

VALLE[®]: A HIGHWAY DESIGN SYSTEM IN A VIRTUAL REALITY ENVIRONMENT

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ABSTRACT

Approximately 3 years ago, the Spanish company DRAGADOS undertook the creation of a Highway Design program completely integrated in a Virtual Reality environment. Throughout the first months of the year 2006, the version 1.0 of VALLE[®] (Virtual roAd modeLLer) is being implanted in the Company.

DRAGADOS' intention was to merge in VALLE[®] the technical and interactive capacities of a Civil Engineering Computer Aided Design application (like InRoads, Civil 3D, etc.) with the graphic and realistic capacities of Virtual Representation software (such as Virtual Map, RDV or similar) so that the user could directly test modifications of horizontal alignments, profiles, sections or other elements in an interactive and realistic way. The ability of editing the road layout in a realistic representation of the environment makes VALLE[®] a valuable aid in the decision making process related to highway design.

KEYWORDS

Virtual Reality. Computer Aided Engineering. Road Design. Civil Design. Computational Engineering.

CHARACTERISTICS AND SPECIFICATIONS

The principal aim of the project consists in offering the advantages of interactive 3D environments to the modeling of highways that is usually done in Civil Engineering CAD programs. The idea that highway design changes made in the Virtual Reality environment are immediately displayed. This way it is not necessary to interpret the highway's 2D schematics, as we shall be seeing the outcome in 3D with photorealistic quality. The Virtual Reality environment is not a mere viewer; it is in itself a highway modeling system. VALLE[®] is not a complete highway design application undertaking tasks that other hardware already solves in an adequate manner. An exchange mechanism allows to import highway definitions from the usual design programs (Civil 3D, ISTRAM, CLIP, etc.), aiming the system at the inspection and minor changes on those imported projects[1][2].

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Bringing together the characteristics of a real-time 3D graphic system with those of a highway design system has required a dual data representation to be defined in VALLE[®]:

- A representation based on layers of topographic and topologic information (contours, hydrographical information, electrical lines, breaklines, highway layout, etc.), to allow the edition of highways.
- A representation based on scene graphs for the real-time representation of the geometric model.

Both representations are correlated so that logic and graph are coherent at all times.

PRINCIPAL ELEMENTS CONSIDERED IN THE VALLE[®] SYSTEM

The principal elements considered are: Terrain, Layers of Auxiliary Information and Highway.

TERRAIN REPRESENTATION MODEL

As the basis for the model's description both contours and breaklines, or Triangular Irregular Meshes (and even Digital Elevation Models) can be used. Internally and at a logical level the system always uses a representation based on a dynamic Delaunay triangulation engine that allows for triangulations with borders. This internal representation model permits the calculation of intersections between the highway model and the terrain, obtaining the cuts and fills that result from editions in the Virtual Reality environment.

The correlated visual representation is based on meshes of triangles optimized as triangle strips. This representation accounts for the fact that for defining n triangles we only need $n+2$ vertices instead of $3n$ vertices necessary in conventional representations. A quadtree hierarchical structuring of the optimized triangle meshes has also been defined for the management of visual LODs (Level Of Detail) according to the distance to the zone displayed on screen (nearby zones are rendered with a higher number of triangles)[3][4][5].

This multiresolution dynamic terrain representation is processed in real-time whenever the scene is displayed. The polygonal meshes are represented as polygonal nodes inside the scene graph allowing for an automatic clipping of the zones out of the angle of vision[6]. Visual property nodes that add realism to the representation can be appended to the displayed terrain model. These nodes allow for the calculation of realistic lighting effects and assigning textures from aerial photographs.

AUXILIARY INFORMATION REPRESENTATION MODEL

This category includes a series of elements that form terrain information layers and that influence the highway layout (rivers, electrical lines, railroads, urban zones, etc.). The logical representation of these elements is materialized through border lines and layout definition polylines. As for the visual representation, a library of basic elements that can be used to represent each type of auxiliary element is used. At loading time 3D objects are generated and inserted as polygonal nodes in the VALLE[®] scene graph.

HIGHWAY REPRESENTATION MODEL

VALLE[®] allows an interactive layout modification in three dimensions and in real-time. To attain this goal it has been necessary to fulfill two requisites:

- To create efficient data structures and calculation algorithms so that the highway is immediately recalculated as soon as its control points are modified.
- To establish relations between the highway segments data and the scene graph nodes that represents the highway.

One of the critical elements in interactive graphic applications is the real-time display of information[7]. Ideally, the time interval between a modification and the system's response should not be perceived for the user. To approach this goal, VALLE[®] optimizes this recalculation and redrawing process as described next:

- A plan or profile control point is selected and modified. This point is associated internally with an alignment within a region.
- The requested displacement's feasibility is calculated. This will depend on a series of constraints that depend on the contiguous alignments and on criteria established by current design standards.
- If possible, the points move and new parameters for to its plan and profile segments are calculated. When a plan control point moves the associated profile is automatically re-calculated.
- The new three-dimensional geometry is generated in accordance with the new parameters. This process is done in two steps. First of all the points of the highway's centerline are calculated using plan and profile data. Next the rest of the highway model is calculated using the superelevations and cross-section type data.

The highway centerline is represented by a collection of sample points. To calculate them it is necessary to know to which plan (for their 2D position) and profile (for their elevation) segments they correspond. To optimize the redrawing and the number of triangles to be generated, a progressive sampling technique is used, generating more points where the highway has more curvature and less in the straight segments. As soon as the highway centerline points are calculated the associated superelevation and cross-section type information is used to generate the points defining the highway model's triangles. Finally the user must select the terrain intersection recalculation option. This process will consist in calculating the intersections of the highway with the terrain and regenerating the affected geometry.

The link between the highway logical representation model and the visual representation model is derived from the sample points described above. The visual representation model generates a set of polygonal nodes based on optimized triangle meshes. For each highway section a different mesh is generated so that different visual properties nodes can be applied in order to display textures of asphalt, curb, etc. To improve performance, models with different amount of detail are generated from the samplings, and LOD nodes are added to the scene graph, for their automatic management according to display requirements[8].

CHARACTERISTICS OF THE INTERFACE

The interface of the tool VALLE[®] is formed by the following windows:

- *Elements Tree View*, displaying information about objects included in the project.

- *Information Grid*, displaying numerical information for the elements selected in the Tree View or in some of the model display windows, and that allows modifying the editable plan and profile parameters.
- *Model Display Windows*, showing: plan view of the project, with a simplified visualization of the highway centerline, terrain contours; selected highway profile view; and three-dimensional scene.

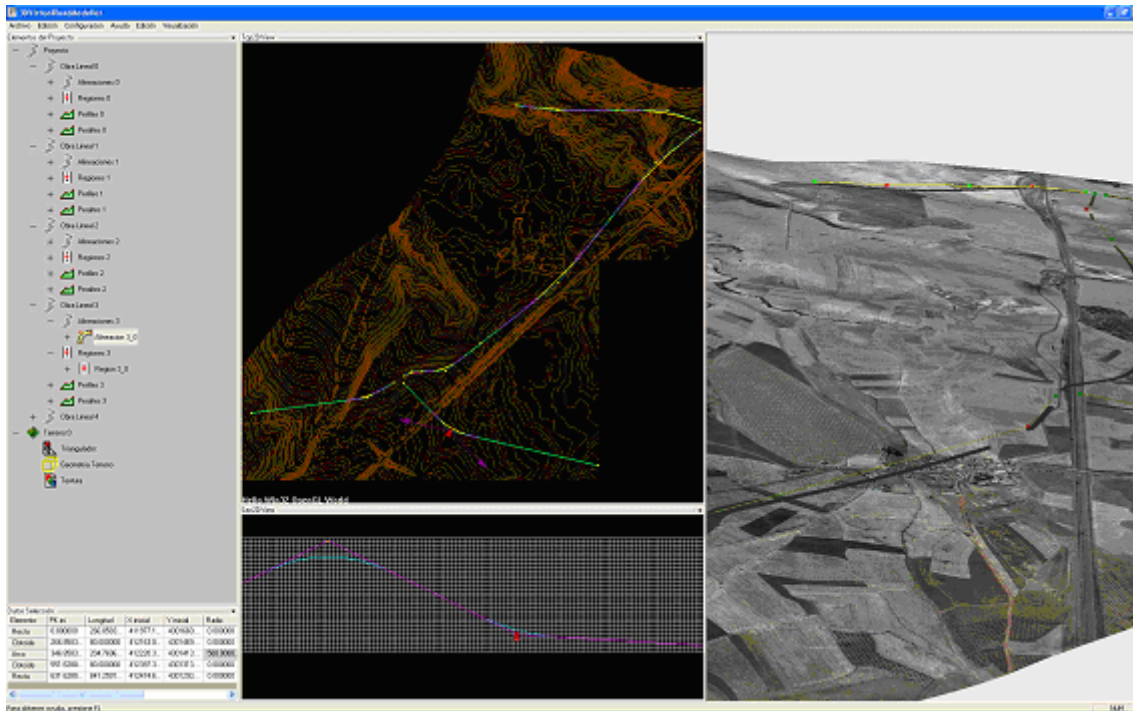


Figure 1. VALLE® user interface.

In the Tree View Window it is possible to expand, to contract and to select elements. On selecting an element in the Tree View, the Information Grid and View Windows are updated accordingly. Selecting elements by means of the mouse, zooming and panning are allowed. The 3D View Window also allows rotations and displacements of the virtual camera along the three coordinate axes. We can also edit interactively the position of the control points in the plan and profile views by means of selection and dragging, triggering the automatic recalculation of the layout (also in 3D), which is followed by the recalculation and display of the new highway-terrain intersection.

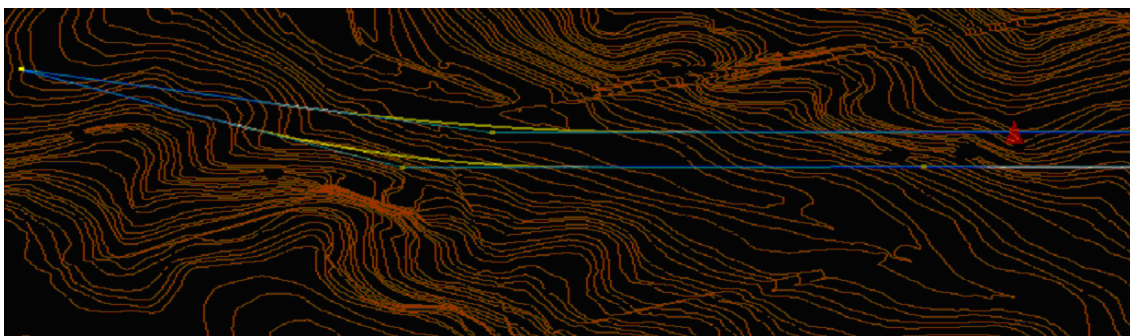


Figure 2. Interactive Edition in Plan View.

DATA IMPORT AND EXPORT

VALLE[®] version 1.0 supports two types of connection with other platforms of engineering: the direct or priority one and the indirect or secondary one.

PRINCIPAL FLOW OF DATA EXCHANGE

The priority connection is established by Autodesk Civil 3D (Civil 3D, 2006)[9][10]. The exchange takes place at bidirectional level with an automatic transference of:

- Terrain models.
- Special terrain areas and lines.
- Horizontal alignments.
- Vertical profiles related to the horizontal alignments.
- Roadway cross-section types and alignment regions where a certain cross-section type is applied.
- Superelevations.
- Finished Road Models (also known as Corridors)
- Roadway model feature lines.

Once transferred between applications, the relations between elements remain intact. This means the corridors are still associated with their alignments, profiles, regions, cross-section types, and feature lines (in case they should exist); the relation between alignments and profiles, superelevations and feature lines is kept; the links between corridor regions and cross-sections types still exist, etc. The alignment objects maintain their geometric and topologic continuity (see Figure 3), in such a way that an interactive edition will not break the alignment's continuity and that elements adjacent to the modified one shall react in a coherent way to the changes proposed by the user. The Corridor object maintains its direction, relations, methods and object properties both in the VALLE[®] → Civil 3D transference as the other way around.

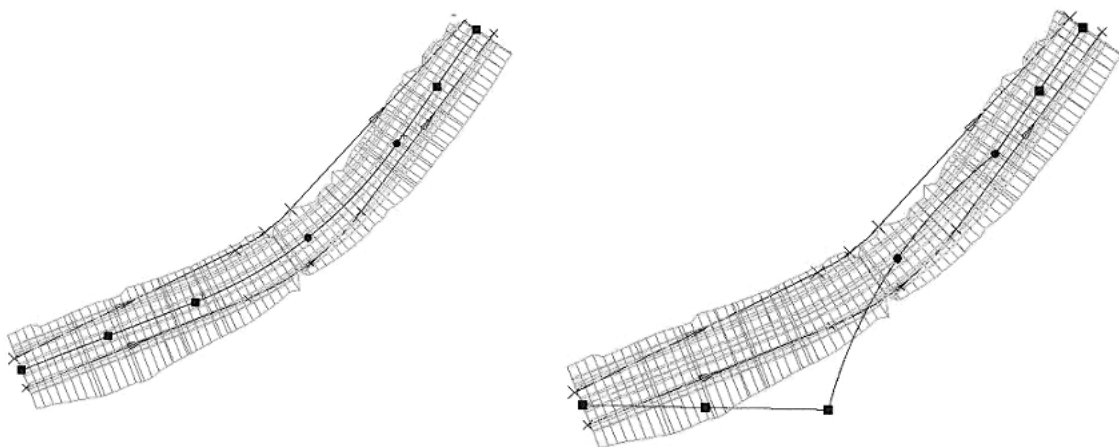


Figure 3 (Left) The centerline grips, represented by square and circular symbols, are fundamental for the interactive edition of the corridor centerlines. Nevertheless (Right) a lack of geometric constraints will result in the alignment not reacting in a coherent way to the modifications, thus presenting impossible transitions.

SECONDARY DATA EXCHANGE FLOW.

The secondary or indirect connection is established with other civil engineering design systems used in Spain. First, the project must be input to Civil 3D (Civil 3D, 2006). The import process done in Civil 3D receives not only the numerical information, but also structures it according to its own object model, making thus possible a "principal" type exportation, as described in the preceding paragraphs. The very different ways in which cross-section type definitions are established in the different systems forces the data importing process to have a manual component.

RELEVANT ALGORITHMS IN THE EXCHANGE PROCESSES.

From the point of view of the development of Civil Engineering software, there are two specific modules that are worth emphasizing:

- The direct data import and export process and the structuring it implies.
- The indirect data import process.

DATA STRUCTURE AND DIRECT IMPORT – EXPORT PROCESS.

The exchange of information between Civil 3D and VALLE[®] is realized in the current version by means of text file in which the information is structured according to the XML specifications.

The information is grouped in five first level elements, the *Corridors*, *Linkers*, *Point Objects*, *Cross-Section Types* and *Terrain* lists.

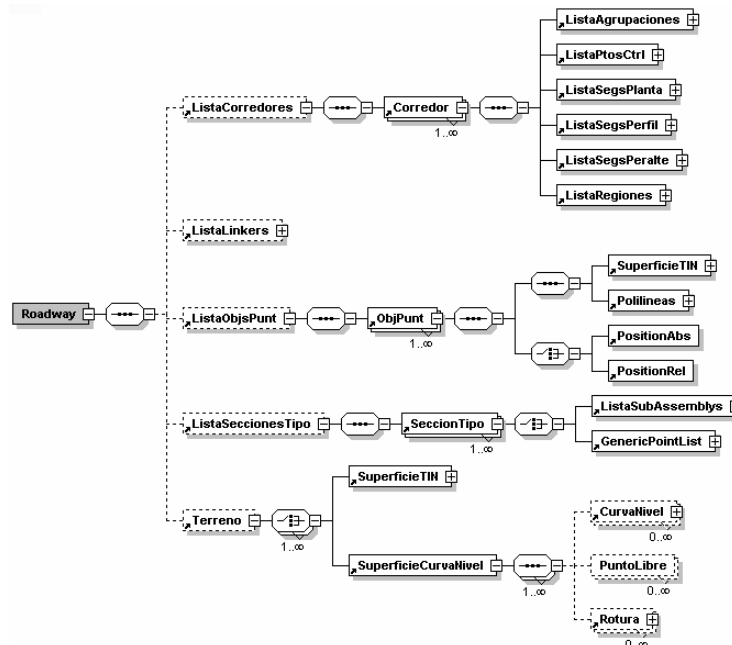


Fig. 4 XML Data Structure Components.

Terrain.

The terrain model can be exported, either as an irregular triangles network (*SuperficieTIN*), or as the set of its defining elements: contours, 3D points and breaklines (*SuperficieCurvaNivel*).

Corridors.

Corridors are the central element of the application and each of them includes a List of *Alignments*, a List of *Control Points*, Lists of *Plan Segments*, *Profile Segments* and *Superelevation Segments* and a List of *Regions*.

Alignment Groupings.

In the Alignments Groupings List, the collections of entities that compose the roads' centrelines are grouped in the different sequences that the virtual reality system can manage. Each of these Groupings possesses three Control Points defined as the group's starting point, the point of intersection of its initial and final directions, and its endpoint. Control Points are registered in the Control Points List.

Segments.

All of the elements identified as "Segments" share the properties *PK_INI* that registers the segment's *initial station* and *PK_FIN*, which registers its *ending station*.

The possible *Plan Segment* types are: *Line*, *Clothoid* and *Arc*. The characteristics of each of these *Plan Segments* are defined by a series of common properties: Initial (*TgIni*) and End (*TgFin*) Directions; Initial (*PosIni*) and End (*PosFin*) Points; previous (*ant*) and following (*sig*) entity Identifiers. In addition to these common properties, Arcs include the Radius (*Radio*) and clothoids include the Parameter (*A*).

The *Profile Segments* are defined from one *Point of Vertical Intersection (PVI)* to the next one. Information includes the Initial and Final elevations (*ZIni* and *ZFin*), the lengths of the initial and final branches of the transition parabolas (*LIni* and *LFin*), the initial and final grade change (*ThetaIni* and *ThetaFin*), the crest or sag nature of the segment's initial and ending PVIs (*SignoIni* and *SignoFin*) and the segment's slope (*Pendiente*).

The *Superelevation Segments* register the right and left initial (*PerDerIni* and *PerIzqIni*) and ending (*PerDerFin* and *PerIzqFin*) superelevations.

Regions.

One or more Regions may be defined for every centerline. The Regions are distinguished by the assigned cross-section type. A reference to a cross-section type (*SecciónTipo*) from the cross-section type list (*ListaSeccionesTipo*) is included.

Cross-Section Types.

Each Cross-Section Type (*SeccionTipo*) stores references to the Sub-Assembly List (*ListaSubAssemblies*) that includes the basic elements from which cross-sections are built in Civil 3D. Every Sub-Assembly contains the parameters defining its dimensions and position within the Cross-Section Type.

Point objects.

By means of the Point Objects List (*ListaObjsPunt*) a variety of 3D elements used to represent in a realistic way the environment may be included in the model.

INDIRECT IMPORT PROCESS.

The secondary or indirect import module receives data from horizontal alignments and profiles (see Figure 5) in a neutral exchange format and generates from this data the corresponding alignments and profiles in Civil 3D. The importing process designed is capable of re-interpreting the set of geometric entities from which the alignments are built, regenerating the constraints that assure its connectivity.

DATO	TIPO	LONGITUD	P. K.	X TANGENCIA	Y TANGENCIA	RADIO	PARAMETRO	AZIMUT
1	RECTA	300.484	0	739585.335	4425591.399			53.5504
2	CIRC.	594.517	300.484	739809.323	4425791.699	-7500		53.5504
3	CIRC.	586.856	895	740267.724	4426170.029	-7500		58.5969
4	RECTA	647.971	1481.856	740720.412	4426543.256			53.6155
5	CIRC.	1628.326	2129.827	741203.865	4426974.694	-10000		53.6155
6	RECTA	563.569	3758.153	742325.326	4428152.793			43.2492
	CLOT.	200	4321.722	742679.413	4428591.236		600	43.2492
7	CIRC.	162.47	4521.722	742802.152	4428749.11	-1800		39.7125
	CLOT.	40	4684.193	742890.979	4428885.083		600	33.9662
8	CIRC.	762.568	4724.193	742910.964	4428919.732	-2250		32.693
	CLOT.	476.1	5486.761	743166.973	4429634.172		1035	11.1167
	CLOT.	336.067	5962.861	743216.413	4430107.46		710	4.3813
9	CIRC.	481.637	6298.928	743252.003	4430441.448	1500		11.5129
	CLOT.	336.067	6780.564	743412.561	4430893.343		710	31.9542
			7116.631	743595.68	4431174.914			39.0857

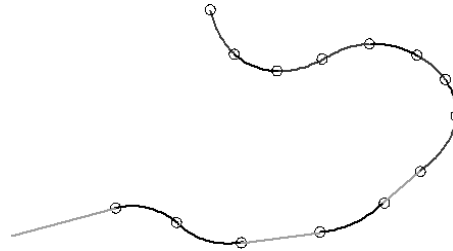


Figure 5. The alignment that appears in the bottom of the figure is represented in the neutral exchange format as shown above. Constraints between geometric entities are not included in this representation, so they must be reconstructed.

This goal is achieved by means of an algorithm that processes the alignment on an entity by entity basis (Kraemer, 2003) searching for their logical associations of the types “Line-Clothoid-Arc-Clothoid-Line” (RCACR), “Line-Arc-Line” (RAR) or other more complex chains where the Clothoid-Arc transitions occur without intermediate straight line segments. Accepting that the straight line elements fulfil the role of curve chain delimiters, the problem consists in detecting the associations of types CAC, CACAC, CCACCAC, etc., which is faced by stating three basic hypotheses:

- An entry Clothoid spiral always initiates a curve typology.
- An exit Clothoid spiral always finishes a curve typology.
- Two contiguous arcs belong to different curves.

Table 1. The datosEje array has so many columns as geometric entities exist in the alignment. The rows reflect the main geometric (and other) characteristics. Row 4 shows the entity’s geometry type and row 28 refers to the nature of the spiral. Only Clothoid entities for which row 4 reads “Spiral” include data in row 28.

datosEje(i,j)											
i\j	0	1	2	3	4	5	6	7	8	9	10
...
4	Arc	Arc	Arc	Spiral	Arc	Spiral	Arc	Spiral	Spiral	Arc	Spiral
...
28	Empty	Empty	Empty	In	Empty	Trans.	Empty	Out	In	Empty	Out
...

The neutral exchange file received is pre-processed to generate for each geometric entity an entry in the bi-dimensional array datosEje(i, j). This array includes a j entry for every entity, whereas the index i corresponds to its characteristics. In particular, the

entry $i = 28$ (see Table 1) indicates if the processed entry constitutes, in a sequence of type CAC, CCACAC or similar, an entry, exit or transition spiral.

Thus, the indirect import process reads each entity described in the input neutral exchange file, filling the $\text{datosEje}(i, j)$ array discovering entity groupings according to association strings of the CAC, CACAC types, etc. These associations are deposited in the TYPOLOGY array, which is generated according to the following algorithm:

```

FUNCTION FOR FINDING SUITABLE COMBINATIONS FOR ROAD CENTERLINE SEGMENTS.
Data:
• ALIGNMENT ENTITIES COLLECTION: TRAMOS (j).
• ARRAY DATOSEJE (i,j).
Output:
• STRINGS ARRAY TYPOLOGY (k).
ALGORITHM
1. CurveType= "", TwoArcs = NIL, k = 1, j=1
2. DO WHILE exists TRAMO = TRAMOS (j)
  2.1. IF TRAMO is of type "ARC"
    2.1.1. (THEN) CurveType = CurveType + "A" , TwoArcs = TRUE
    2.1.2. (ELSE) CurveType = CurveType + "C"
  END IF 2.1.
  2.2. CurveCreated = NIL
  2.3. DO WHILE CurveCreated = NIL
    2.3.1. j=j+1 , TRAMO = TRAMOS (j)
    2.3.2. IF TRAMO is of type "ARC"
      2.3.2.1 (THEN) CurveCreated = TREATARC ( CurveType , TwoArcs)
      2.3.2.2. (ELSE)
        CurveCreated = TREATSPIRAL ( CurveType , TwoArcs, j)
      END IF 2.3.2.
    END DO 2.3.
  2.4. TYPOLOGY (k) = CurveType, k = k+1, CurveType = "", TwoArcs = NIL
END DO 2.
6. Return the TYPOLOGY () array
7. END
    
```

The output is an alignment constituted by groupings of elements that possess constraints and that can be subject to edition in Civil 3D, like figure 6 shows.

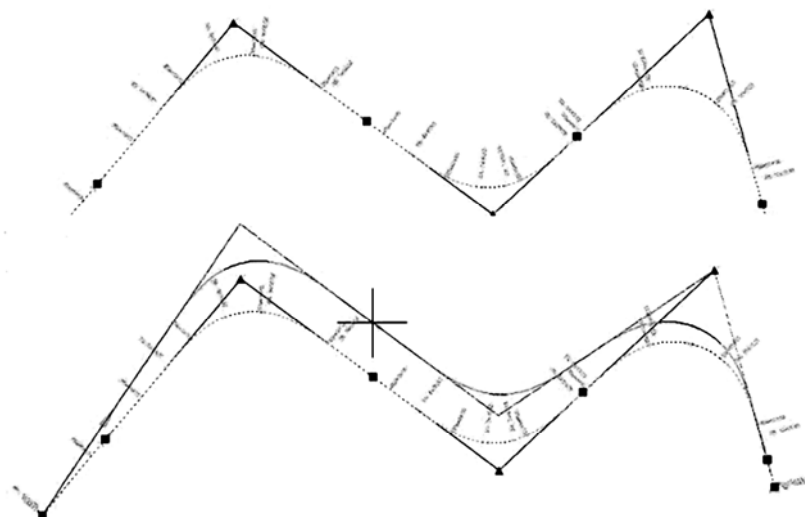


Figure 6. Once the entities association is detected, it is possible to interactively edit its segments in VALLE[®] so that the modifications are assimilated in a logical way by the alignment as a whole. For example, the straight central segment of the alignment (top) is moved (bottom) but the affected alignment, is capable of adapting itself.

CONCLUSION:

With this application, DRAGADOS aims fundamentally at increasing their simulation capabilities as an aid in the decision-making process by means of the Interactive Virtual Graphic Information. VALLE[®] will be a system on which the analysis of variants, modifications or alternative details can be evaluated in real-time and with the sufficient technical and numerical precision.

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