An Interactive Application Method in Highway Geometric Design

By

A. S. Adedimila and I. Akiije
Department of Civil and Environmental Engineering
University of Lagos, Akoka, Lagos

ABSTRACT

An innovative methodology is developed for solving the geometric design of highway problems in an analytical and autographic user-friendly interactive application system with successful conformity to the standards of relevant highway agencies at optimal level. The method developed in the research reported in this paper is analogous in steps and format to the manual method and it is a useful way to create templates and standard data disc for routine work in order to prepare plan, profile and estimates of a highway. The method, which involves the strategic application of Excel-Spreadsheet for analysis and plotting, and AutoCAD for drafting in highway geometric design is useful in generating coding statements automatically rather than the manual approach experienced with programming aids such as FORTRAN, BASIC, C++, Visual Basic, etc. Also the developed method which was adopted in carrying out the geometric design of a 5km road is easy, fast, reliable, efficient and cost-effective.

INTRODUCTION

Preamble

The geometric design of highways is usually a problem of optimisation of cost and profit subject to the constraints of budget, standard, time, environmental impact assessment (EIA) and acceptable quality work. Moreover, solving the problems of geometric design of highways requires a large number of iterations and repetitive tasks of analysis and drafting. Currently, the application of information technology techniques such as programming aids and integrated programs does not constitute a generalised, unique, fast and cost-effective highway geometric design method. In addition, many Nigerian engineers today still adopt the conventional manual method of geometric design of highways, which is inefficient and ultimately expensive. Consequently a unique design methodology through information technology technique is desired for solving the problems of highway geometric design.

Aims and Objectives of the Study

The aims of the study reported in this paper include the development of a method that is cheaper, faster, easier, more accessible, more reliable and more effective than the conventional manual methods currently used for the geometric design of highways, and other means of applying Information Technology facilities such as the use of programming aids and integrated programs.

The specific objectives include the following:

1. To incorporate a high-speed and high level of accuracy required in the geometric design of highways, including iterative and repetitive computations at optimal level by interaction with application software.

2. To utilize spreadsheet, a general purpose application software that is generally considered an accounting tool for the analysis and plotting required in highway geometric design.

3. To integrate strategically objects developed both in spreadsheet and AutoCAD through the object link embedment (OLE) capability to produce the plan and profile of a road.

Significance of the Study

The proposed design method will enhance the ability of a highway engineer to conduct numerous design iterations for the purpose of improving and refining the design without expending a large amount of time and effort, and thus avoid the design and drafting drudgery associated with the more conventional manual methods.

The method is expected to allow for easy production of many trial designs to satisfy traffic operational safety, economy viability, sociological impact and certain requirements now expected under the EIA legislation. The procedure is also useful not just for the processing of new and improvements to the geometric design of highways and streets but also for runways and taxiways, railways and tunnels.

CURRENT STATUS

The procedures for analysis and drafting in the geometric design of highways presented by the Federal Ministry of Works as a standard for road construction specification [1] allow for manual method of execution and they constitute design drudgery. The process of manual techniques in the geometric design of highways is very time consuming and oftentimes the individual engineer does not have the ability to achieve the required high standard of precision and graphic presentation in a timely and cost-effective manner to meet up with the pressure for design or adjustments for improvement needed for the site-specific design for construction [2]. The consequential effect of the slow-speed manual method is that it will not be able to cope with the desired level of efficiency in highway geometric design in Nigeria.

Currently, supervisory authorities are insisting on modern techniques in the presentation of engineering designs through the use of IT facilities. For example towards the end of 1990s the Federal Ministry of Works directed that all plans for the geometric design of highways should be in AutoCAD or any other computer aided design software [3]. The order brought about the use of some integrated programs that are being used in advanced countries for similar engineering designs. Some of the integrated software that are available in Nigeria are market driven and they include Softdesk 8 Civil/Survey, Eagle Point, Inroads, AutoCIVIL and AASHTO IGrds [4]. Unfortunately, these integrated programs are very costly with periodic subscription, licensing fees, proprietary, and will require reading voluminous manuals while they oftentimes become obsolete rapidly. Some of them require the use of dongle that will allow for only a single user. It is pertinent to note that the cost of purchasing any of these programs is higher than the price of the computer hardware.

Moreover, there is also the use of programming aids to write coded programming statements such as subroutine by typing them manually before they can be used to solve engineering problems. Such programming aids include FORTRAN and BASIC which are in command driven interface, and C++ and Visual Basic that are in graphical user interface.

Procedures using programming aids for solving tasks in the geometric design of highways are not generally analogous to the manual methodology as their use is best suited for software developers. Such procedures include HORIZON, VERTICA, EARTHWORK and CO-ORD [5] for computing data for horizontal alignment, profile, earthworks and co-ordinates, respectively; RoadCAD [6] for general road design calculations and REDUCE [7] for computing reduced levels for road design. The procedures are readily available market driven sub-routines in Nigeria. They are written in FORTRAN language for the geometric design of highways, but share the common setback of lacking drafting capabilities.

However, the use of programming aids has been superseded by the use of application software for problem-solving [8]. Programs now deal with adaptive problem solving through interaction with professional or other specialists, thus leading to the recent upsurge of interest in artificial intelligence and knowledge-based (expert) systems. Expert system has some problem-solving capability tied to an organised base of knowledge of information technology. A strategic combination of application programs using the object link embedment (OLE) capability, which is capable of producing substantially improved plan and profile with project cost at optimal level is the method adopted in this study for solving the problems of highway geometric design.

METHODOLOGY

Optimisation

By far the greatest achievement of highway geometric design optimisation is the demonstration that the ad-hoc processes which seemed to have little mathematical logic, could now be expressed formally in mathematical terms with much rigour and logic under a unified formal mathematical basis. The guiding equations are as follows [9]:

Minimise or Maximise $\quad f_0(x_i), \qquad (1)$

$i = 1,.........N$

Subject to constraints $\quad f_j(x_j)\begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 0, \qquad (2)$

$j = 1,.........M$

Variables $\quad x_i \geq 0 \qquad (3)$

$i = 1,.........N$

Where

The variable x_i , $i = 1,.........N$, in this case, represent physical parameters of the highway structure which is being designed such as (x, y, z). coordinates, dimensions, angles, tangent lengths, curve lengths, radius of curvature, superelevation, gradients, areas and volumes. The objective or merit function $f_0(x_i)$ is the efficiency criterion in the form of minimum time or minimum cost that must be optimised. The M constraints $f_j(x_i)$, which may be equalities or inequalities, specify all the relevant restriction, for example, known material properties, requirements of code of practice, standards, construction requirements, general shape requirements with cost effective hardware and software requirements. The N non-negative conditions specify the practical nature of the problem in that the entire engineering variable must be real and feasible.

Solution Algorithm

The process of generating an initial solution and improving objective function through the substitution algorithm is depicted by the flow diagram in Figure 1. The sub problem is solved by a "path construction sub model" that presents lowest number of intersections and also at each intersection a corresponding minimum radius according to standard based on the assumed design speed. The restricted master problem, in turn, is solved firstly by an initial feasible solution containing a subset of all paths constructed so far by the sub problem by solution modelling. Then, the substitution algorithm iteratively calculates the marginal profit attributed to replacing each in-solution path with, in turn, every out-of-solution path. The substitution that maximizes the potential improvement to the objective function is made, and the flow configuration resulting from the new set of in-solution paths (current best solution) is sent back to the sub problem.

Horizontal and Vertical Curves

Horizontal and vertical curves (symmetrical) were designed in accordance with standard equations which are readily available in the literature.

Data Collection for Variables

Currently, (x, y, z) coordinates to define geometric elements can be stored as images in the Geographic Information System (GIS) using global positioning system (GPS) and satellites as data collection instruments. Establishment of the (x, y, z) coordinates for the final location survey is done by basic or robotic Total Station and GPS. Accuracies in the order of 5 mm ± 1 ppm (paths per million) of the baseline are achievable by majority of GPS instruments of 12 to 24 channels while accuracies in the order of 2 mm ± 2 ppm are achievable by many total stations with a measurement time of 3.0 seconds over a distance of 2.3 km to 3.1 km using one or three prisms [2, 10].

However, the cost of each of these GPS instruments is between five and ten times that of total station and they are not fully kinematics couple with problems of selective availability (SA) of accuracy denial or satellite coverage which can result to long occupation of time.

Hand held GPS electronic instruments cost less and it is capable of providing location map and primary reference control points for link traversing in between them while using total station [2, 10].

Total station and hand held GPS electronic instruments were used to collect data on a 5km road. The summary of the horizontal alignment data is presented in Table 1.

Design Standards

Highway geometric design practices of the various designing agencies are not entirely uniform on a national or international basis. For purposes of design, for example, the assumed heights of eye and object above roadway surface for the determination of stopping and passing sight distances vary from one country to another as shown in Table 2. As indicated in Table 2, the standard values required for stopping and passing of vehicles in Nigeria are the same for United States of America (USA). This allows for the possible application of standard equations and values of highway geometric design valid in USA to similar designs in Nigeria.

ANALYSIS AND DRAFTING

In an analytical interactive program such as Excel-Spreadsheet (Table 3), the computation of the horizontal circular curve data is by modelling and simulation method using two columns of table of cells. The first column is used to enter text containing labels or algebraic expressions while the second column is used to store design data and models which produce automatic results. In Table 4, the computation of a crest vertical curve data by modelling and simulation method is presented in a tabular form that is analogous to the manual approach. Similarly, tabular forms that are analogous to the manual approach can be used to simulate data for sag vertical curve, gradient, ordinates for cut and fill, area and volume, and also estimation of cost. Templates and standard data disc are created for routine application of developed modules.

Excel-Spreadsheet also has the capability of extracting data from a developed table and then turns it automatically into a graphic form. Thus, the spreadsheet program can produce the graphics of the data for the existing road level and the proposed road level as illustrated in Figure 2. The Object Link Embedment (OLE) capability of the application programs offers the designer the ability to drag data and graphics for vertical alignment as in Figure 2 into AutoCAD to produce the road profile illustrated in Figure 3. Similarly, data for the horizontal alignment in Excel-Spreadsheet are dragged into AutoCAD for the drafting of the plan in Figure 3 using menus which are on the screen to select commands and with the aid of input devices, such as a mouse, puck, digitizer or light pen.

CONCLUSION

This paper has presented a newly developed interactive procedure with application programs strategically for solving the problems of analysis and drafting in the geometric design of highways. The developed methodology enhancements and applications include

- A new algorithm for optimization of cost, time, EIA and acceptable quality of work.

- Introduction of modelling of visual module logic as mobilization function to evaluate and simulate desired multiple values automatically with alteration of data during iteration.

- Utilization of Excel-Spreadsheet for analysis and plotting in highway geometric design.
- Adaptation of design information by linking the database from Excel-Spreadsheet into or interfacing graphic in AutoCAD to produce desired quality plan and profile of a road.

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TABLE 1: SUMMARY OF HORIZONTAL ALIGNMENT DATA FOR A 5KM ROAD

Station	Chainage (km)	Distance to Next Station (m)	Whole Circle Bearing	Intersection Angle	Radius (m)	Tangent Length (m)	Length of Curve (m)
Beginning Point	0+000	450	86 ° 2' 26"				
PI 1	0+450	1725	96 ° 5' 27"	10 ° 3' 1"	852.94	75.00	150
PI 2	2+175	1475	106 ° 52' 15"	10 ° 45' 48"	1061.51	100.00	200
PI 3	3+650	1350	112 ° 52' 29"	6 ° 0' 14"	2860.31	150.00	300
End Point	5+000						

TABLE 2: HEIGHT OF EYE AND HEIGHT OF OBJECT ABOVE ROADWAY SURFACE FOR SOME COUNTRIES

Country	Height of eye above roadway surface (m)		Height of object above roadway surface (m)		Source
	Stopping	Passing	Stopping	Passing	
Nigeria	1.07	1.07	0.15	1.3	[1]
India	1.2	1.2	0.15	1.2	[11]
United Kingdom	1.05	1.05	0.26	1.05	[2]
United States of America	1.07	1.07	0.15	1.3	[12]

TABLE 3: MODELLING MODULE FOR THE HORIZONTAL CURVE DATA

	A	B
1	**LABEL/ALGEBRAIC EXPRESSIONS**	**MODELLING**
2	Assumed Design Speed Km/h	B2
3	Horizontal Point of Intersection HP	B3
4	Degree	B4
5	Minute	B5
6	Second	B6
7	Central Angle Δ	=B4+B5/60+B6/3600
8	Tangent Distance T is to be iterated for minimum radius based on B2	B8
9	Radius R = T/(TAN 0.5Δ)	=B8/TAN(RADIANS(B7/2))
10	Horizontal Point of Curvature HPC = HPI – Ts	=B3-B8
11	Horizontal Point of Tangency HPT = HPI + T	=B3+B8
12	Length of curve = $2\pi R\Delta/360$	=2*22/7*B9*B7/360
13	Chord Length C = 2RSIN½Δ	=2*B9*SIN(RADIANS(B7))
14	External Distance EH = R(SEC½Δ)-1)	=B9*(1/COS(RADIANS(B7/2))-1)
15	Middle Ordinate M= R(1-COS½Δ)	=B9*(1-COS(RADIANS(B7/2))))

TABLE 4: MODELLING MODULE FOR THE COMPUTATION OF A CREST VERTICAL CURVE DATA

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2					CREST VERTICAL CURVE							
3					E3	F3	G3	H3	I3	J3	K3	L3
4												
5		HORIZONTAL DISTANCE (x)										
6										L =	K6	
7					G =	F7				A =	K7	
8		VERTICAL ALIGNMENT								K =	K8	
9					E9							
10						=$E$9+$F$7/F3-F3^2/200/$K$8	=$E$9+$F$7/G3-G3^2/200/$K$8	=$E$9+$F$7/H3-H3^2/200/$K$8	=$E$9+$F$7/I3-I3^2/200/$K$8	=$E$9+$F$7/J3-J3^2/200/$K$8	=$E$9+$F$7/K3-K3^2/200/$K$8	=$E$9+$F$7/L3-L3^2/200/$K$8
11		PROPOSED ROAD $= E_{PC} + G_1x + x^2/200/K$		E_x								
12					E12	F12	G12	H12	I12	J12	K12	L12
13												
14		EXISTING ROAD LEVEL										
15					E15	F15	G15	H15	I15	J15	K15	L15
16												
17		CHAINAGE										

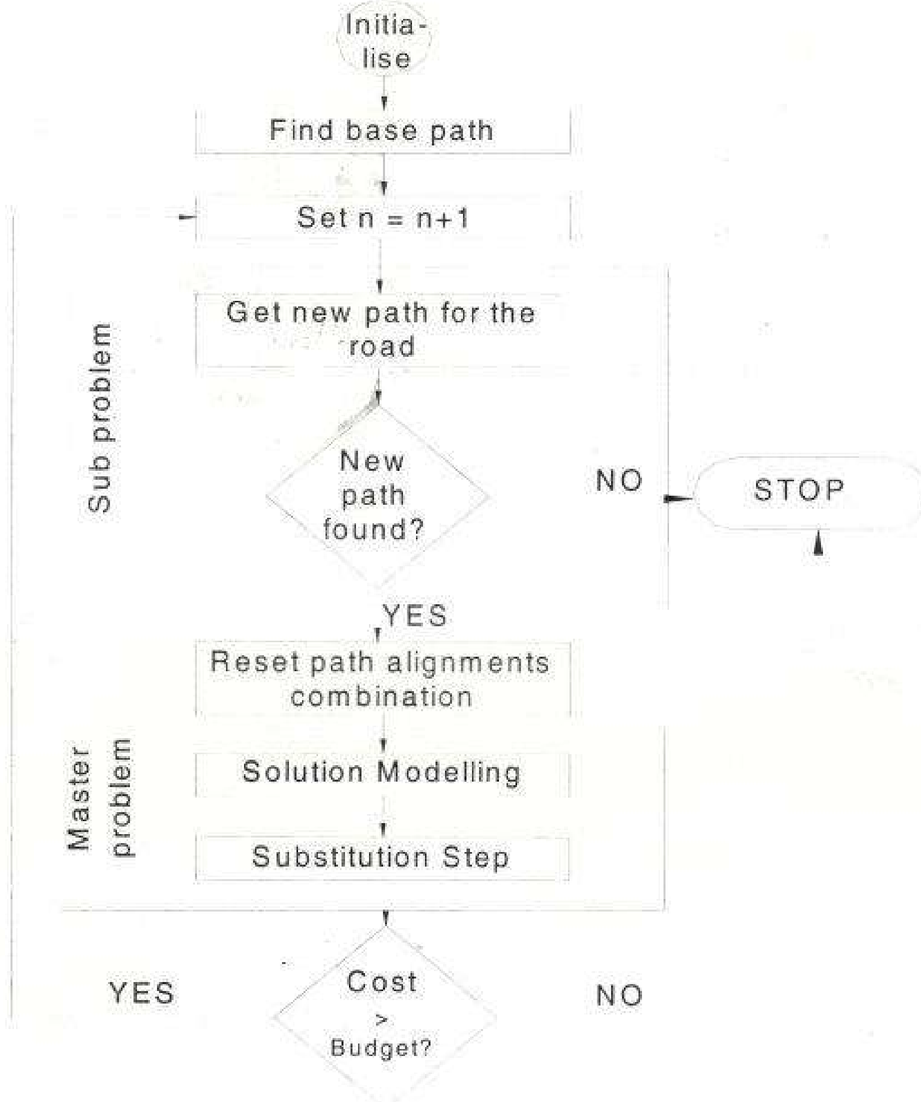

Figure 1: Flow Diagram for Solution Algorithm

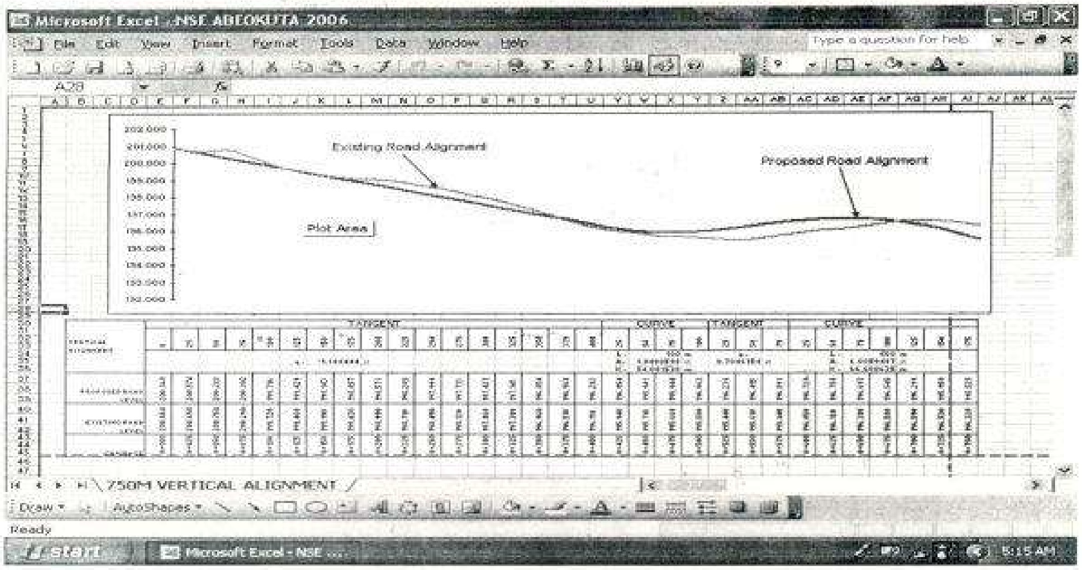

Figure 2: Excel-Spreadsheet Screen with Vertical Alignment Data and Graphics of a 750m Section of a 5km Road

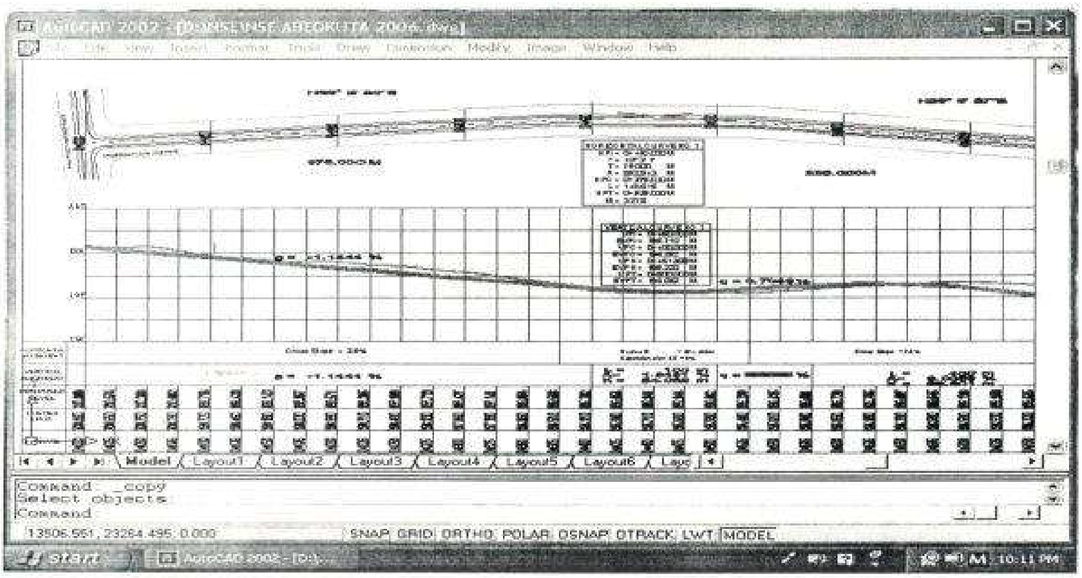

Figure 3: AutoCAD Screen with Plan and Profile of a 750m Section of a 5km Road in Model Environment