Knowledge-Based Personal Computer Software Package for Applying and Placing Curve Delineation Devices

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The delineation of curves on rural two-lane highways in Ohio is the responsibility of traffic engineers in the Ohio Department of Transportation (ODOT). The traffic engineers currently use the Ohio Manual of Uniform Traffic Control Devices (OMUTCD) as a guide for the curve delineation planning and implementation. However, the rules that are given in the OMUTCD and the federal MUTCD do not guarantee that the curve delineation provides optimal, uniform information to the driver. OCARD (ODOT computer-aided road delineation), a knowledge-based system running on an MS DOS personal computer assists the user in the delineation task and treats similar or equal curves with the same traffic characteristics in exactly the same, consistent, and uniform way. The basis for the development of OCARD is the idea that an adequate number of roughly equally spaced delineation devices in a curve provides an unfamiliar driver with curvature information that may be helpful in the curve speed selection, thus resulting in fewer run-off-the-road accidents. The computed curve and delineation information can be stored and easily distributed if required. OCARD was carefully developed with regard to easy human-computer interaction. An extensive context sensitive on-line help utility describes the system, the required input data, the handling, all field measurement procedures, and the produced output data in great detail. As with any other software package it would be strongly recommended to use it only after the user has had adequate user training in obtaining the required measurements in the field and running a number of case studies using the system.

The Manual on Uniform Traffic Control Devices MUTCD (*1*) and the Ohio Manual of Uniform Traffic Control Devices OMUTCD (*2*) describe the application for a number of roadside delineation devices that may be used in curves on rural two-lane highways to provide drivers with visual cues that indicate the severity of the curve before they enter the curve. However, on the basis of an overall system point of view, there are no application guidelines in the federal MUTCD (*1*) and in the OMUTCD (*2*) that explicitly specify the prevalent physical or traffic conditions or both, in which a particular type or combination of types of roadside delineation devices would be optimal to apply from a driver visibility, performance, and safety point of view. Therefore, one can find curves on rural state highways in Ohio that are similar, have similar traffic characteristics, and are equipped with none or any one or any combination of the roadside delineation devices specified in the OMUTCD (*2*).

A survey of the current delineation practices used in the various states in the United States and provinces of Canada (*3*) found that the importance of the development of a set of quantitative guidelines seems to be recognized and desired by the surveyed traffic engineers. Further, the survey indicates that there is no U.S. state or Canadian province that uses computer-assisted methods for the curve delineation task. At the same time 66 percent of the surveyed Ohio Department of Transportation (ODOT) district traffic engineers, 42 percent of the surveyed U.S. state traffic engineers, and 66 percent of the Canadian province traffic engineers expressed the desire and need for a computer-assisted curve delineation package such as OCARD (ODOT computer-aided road delineation).

A photolog analysis (*3*) of ODOT Districts 5 and 10 was conducted and the information about the delineation of the curves on selected two-lane rural highways was documented. The photologs contained recent frames (one to several years old) for each 1/100 mi (16 m) of roadway. Surprisingly it was found in both districts that chevron signs are rarely used together with an arrow sign, even though an arrow sign by itself does not provide adequate curvature information, especially at night.

To make certain that there are no unexpected adverse effects caused by the curve delineation and to acquire more knowledge about the way traffic engineers tend to judge curves on rural two-lane highways and to delineate them according to their engineering judgment, an extensive before/after delineation evaluation involving 12 evaluators (ODOT/FHWA personnel) was conducted (*3*). From the answers of the interviewed evaluators the following can be seen: (*a*) even experienced evaluators have difficulties recommending the correct type, number, and location of curve delineation devices by just looking at a particular curve when driving through that curve at night with low beams; (*b*) subjective evaluation of an undelineated curve tends to provide a required number of devices that is too low; (*c*) the optimal type, number, and location of the delineation devices may be more accurately and more consistently determined by using a set of algorithms, which should be implemented in a computer software package to simplify their use, and (*d*) the opinion of an experienced evaluator is extremely valuable for the evaluation of a delineated curve. These findings supported the need for the development and use of a knowledge-based interactive delineation package such as OCARD.

In addition to the research mentioned earlier, a series of approach and center-speed measurements before and after installing curve delineation devices were conducted. The measurement results indicate that there is no systematic pattern in speed increase or speed reduction before and after the delineation devices are installed. The sharpness of tight curves may be emphasized by the delineation, thus leading to a speed reduction, whereas somewhat flatter curves may be more easily recognized as such, after the delineation is installed, thus leading to a speed increase. In both instances, it seems that the curve delineation appears to provide the perceptual basis for a more adequate curve speed selection.

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From the above research, which was described previously (*3*), a number of delineation rules and algorithms were developed and implemented into OCARD. The system was carefully developed with respect to easy human-computer interaction. The computed delineation can be previewed both in a perspective view and in a top view. A hard copy of the preview screens can be printed if desired. OCARD not only computes the curve delineation devices but also specifies the type and advance location of the advance curve warning sign. In addition to this, OCARD creates a number of output documents that are used for the delineation material preparation in the warehouse during the actual delineation device installation in the curve and for reference purposes in the archive.

OCARD SYSTEM DESCRIPTION

The personal computer hardware (minimum 386 with math coprocessor) and software requirements have been described previously (*3*).

Field Tools

For the curve data acquisition in the field use of an electronic car compass to measure the heading change of the curve, an electronic digital level to determine the superelevation and grade in the curve, a distance measuring wheel to measure long distances such as the outside curve length, and a 100-ft tape for measuring the chord height and for measuring shorter distances such as the road width, is recommended. A can of white spray paint is needed to mark the beginning, the center, the location with the minimum curve radius and the end of the curve, as well as the maximum chord height (along the curve center line), which is needed to determine the minimum radius of the curve. The measured distances, superelevations, grades, and angles should be summarized on an empty data collection sheet while the user is in the field.

System Architecture

OCARD consists of a number of programs and control data files embedded in a software environment. Figure 1*a* illustrates how OCARD interacts with the external programs that are an integral part of the package. The user can operate OCARD with a mouse and a keyboard. The perspective view program and the top view program read the communication data files Persp.DAT and Topv.DAT on activation and display a perspective view or top view of the current curve. Context-sensitive help is provided in all data entry masks. A separate file handler program was required because Level5 Object 2.5 cannot easily access MS Windows common user dialogs (future releases of Level5 Object may offer this capability). The file handler is needed to create the curve data file that stores the curve geometry and other features of the curve and the delineation output files .GEO, .STC, and .DEL, which are generated by OCARD and can be edited or printed, or both. These files contain the geometrical curve data, a bill of materials for the delineation, and an instruction list containing the spacing distances needed to install the devices, respectively.

Level5 Object

A detailed description of Level5 Object V2.5 is found in the User's Guide (*4*) and the Reference Guide (*5*). Level5 Object is an advanced tool to develop object-oriented, knowledge-based applications. During the development of OCARD a number of drawbacks of the Level5 Object 2.5 development system became evident.

1. The MS Windows drop-down menus are completely missing;
2. Access to common dialog boxes of MS Windows is not possible. For this reason it was necessary to build an external file handler;
3. The drawing tools needed to place and design the items of the graphical user interface are difficult to handle;
4. Documenting the code is impossible;
5. Generated code is hard to read because of the many line breaks produced by the output processor;
6. Compiled knowledge bases usually become very big;
7. Bitmap pictures that are used in the application are stored external to the knowledge base. Level5 Object does not purge old or obsolete versions of these bitmap files. This causes the hard disk to fill up quickly during the application development phase. Manually purging the hard disk is time consuming; and
8. Level5 Object requires the user to purchase a run time license.

In spite of these drawbacks (some may actually be eliminated by future releases of Level5 Object), the expert system shell Level5 Object provided the required flexibility to model the curve delineation task, which uses geometric calculations and rule-based knowledge.

CURVE DATA INPUT

Menu Structure

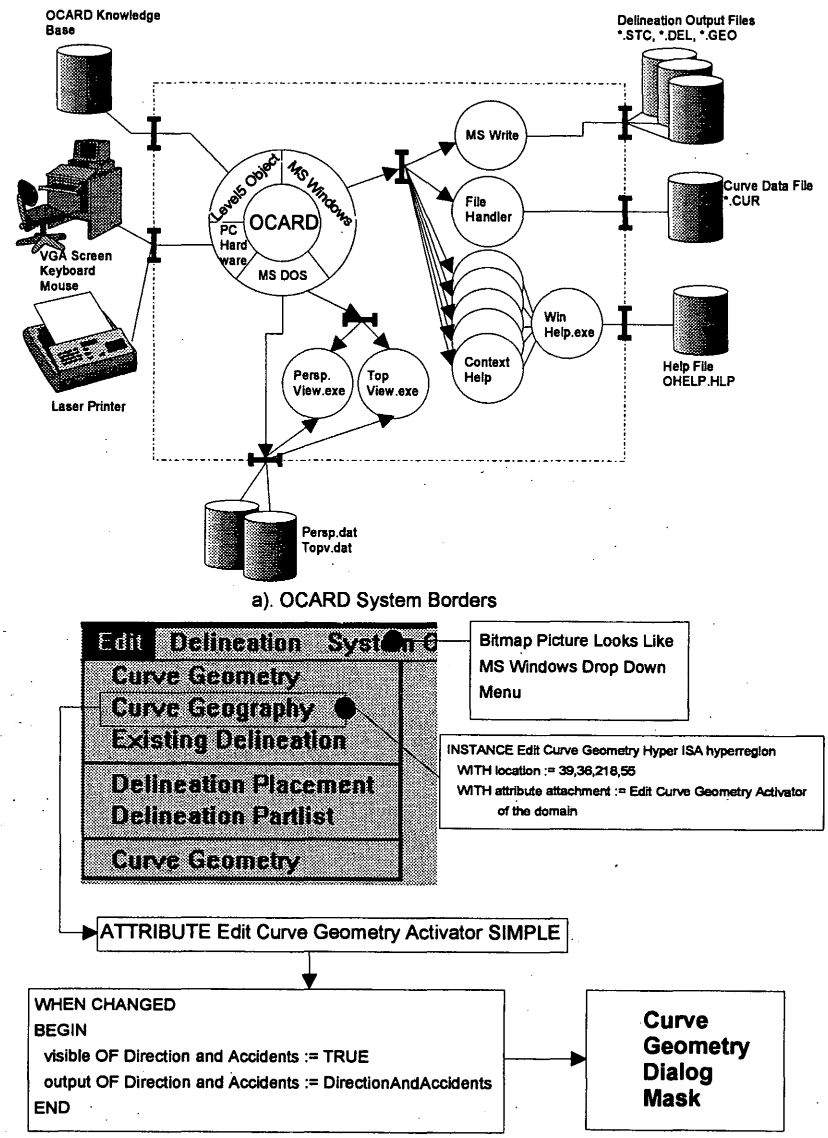
For easy human-computer interaction it was essential to include the standard MS Windows drop-down menus for the flow control of the application. However, as mentioned earlier, Level5 Object 2.5 does not offer this feature. It was therefore necessary to implement a substitute drop-down menu structure using bitmap pictures and hyperregions. The bitmap picture that resembles the drop-down menu is pasted statically on a Level5 Display background.

As shown in Figure 1*b,* hyperregions are placed over the menu item keywords. As the user clicks with the mouse in such an invisible hyperregion a signal is sent to the attached [S] attribute which has a when-changed method attached that then fires. For each menu item there is a separate menu attribute and when-changed method. If the user changes from one main menu to the other, a Level5 display containing another bitmap picture of a drop-down menu is displayed.

A Sample Session

OCARD is a fairly large application that offers a number of different ways of handling it. In most cases however a typical session with OCARD follows a certain pattern. Figure 2 shows a strongly simplified typical curve delineation session. Note that the figure does not show all features that are offered in OCARD. The numbered steps refer to the numbers in Figure 2.

1. After OCARD is started, the first action a user usually takes is to create a new curve or to open an existing one.



a). OCARD System Borders

b). OCARD Drop Down Menu Technique

FIGURE 1 OCARD Level5 environment.

2. The external file handler calls an MS Windows common dialog box that is needed to enter the filename and the path of the new curve.

3. Then the user switches from the file menu to the edit menu where the curve geometry can be entered or edited, or both. Note that for simplicity there is only one data entry mask shown in Figure 2. Values for distances or speeds may be entered in either metric or English.

4. From the edit menu the user changes over to the compute menu where a data output mask with an empty table is displayed. OCARD first determines whether an arrow sign must be used. After this step OCARD offers the three following device-type selection options:

a. User specifies whether flexible postdelineators, object markers, or chevrons (four different sizes) are to be used by OCARD;

b. OCARD determines the device type solely on the basis of the accident severity (none, minor damage, substantial damage, minor injuries, and fatalities) judged by the user for a given curve; and

c. OCARD determines the device type on the basis of the user-judged accident severity and the accident frequency provided by an automatic computation using an accident prediction model (*6*) and the ADT (average daily traffic) volume. Alternatively, the user could provide the accident frequency on the basis of accident records or any other applicable method. Then the central device is placed using the central device algorithm (Figure 3). OCARD always places three devices around the central device, all within the driver's functional visual field using another algorithm. Finally OCARD determines the location of the remaining devices (to the end of the curve) using the computed average spacing between the devices. Delin-

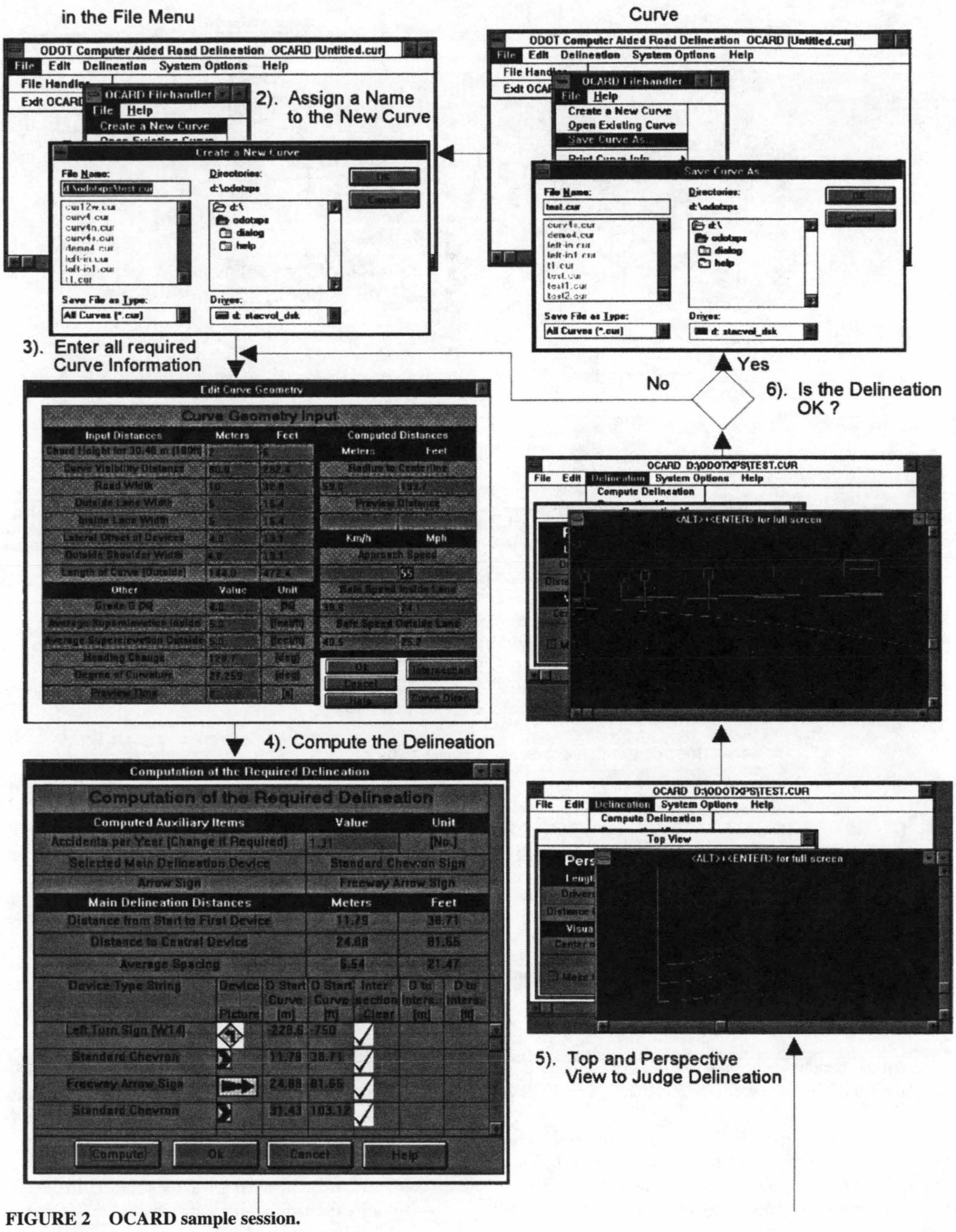


FIGURE 2 OCARD sample session.

eation devices that would interfere with an outside intersection can be deleted or relocated to the intersecting road.

5. The type of the advance warning sign (curve, turn, reverse curve, or reverse turn) and the corresponding approach speed dependent advance location [Table S-1 in the OMUTCD (2)], are displayed in the table on the screen and listed in the delineation output files along with the other devices.

6. The newly computed curve delineation can be previewed with the TopView and the PerspectiveView utility. Users can then judge whether they are satisfied with the appearance of the delineation.

7. The final curve delineation is usually saved to disk. For this the user must change to the file menu and activate the file handler again, this time however to save the curve information. To allow the

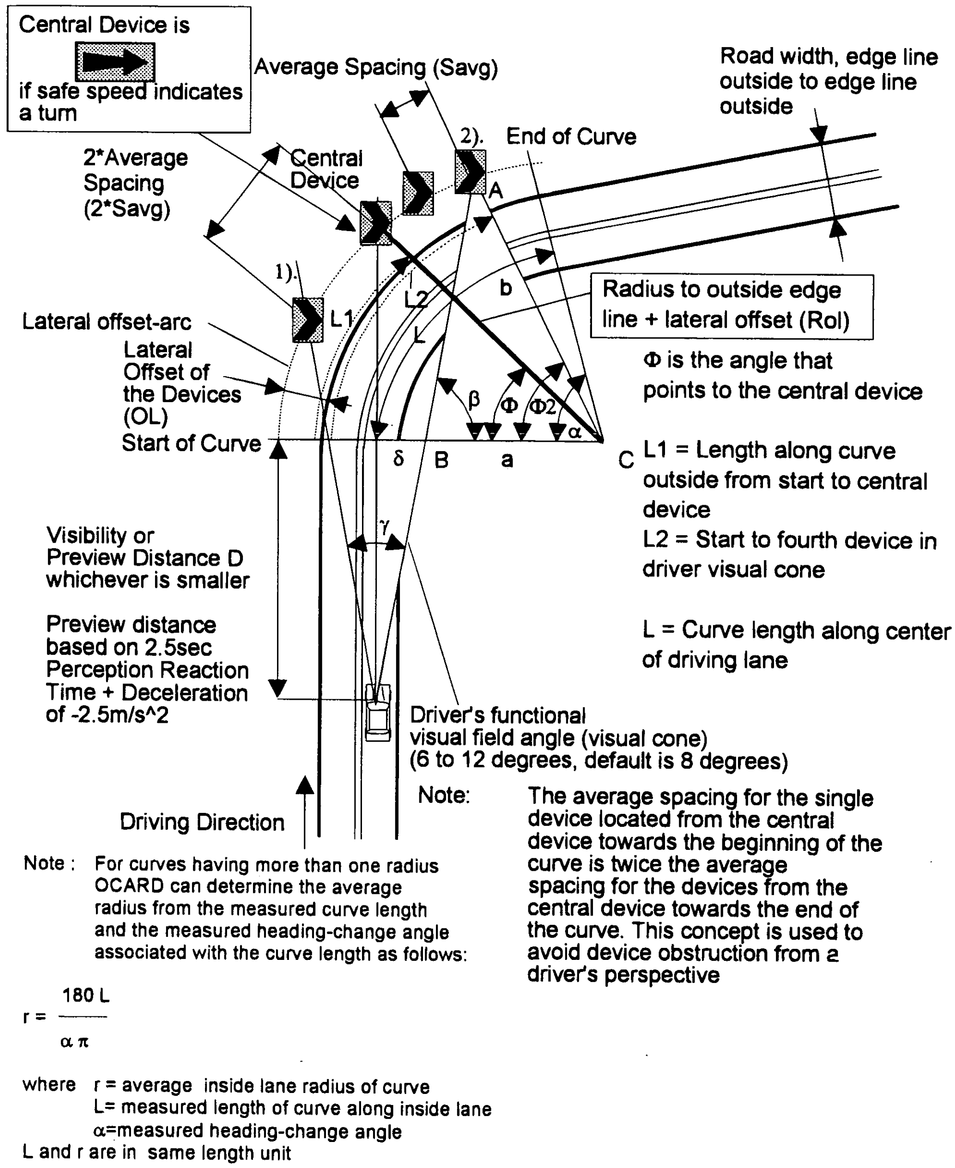


FIGURE 3 Algorithm for placing central device and four devices in driver's visual cone.

user to select the name and path of the curve data file a save dialog box is opened.

DELINEATION COMPUTATION

The delineation is computed on the basis of the curve geometry, which is measured in the field and entered by the user. OCARD V1.0 is suited for curves with fairly long straight approaches with typical approach speeds of approximately 50 mph or more. It is possible to use OCARD for curves with slower approach speeds, but the number of placed delineation devices could be slightly too high. The grade in the curve approach section and in the curve is used in the accident prediction model (*6*) only. OCARD contains no rule that directly uses the grade (either positive, going up, or negative, going down) for the selection and the placement of the delineation devices. The delineation algorithms were developed on the basis of the research results that were briefly described in the introduction of this paper.

In general, the following algorithms are used to determine the optimal delineation for a given curve geometry:

- Device-type selection,
- Placing the central device,
- Placing four devices in the driver's functional visual field (central device embedded within three curve delineation devices),
- Placing the remaining devices to the end of the curve,
- Relocating devices to the outside edge line of the intersecting road, if desirable, and
- Computing the location of the advance warning sign from the beginning of the curve.

Device-Type Selection Options

Option 1: User-Specified Device Type

Users can override the automatic device-type selection of OCARD according to their own judgment.

Option 2: OCARD Selects Device Type on Basis of Accident Severity

Users estimate the accident severity (consequences) for a given curve according to their own judgment. OCARD then determines the device type as follows:

- No consequences: Flexible post delineators 1.06 m (42 in.) high with 2.54 × 20.32 cm (1 × 8 in.) white microprismatic sheeting installed on both sides;
- Minor damage: Object marker, 22.8 × 38.1 cm (9 × 15 in.) with yellow high-intensity sheeting, 1.82 m (6 ft) above the road edge;
- Substantial damage: Standard chevron sign ODOT W-33-12, 30.48 × 45.72 cm (12 × 18 in.) with yellow high-intensity sheeting;
- Minor injuries: Major standard chevron sign ODOT W-33-18, 45.72 × 60.96 cm (18 × 24 in.) with yellow high-intensity sheeting;
- Substantial injuries: Large chevron sign ODOT W-33-30, 76.2 × 91.44 cm (30 × 36 in.) with yellow high-intensity sheeting;
- Fatalities: Extralarge chevron sign ODOT W-33-36, 91.44 × 121.92 cm (36 × 48 in.) with yellow high-intensity sheeting.

This list is a tentative, proposed delineation device selection strategy. Other strategies could be implemented into OCARD with a minor programming effort.

Option 3: OCARD Selects Device Type On Basis of Accident Severity and Accident Frequency

OCARD can select the type of delineation devices on the basis of estimated accident severity and the number of accidents in the given curve per year as indicated in Table 1.

If a full guardrail around the outside of the curve is present the selected device is always a guardrail reflector. Users may provide the actual number of accidents per year on the basis of accident records or their own judgment. If desirable, users may also leave the computation of the accident frequency up to OCARD, which uses an accident prediction model for curves on rural two-lane roads, as described in the paper of Kalakota et al. (*6*).

$$AR = -0.3 + 3.8(L) + 0.37(D)(L) + 0.011\,(D)(G) + 0.004\,(D)(SWR) - 0.012(L)(G)(D) \quad (1)$$

with an $R^2 = 0.28$

where

AR = accidents per million vehicles per year,
D = degree of curvature (degrees),
L = section length (mil),
G = percent grade, and
SWR = outside shoulder width (ft).

The device-type selection algorithm according to Table 1 requires OCARD to compute the number of accidents per year. This number can be obtained from Equation 1, as follows:

$$AYR = \frac{365(ADT)}{10^6} AR \quad (2)$$

where AYR is the number of accidents per year and ADT is the average daily traffic volume.

The accident prediction model given in Equation 1 is tentative because of the apparent lack of fit ($R^2 = 0.28$) and should be replaced by a more efficient model when available. To estimate and enter the correct accident severity (consequences) in case of an ROR (run-off-the-road) incident the user can obtain a detailed description of the various severities from the on-line help utility.

Placing the Central Device

For an optimal delineation it is essential to have one delineation device straight ahead of the vehicle approaching a curve along the tangent section of a highway. This device is called the central device. In cases in which the computed safe speed is less than 45.06 kph (28 mph) this device must always be an arrow sign. Otherwise the central device is of the same type as the remaining devices that were selected with the device-type Selection algorithm. When an arrow sign is required OCARD automatically specifies that a turn or reverse-turn sign must be used as an advance warning sign (with a speed-dependent advance location computed by OCARD). The

TABLE 1 Device Type Selection Based on Accident Severity and Accident Frequency (Excluding Central Device and Reflectors on Outside Guardrail)

Estimated ROR	Accident Frequency (Number of Accidents per Year)									
Consequences	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
None	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP
Minor Damage	FP	FP	FP	FP	FP	FP	FP	OB	OB	OB
Subst. Damage	FP	OB	OB	OB	CHS	CHS	CHS	CHM	CHM	CHM
Minor Injuries	OB	OB	OB	CHS	CHS	CHM	CHM	CHM	CHM	CHL
Subst. Injuries	OB	CHS	CHS	CHM	CHM	CHM	CHL	CHL	CHL	CHL
Fatalities	CHL	CHL	CHL	CHL	CHL+	CHL+	CHL+	CHL+	CHL+	CHL+

- FP = Flexible Post Delineator, 1.06 m (42") high with 2.54 cm x 20.32 cm (1" x 8") white microprismatic sheeting
- OB = Object Marker, 22.8 cm x 38.1 cm (9" x 15") with yellow high-intensity sheeting, 1.82 m (6 ft) above the road edge
- CHS = Small Chevron Sign (Standard), 30.48 cm x 45.72 cm (12" x 18") ,yellow high-intensity sheeting
- CHM = Medium Chevron Sign (Major Standard), 45.72 cm x 60.96 cm (18" x 24") with yellow high-intensity sheeting
- CHL = Large Chevron Sign (Freeway and Expressway Exit Ramps), 76.2 cm x 91.44 cm (30" x 36") with yellow high-intensity sheeting
- CHL+ = Extra Large Chevron Sign (Freeway and Expressway),91.44 cm x 121.92 cm (36" x 48") with yellow high-intensity sheeting

arrow and advance turn, or reverse-turn warning sign must always be placed as a pair, together for both approaches to the curve, regardless of whether or not the traffic characteristics for one of the approaches are less severe than for the other approach. When no arrow is placed in the curve, the advance warning sign (again absolutely needed for both approach directions) can be at most a curve, reverse curve, or winding road sign (with a speed-dependent advance location computed by OCARD). If a curve within a winding road section requires an arrow, that curve must be signed with an advance-turn or reverse-turn warning sign. OCARD computes the safe speed in the curve for both travel directions according to the formula given in the OMUTCD (*2*)

$$V_s = \sqrt{(e + f)\, 15R} \tag{3a}$$

where

V_s = safe speed of vehicle (mph),
e = superelevation (ft per 1 ft of horizontal width),
f = transverse friction coefficient (slightly speed dependent),
R = radius of curvature (ft)

or

$$V_s = 11.289 \sqrt{(e + f)\, R} \tag{3b}$$

where

V_s = safe speed of vehicle (kph),
e = superelevation (m per 1 m of horizontal width),
f = transverse friction coefficient (slightly speed dependent), and
R = radius of curvature (m).

A field investigation has shown that the computed safe speed is a superior statistical and more stable measure when compared with the Ball Bank method described in the OMUTCD (*2*). The Ball Bank method has a number of serious shortcomings, including the fairly substantial time required to take a sufficient number of readings, the sensitivity to slight sudden steering corrections and the resulting fairly bad statistical properties, although it provides basically the same values as those in Equation 3.

By finding the angle Φ of the triangle indicated in Figure 3 it is possible to compute the distance L_1 to the central device along the outside road edge. For left curves this angle is given by

$$\Phi = a\cos\left(\frac{R_{ol}}{R_{el} + O_L}\right) \tag{4}$$

and for right curves by

$$\Phi = a\cos\left(\frac{R_{il}}{R_{el} + O_L}\right) \tag{5}$$

where

Φ = angle in radians to central device, as indicated in Figure 3,
R_{ol} = radius to center of outside lane,
R_{il} = radius to center of inside lane,
R_{el} = radius to outside edge line, and
O_L = lateral offset of devices as indicated in Figure 3.

Using Equation 3 or 4 it is possible to compute the distance to the central device along the outside edge line.

$$L_1 = \Phi\, R_{el} \tag{6}$$

To install the device later, this distance can be measured from the start of the curve with a distance measuring wheel.

Placing Four Devices in the Driver's Field of View

Previously conducted laboratory experiments (Zwahlen in a paper in this Record) (1:50 scale, three-dimensional model situation under low-beam nighttime driving conditions) indicate that at least four delineation devices should be placed within the driver's functional visual field, assuming that the approach to the curve is fairly straight and the approach speed is approximately 50 mph or more. There appears to be no practically significant increase in the accuracy of curvature judgment if more than four devices within the functional visual field are used, but there is a loss with respect to the accuracy of curvature judgment if fewer than four devices are placed within a driver's functional visual field.

The algorithm first compares the preview distance and the visibility distance. The tip of the driver's visual cone is placed at a distance D away from the start of the curve into the tangent section of the curve approach. D is equal to the visibility or preview distance, whichever is smaller. Then the algorithm attempts to find the location where the sides of the visual cone meet the lateral offset arc. These two locations are marked with 1 and 2 in Figure 3, respectively. The sides a and b of the triangle ABC can be determined as follows:

$$b = R_{el} + O_L \tag{7}$$

For left curves

$$a = R_{ol} - \delta \tag{8}$$

For right curves

$$a = R_{il} - \delta \tag{9}$$

Findings from eye scan research conducted by Zwahlen (*7,8*) may be used to estimate the extent of the functional visual field angle γ (visual cone) for a driver approaching a curve. The extent of the functional visual field angle is estimated to be between 6 and 12 degrees. Mackworth (*9*) found in his research that the useful field of view (UFOV) from which a subject can extract accurate visual information, varies between 1 and 4 degrees per eye fixation and that operators search a region so that two adjacent UFOV may touch each other but do not overlap. The extent of the UFOV appears further to be dependent on the density and the conspicuity of the searched-for items against a given background. In the case of yellow or white retroreflective devices at night in typical rural fairly dark and uniform surroundings it would be reasonable to assume a somewhat larger UFOV.

Considering a driver's short-term memory limitations and the dynamics of the driving process, it is safe to tentatively assume that fairly accurate curvature information can be extracted and integrated on the basis of two, maximally maybe three, successive eye fixations of about 0.4 to 0.8 sec duration each. Thus, based on the basis of the above information OCARD uses a functional field-of-view angle γ of 8 degrees as a default value. The user may select any other angle γ within the range of 6 to 12 degrees. Using γ and the visibility or preview distance D (whichever is smaller), it is possible to determine δ as follows:

$$\delta = D \tan\left(\frac{\gamma}{2}\right) \tag{10}$$

The angle $\Phi 2$ that points to the outermost of the four devices within the visual cone can be computed as follows:

$$\beta = \frac{\pi}{2} - \frac{\gamma}{2} \tag{11}$$

$$c = \frac{1}{2}\left\{2a\cos(\beta) + \sqrt{[-2a\cos(\beta)]^2 - 4(a^2 - b^2)}\right\} \tag{12}$$

$$\Phi_2 = a\cos\left(\frac{a - \cos(\beta)c}{b}\right) \tag{13}$$

Using Equation 12 it is possible to compute the distance L_2 from the start of the curve to the outermost device in the driver's visual cone, along the outside edge line of the road.

$$L_2 = \Phi_2 R_{el} \tag{14}$$

The average spacing with which all subsequent devices (from central device to end of curve) are placed can be computed from the position of the central device and the position of the outermost device in the visual cone as follows:

$$S_{avg} = \frac{L_2 - L_1}{2} \tag{15}$$

Placing the Remaining Devices

The remaining devices are placed using the average spacing that was computed for having four devices in the functional visual field of the driver. The algorithm stops when a device would be placed beyond the end of the curve.

Relocating Devices to the Intersection Edge Line

The basic device-placing algorithm of OCARD does not consider outside intersections. With a few geometric calculations it is, however, possible to relocate devices that interfere with the outside intersection along the outside edge of the intersecting road. The approaching driver may not notice such a relocation easily because the algorithm relocates the devices such that the delineation appears as if it would follow the curve. The size and the luminances of the relocated devices, however, may appear slightly smaller, which could result in a reduction of the available perceptual curvature information.

Figure 4 illustrates how the devices that would have been placed on the intersection are projected along the outside edge of the intersecting road. OCARD provides the position for each relocated device in terms of a distance D_{rel} along the outside intersection edge line as illustrated in Figure 4. The following describes the calculations that are performed by OCARD to determine D_{rel}.

Two coordinate systems X_1Y_1 and X_2Y_2 are placed at the beginning and at the end of the intersection, as shown in Figure 4. The inclination angles ϑ_1 and ϑ_2 can be determined by using

$$\vartheta_1 = \omega - \Phi_{is} \tag{16}$$

$$\vartheta_2 = \omega - \Phi_{ie} \tag{17}$$

OCARD can determine the angle Φ_{is} between the start of the curve and the start of the intersection with respect to the origin O from R_{el} and the distance from the start of the curve to the start of the intersection. Likewise, it is possible for OCARD to determine Φ_{ie} by using R_{el}, the distance from the start of the curve to the start of the intersection and with the width W of the intersection. The inside intersection offset line, which is parallel to the inside intersection edge line can be described with respect to X_1Y_1 as

$$F_1(X) = -\tan(\vartheta)X + O_L\{\tan(\vartheta)[1-\sin(\vartheta)]-\cos(\vartheta)\} \tag{18}$$

The outside intersection offset line, which is parallel to the outside intersection edge line, can be described with respect to X_2Y_2 as

$$F_2(X) = -\tan(\vartheta)X + O_L\{\tan(\vartheta)[1 + \sin(\vartheta) + \cos(\vartheta)]\} \tag{19}$$

Using the radius to the lateral offset arc as shown in Figure 4

$$R_{ol} = R_{el} + O_L \tag{20}$$

it is possible to describe the lateral offset arc as

$$F_3(X) = \sqrt{2X R_{ol} - X^2} \tag{21}$$

To determine whether a given delineation device with its coordinates X_{dev}, Y_{dev} with respect to the coordinate system X_D, Y_D interferes with the outside intersection it is necessary for OCARD to determine the projected start and the projected end of the intersection, including the lateral offset buffer O_L at both sides of the intersection. The distance from the start of the curve to the projected start of the intersection can be determined by searching for the point of intersection of the offset arc $F_3(X)$ with the inside offset line $F_1(X)$.

$$F_1(X) = F_3(X) \tag{22}$$

solving the quadratic Equation 21 with respect to X yields the X-coordinate:

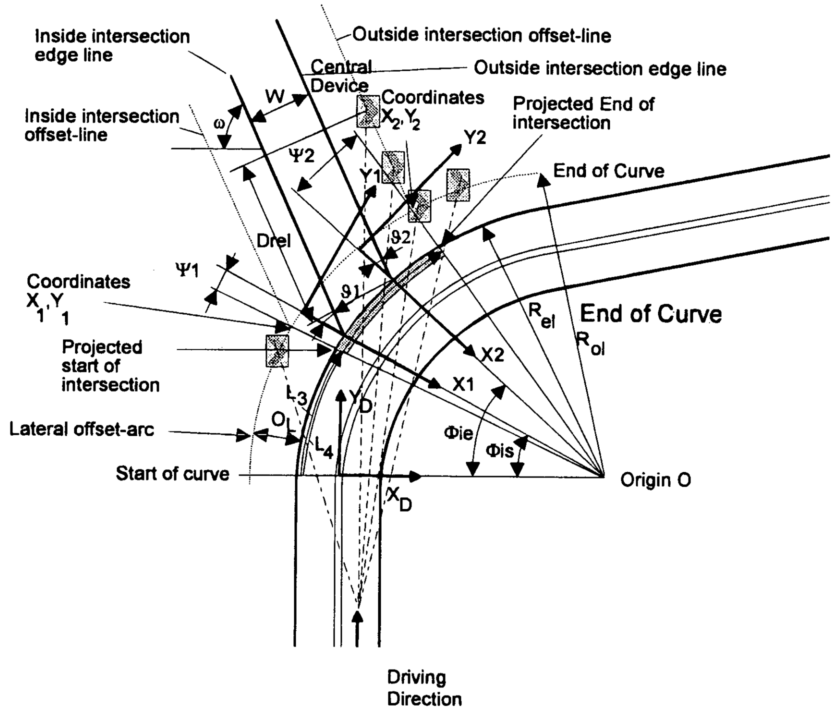
$$X_1 = \frac{R_{ol}\cos^2(\vartheta_1) - \sqrt{R_{ol}^2\cos^4(\vartheta_1) + O_L^2[2\cos^4(\vartheta_1)} \quad \overline{\sqrt{-5\cos^2(\vartheta_1) - 2\sin(\vartheta_1) + 4\sin(\vartheta_1)\cos^2(\vartheta_1) + 2]}}}{2\cos^2(\vartheta_1) - 1} \tag{23}$$

and by inserting Equation 22 into 17 it is possible to obtain the Y-coordinate

$$Y_1 = -\tan(\vartheta_1)X_1 + O_L\{\tan(\vartheta_1)[1 - \sin(\vartheta_1)] - \cos(\vartheta_1)\} \tag{24}$$

The angle Ψ_1 between the start of the curve and the location where $F_1(X) = F_3(X)$ is given by

$$\Psi_1 = 2\,\mathrm{asin}\left(\frac{\sqrt{X_1^2 + Y_1^2}}{2R_{el}}\right) \tag{25}$$



Note: Delineation devices cannot be placed within the shaded section of the curve. The user has the following options in OCARD:

1). Discard the devices that otherwise would obstruct the intersection

2). Relocate these devices to the outside edge of the intersecting road

FIGURE 4 Coordinate transformation for devices that were placed on intersection.

Using this angle it is possible to determine the projected start of the intersection in terms of distance from the start of the curve along the outside edge line. Between the projected start of the intersection and the projected end of the intersection, installation of any delineation devices is not recommended.

$$L_3 = R_{el}(\Phi_{is} + \Psi_1) \tag{26}$$

The coordinates of the projected end of the intersection can be determined by searching for the intersection of the offset arc $F_3(X)$ with the outside offset line $F_3(X)$.

$$F_2(X) = F_3(X) \tag{27}$$

$$X_2 = \frac{R_{ol}^2\cos^2(\vartheta_2) - \sqrt{R_{ol}^2\cos^4(\vartheta_2) + O_L^2[2\cos^4(\vartheta_2) - 5\cos^2(\vartheta_2) + 2\sin(\vartheta_2) - 4\sin(\vartheta_2)\cos^2(\vartheta_2) + 2]}}{2\cos^2(\vartheta_2) - 1} \tag{28}$$

$$Y_2 = -\tan(\vartheta_2)X_1 + O_L\{\tan(\vartheta_2)[1 + \sin(\vartheta_2)] + \cos(\vartheta_2)\} \tag{29}$$

$$\Psi_2 = 2\,\mathrm{asin}\left(\frac{\sqrt{X_2^2 + Y_2^2}}{2\,R_{el}}\right) \tag{30}$$

The true end of the intersection is finally given by

$$L_4 = R_{el}(\Phi_{ie} + \Psi_2) \tag{31}$$

A delineation device within the projected start and the projected end of the intersection should either be left out or relocated to the outside edge line of the intersecting road as shown in Figure 4. This transformation involves only the Y-coordinate so that for the driver the relocated device appears to be in the same direction ahead. The Y-coordinate is transformed using

$$Y_i = \tan(\omega)X_{dev} + \sin(\Phi_{ie} + \Psi_2)(R_{el} + O_L) + \tan(\omega)[R_{cl} - \cos(\Phi_{ie} + \Psi_2)(R_{el} + O_L)] \tag{32}$$

where

ω = the angle of the intersection,
X_{dev} = the X-coordinate from the base delineation algorithm of a device that is located in the intersection, and
R_{cl} = the radius of the curve to the center line.

The distance D_{rel} (see Figure 4) from the intersection to the relocated device along the outside edge line of the intersection is determined as follows:

$$D_{rel} = \frac{[Y_i - \sin(\omega)\,O_L] - \sin(\Phi_{ie})(R_{el} + O_L)}{\sin(\omega)} \tag{33}$$

This distance can be measured with the distance measuring wheel. The distances for all relocated devices are displayed in the data output mask indicated in Figure 2. The delineation output file contains the list of all installation distances for the delineation devices.

CONCLUSIONS AND LIMITATIONS OF OCARD

In a number of test cases the delineation designs obtained by the use of OCARD appear to be in fairly close agreement with the designs that are based on the use of extensive and sound traffic engineering judgment. As with any other software package, use of OCARD is strongly recommended only after having completed prior adequate user training. Such a user training would include the following major activities:

1. Train the traffic engineers or route markers responsible for curve delineation in the proper method and procedure to take the few field measurements; and
2. Train the traffic engineers or route markers in the actual use of OCARD on the PC in the office or in the field for the application and placement of curve delineation devices for selected simple curves and for selected curves with an outside intersection that may or may not require the relocation of delineation devices along the intersecting road.

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