they hope that H11 constitutes a useful tool not only for the students of School of Civil Engineering of NTUA but also for Greek highway designers.

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