INTERACTIVE AND GRAPHIC SYSTEMS FOR HIGHWAY LOCATION AND ROUTE SELECTION

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ABSTRACT

Computer-assisted systems are fast becoming more of a necessity than just an expensive option. The price of acquiring such systems, although quite high, may often be offset by increases in productivity and reduction in work time, thus gaining significant net savings in the long run. This study presents and evaluates a technique in highway location and route selection that uses interactive and graphic systems. A system was developed that would provide a means for efficient drawing conversion and data manipulation. Hand-drawn alignment sketches on maps were easily converted into vector drawings and all alignment coordinate and element data were stored in a data bank. Also included in the system was the evaluation module for the generated vector representation of alignments. The concept of cost models was used for the evaluation procedures, where three-dimensional cost representations of the surrounding environs of the alignment were depicted. From these models, the total alignment costs may be calculated, which may then be used as a basis for selecting the best route. The system was found to be effective in evaluating and comparing results given different alignment schemes, based on the two test cases presented.

1. INTRODUCTION

Highway design, in its broadest sense, is composed of numerous processes and sub-processes from the planning stage up to the actual road construction. A general two-step procedure is usually done in developing highway geometry. Prior to the detailed engineering and design of the road, a preliminary process of locating the road should be done. This is normally called in most design agencies as *preliminary design* – a step where a lot of options are weighed, evaluated and prioritized before extensive effort is put into the final engineering design process.

Route selection, a sub-process of highway location, plays a very critical part in the overall highway design process since it is in this phase where the basic criteria should be met with the least possible negative financial, social and environmental effects. The basic alignment alternatives are laid or drawn out on a map in consideration of topography, land use, aesthetics and environmental impact, among many other factors. From these schemes, the most suitable choice is selected, which will then be subjected to further refinements during the detailed design phase.

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2. OBJECTIVES OF THE STUDY

- Develop a system for highway location that would facilitate an efficient means of drawing conversion and data storage, retrieval and assimilation;
- Provide a decision-guidance tool in route selection that would evaluate the impacts of proposed highway systems through engineering, socioeconomic and environmental costs;
- Evaluate the interactive and graphic system as a technique employed in the highway location and route selection process.

3. LITERATURE REVIEW

3.1. Highway Development

A graphical illustration of a highway design process flow as described in the Highway Design Guidelines (Bureau of Design, DPWH) is shown in Figure 3.1. The flowchart provides more detail on the preliminary design (or highway location) phase to highlight the route selection process, which is the focus of this study.

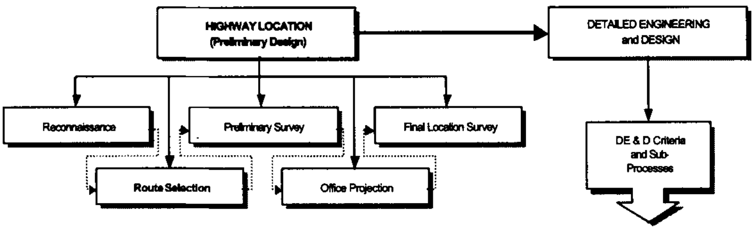

Figure 3.1 Highway Development Flow

The figure shows the basic steps in highway / road development. The two major steps are *highway location* and *detailed engineering and design*. Sub-processes of highway location include *reconnaissance*, which is the survey of the area usually through aerial photography and field inspection; *route selection* (explained in the next section); *preliminary survey*, which is the initial "walk-through" of proposed road alignments; *office projection*, which is the laying-out of the alignment/s on paper - usually on a topographical map; and the final location survey, which is a more detailed procedure similar to preliminary survey. Detailed engineering and design procedures and sub-processes are no longer within the scope of this study, so the illustration of its relationship with highway location shown in Figure 3.1 will suffice.

3.2. Route Selection

Route selection is basically a refinement of feasible alternatives. This usually include such items as approximate construction costs; alignment and profile studies; typical section development; preliminary designs for geometric layout, drainage, right-of-way, and utilities; location of interchanges, grade separations, and at-grade intersections;

preliminary bridge designs at critical locations; channel work; air, noise and water studies; flood hazard evaluations; and other supplemental studies and right-of-way information.[3]

The road designer can locate his proposed alignment practically anywhere between the nodes he intends to connect. His aim however is to choose a location which has the lowest overall costs of construction, land, traffic and social consequences and which obeys any constraints on geometric design and passage.[4] Lowest travel times or lowest capital investment required does not necessarily constitute the best location choice. It should primarily involve the design that yields the highest social returns and resolves most if not all of the major issues and conflicts arising from the proposed construction of the highway system.

3.3. Interactive and Graphic Techniques

The application of models that describe the regional environment within the corridor options is an efficient technique in evaluating and analyzing possible route locations. Through the aid of a computer, a wide variety of digital models may be derived from given base maps, which define some of the components of the regional environment.

A study similar in nature involved the development of the Generalized Computer-Aided Route Selection (GCARS) system,[5] and its application in an environmental impact analysis in western New York. It had a companion system called the Generalized Map Analysis Planning System (GMAPS), which was primarily responsible for model building.

The basic concept of the GCARS system was the application of minimum-path analysis techniques to "numerical cost models" in order to produce a series of ranked alignment options. These models are depicted as solid three-dimensional surfaces, which are actually graphical representations of cost-model matrices stored in a computer's data bank.

With the application of minimum-path algorithms, routes will follow the "valleys" across the cost models. A cost model is actually a grid network that is formed by joining the nodes of a cost-model matrix, where each node is assigned a cost of traversing it. The optimum path can therefore be obtained through minimum-path analysis. The initial optimal path shall then be raised in value so as to inhibit its inclusion in the next run, thus producing a "second-best" alternative in the re-evaluation of the revised network. Repetition of this process would then produce a series of ranked alternatives, which may be compared for sensitivity analyses and impact assessments.

4. BASIC CONCEPTS / THEORETICAL CONSIDERATIONS

4.1. Road Geometry

Some basic road design concepts are applied in the system, particularly in the highway location part. Horizontal alignment is of particular concern, which means fundamental theories for highway geometrics are applied. This includes the drawing of straights and

[3] Larry J. Shannon, Highway Engineering Handbook, edited by Brockenbrough and Boedecker (USA: McGraw-Hill, 1996), p. 2.4
[4] Optimisation of Road Alignment by the Use of Computers, Road Research, OECD, 1973
[5] ibid.

curves along the alignment and the location of the coordinates of tangent intersections, tangent to curve points and curve to tangent points.

4.2. Numerical Cost Models

The concept of numerical cost models was used in the GMAPS-GCARS model as described by Turner (1979). The model is a three-dimensional representation of costs in the regional environment of a proposed alignment based on a given base map. It is generated using a rectangular mesh of size $n \times m$, with d as the mesh spacing.

The cost model is based on Cartesian coordinates in three dimensions. The cost of traversing a certain area per meter of road[6] within the grid and the base map is assigned to the mesh node closest to that area. This cost input shall be the z-coordinate of that particular node. All nodes are assigned cost values so as to produce the three-dimensional cost model. Figure 4.1 shows a raised cost model (for purposes of better illustration) over the base grid and the alignment to be evaluated.

Each point in the alignment has a corresponding cost value in the cost model. To get the total cost of the alignment for a particular base map, these "point" costs are added up. The procedure for doing this is discussed in the next section.

The cost input for the nodes of the cost model may not be strictly limited to costs alone. The resulting benefits may be integrated to the values derived for node input. In fact, a 'benefit model' may even be generated similar to the process of cost model generation, using benefits instead of costs as node input values. Another approach is to subtract the benefits from the derived costs so that the models produced have the corresponding benefits already considered.

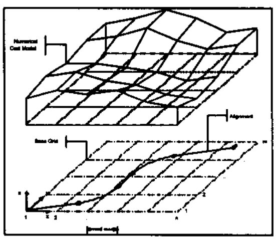

Figure 4.1 Cost Model Concept

The three-dimensional mesh shown in the figure is actually the cost model with nodes as costs projected from the base map where a proposed road alignment is laid-out. The model represents the varying costs per unit of road length (meters. kilometers, etc.) within the vicinity of the alignment.

[6] The cost input shall be the discretion of the user. This should have already taken into consideration the road width (i.e., number of lanes, lane width, etc.) and the road surface type.

4.3. Alignment Evaluation Method

If the whole length of the alignment is projected upwards (i.e., towards the positive z direction), the projection will intersect the cost model. This intersection may now be referred to as a certain function *g(a)*, where *a* represents points along the alignment. The total alignment cost is equal to the area bounded by *g(a)*, the alignment *start point* ($a = a_{start}$), *end point* ($a = a_{end}$) and the alignment itself.

The Trapezoid Rule

A widely used method for approximating areas for a given function is the *trapezoid rule*. Recall that rectangular rules (where the function is divided into rectangular strips of Δx width) approximated the function by a horizontal line in each interval. If the approximation method uses the function values in the edges of the strip, say g_1 and g_2 then a segment g_1-g_2 may be derived, which is not necessarily horizontal, to form a general parallelogram and not necessarily a rectangle. Usually, this takes the form of a trapezoid (g_1 is not equal to g_2).

This is best illustrated in Figure 4.2 where given a function *g(a)*, is divided into strips of width *h* within the boundaries a_{start} and a_{end}. Given two points, g_1 and g_2, with a gap *h*, the trapezoidal strip formed has an area A_i, which is defined by the equation:

$$A_i = \frac{g_1 + g_2}{2}(h) \tag{1}$$

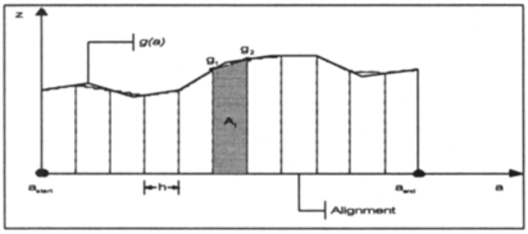

Figure 4.2 The Trapezoid Rule As Applied to the Alignment

If all the trapezoidal areas were added, the resulting equation would be:

$$A_T = \sum_{i=1}^{n} A_i \tag{2}$$

where:
A_T : total area
A_i : area of one trapezoidal strip
n : number of trapezoidal strips of width *h*

Based on the original premise that the total area is actually the total alignment cost, the following equation is derived:

$$A_T = \int_{a_{start}}^{a_{end}} g(a) \cdot da \approx \sum_{i=0}^{n-1} \left[\left(\frac{g_i + g_{i+1}}{2} \right) (h) \right] \tag{3}$$

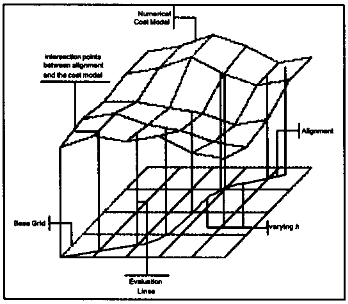

Figure 4.3 Evaluation Lines Intersecting the Cost Model

The trapezoid rule requires that the gap or the trapezoid width be constant for the whole length of the bounded region. This however will not hold for the system to be developed in this research since the model is limited to be just a three-dimensional mesh and not a solid surface. Therefore, intersection points between the alignment projection towards the positive z-axis and the cost model are only existent on the mesh "wires". This is illustrated in Figure 4.3, where evaluation lines are drawn to show where the alignment projections intersect the cost model, thus defining either points g_1 or g_2 (see Figure 4.2).

From this, instead of adopting the trapezoid rule in the evaluation procedures, a similar approach will be used. Since the value of h is not constant, a <u>simple summation of trapezoids</u> is the most appropriate approach. For any trapezoid T_i within the alignment boundaries of given width, h_i, the trapezoidal area may be computed using this equation:

$$A_{T_i} = \left(\frac{g_i + g_{i+1}}{2} \right) (h_i) \tag{4}$$

The resulting evaluation equation is therefore similar to the trapezoid rule; only this one uses varying trapezoidal widths:

$$C = A_{T_i} = \sum_{i=0}^{n-1} \left[\left(\frac{g_i + g_{i+1}}{2} \right) (h_i) \right] \tag{5}$$

5. DEVELOPMENT PROCESS

Given the basic theoretical foundations and preliminary evaluation methods, an interactive and graphic system was developed. The application has two parts – one part converts a hand-drawn sketch into a vector drawing and subsequently exports all alignment data to a spreadsheet. The other part is where the numerical cost model is developed interactively and alignments superimposed within the model are evaluated. The development of this system required several tests in trial alignments and models to remove as many errors and inconsistencies as possible in any design scenario.

Note that when deciding which route or alignment scheme is the best, numerous factors are considered and these usually have varying units or degrees of measurement. The system rests on the assumption that most, if not all factors considered in route selection have costs associated with it. The basic idea behind this system is to normalize the variables associated with the route selection process and convert (if applicable) those variables into costs. These will then be the basis for the generation of three-dimensional cost models that may be used to evaluate any alignment scheme that passes within the boundaries of the model.

A main system algorithm was designed to direct the flow of the application and to provide guidance in the development of the sub-algorithms in the module level. The idea is to transform the hand-drawn alignments on the map, store the necessary alignment data on a suitable data bank and evaluate the alignments through numerical cost models. From the cost evaluations, the user can then decide which alignment alternative is best in terms of cost.

6. SYSTEM APPLICATION

The application was assessed on its applicability and suitability in evaluating proposed alignments based on the concept of numerical cost models. Two test cases were done for this study to demonstrate the interactive and graphical technique for alignment evaluation. One is based on a hypothetical map and the other uses the map of the municipality of Taytay. The alignments proposed in both cases were arbitrarily drawn, since the main purpose of the test cases is to demonstrate the functionality and capability of the system to convert hand-drawn alignments, produce cost models and evaluate the drawn alignments.

The maps used in this study were also arbitrarily chosen, meaning these may or may not be used in actual practice, depending on the user's requirements. That also goes to say that other types of maps not included in this study may also be used if the evaluation of the proposed alignment calls for it. The cost inputs used for each map were assumed values.

6.1. Test Case 1 (Hypothetical Map)

The first test case made use of a hypothetical map with an existing coastal road connecting three built-up areas with some agricultural land in between. A bypass road is proposed to be constructed that would connect points A and B (refer to Figure 6.1). Three bypass alignment schemes were proposed and were evaluated based on three cost models based on the following maps: *Land Use Map*, *Slope Map* and *Land Capability Map*. The proposal is a two-lane rural road with either concrete or asphalt surfacing.

Hypothetical base maps were used to generate the three models shown in Figure 6.2. The slope map is directly associated with drainage costs, which means that if the ground slope is high, drainage costs are lower compared to flatter grounds. The land use map describes the land use classification of areas within the study area. The cost of traversing a new road system in a built-up area is much higher than those of, say agricultural or idle lands. Land capability is a given area's urbanization potential. The models produced were able to approximate the total alignment costs based on the said base maps.

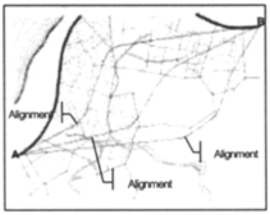

Figure 6.1 Hypothetical Base Map with the Proposed Alignments

<u>*Cost Models for Test Case 1*</u>

Figure 6.2 Slope Map, Land Use Map Model and Land Capability Map Model

The figure shows the different models generated for Test Case 1. These are (from left to right) the slope cost model, land use cost model and the land capability cost model.

6.2. *Test Case 2 (Taytay Land Use Maps)*

Land use maps of the Municipality of Taytay[7] were used for this test case. Three hypothetical alignment schemes were made that would connect the city of Pasig and Antipolo, passing through the Taytay municipality. Again, a two-lane road is assumed having a width of 7.5-meters (@ 3.75-m per lane). This case however made use of six cost models based on the maps obtained from the HLURB publication, namely, *Basic Soil Map, Development Constraints Map, Existing Land Use Map, Land Capability Map, Slope Map* and *Soil Suitability for Urban Use*.

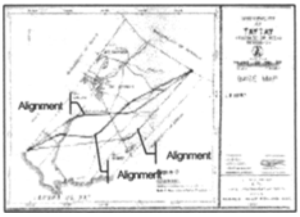

Figure 6.3 Taytay Base Map with the Proposed Alignments

[7] The maps were taken from the HLURB publication, "Guidelines for the Formulation / Revision of a Comprehensive Land Use Plan – Mapping"

Similar to the process done in the first (hypothetical) case, the alignments were hand-drawn on the map and then converted by the system into vector drawings. Six models were generated and each of the proposed alignments was evaluated for each of the models.

Taytay land use base maps were used to generate the six models shown in Figures 6.4 and 6.5.

Cost Models for Test Case 2

Figure 6.4 Taytay Basic Soil, Development Constraints and Existing Land Use Models

Figure 6.5 Taytay Land Capability, Slope and Soil Suitability Models

The figures show the different models generated for Test Case 2. Figure 6.4 illustrates (from left to right) the basic soil cost model, development constraints cost model and the existing land use cost model. Figure 6.5 shows (from left to right) the land capability cost model, slope cost model and the soil suitability cost model.

6.3. Summary of Evaluations

The resulting alignment costs were the products of applying the developed system for this study and are presented here to demonstrate the system's ability to provide data in ranking alignment alternatives. The number of models for each case may or may not be sufficient to evaluate the entire cost of each alignment, but the main goal of presenting these test cases is to show the processes and the resulting products involved when using this system.

From the table, it appears that the third alignment alternative is the least costly among the three schemes. Note that a difference of more than 7 million pesos between the first and third alignment was computed even though the third alternative had a length that is 76.8-meters longer than the first one. The length difference is even greater between alignment 2 and 3, which is around 242-meters, but alignment 3 is still less costly by about 4.86 million pesos even if it is longer.

Test Case 1 (Hypothetical Map)

Table 6.1 Test Case 1 Cost Evaluation Summary

Maps (Associated Cost)	Alignment 1	Alignment 2	Alignment 3
	Length (m): 3380.9552	*Length (m):* 3215.6180	*Length (m):* 3457.7463
	Cost (Philippine Pesos)	Cost (Philippine Pesos)	Cost (Philippine Pesos)
Land Use Map (Land Prices)	19,530,502.82	17,846,110.49	13,306,792.82
Slope Map (Drainage Costs)	1,468,002.67	1,239,898.22	1,166,353.92
Land Capability Map (Agricultural Productivity)	2,372,477.83	1,934,567.52	1,687,325.49
Total	23,370,983.32	21,020,576.23	16,160,472.24

Alignment 3 was the most favorable among the choices. Based on the land use model, this scheme had the least cost since this alternative passed through mostly forested land and did minimal passage through built-up or industrial areas, which are the most costly in terms of land price. In terms of drainage cost the third scheme still came out to be the most favorable since for the most part of its entire length, it passed through areas of high slopes. Of course, if other models were presented such as soil erosion or slope stability cost models and be used as bases for evaluation, this alignment would surely be more costly than the others.

Test Case 2 (Taytay Map)

Table 6.2 Test Case 2 Cost Evaluation Summary

Maps (Associated Cost)	Alignment 1	Alignment 2	Alignment 3
	Length (m): 6742.2149	*Length (m):* 6774.1183	*Length (m):* 6956.8149
	Cost (Philippine Pesos)	Cost (Philippine Pesos)	Cost (Philippine Pesos)
Basic Soil Map (Soil Condition for Const'n.)	3,378,122.66	3,335,339.49	3,399,991.47
Dev't. Constraints Map (Road Constructability)	2,686,807.12	2,782,508.11	2,778,854.08
Existing Land Use Map (Land Prices)	26,758,188.14	27,172,357.12	28,035,855.70
Land Capability Map (Agricultural Productivity)	3,917,887.26	3,967,823.33	4,055,132.38
Slope Map (Drainage)	2,546,859.98	2,575,626.05	2,646,165.57
Soil Suitability for Urban Use (Soil Effects on Road)	2,085,671.15	2,059,855.71	2,100,120.51
Total	41,373,536.31	41,893,509.81	43,016,119.71

The results did not show much disparity in the resulting total costs. The first alignment appeared the least costly among the three choices consistent with the alignment lengths having alignment 1 as the shortest alternative. The minimal difference in costs may be attributed to the fact that the area covered is large, covering a whole municipality and that the alignments generally traversed similar areas. Another reason may be that none or very minimal passage through built-up areas were noted for all alternatives. Land prices based on land use proved to be critical in the previous test case, accounting for much of the differences in cost between the three choices.

7. CONCLUSION

The development of an interactive and graphic system for highway location and route selection provides another approach in the preliminary stages of the highway development process. The application developed for this study was able to accurately transform the hand-drawn alignments into vector drawings and evaluate those alignments through cost models. This technique isolates each independent factor in constructing the alignment and normalizes the variables to become costs per linear unit of the proposed road. This enables the designer or planner to see in a much bigger picture the effects of each variable and to identify the factors that creates the greatest (or least) impact on the highway alignment.

The developed system was interactive and provided sufficient instructions to guide the user during the course of system operation. Careful algorithm formulation gave the system ample decision making capabilities that would otherwise take hours or even days if done manually. Drawing conversion from a rough hand-drawn sketch to a digital vector drawing was made efficient by the highway location modules as well as data storage, retrieval and assimilation. Test cases were used to demonstrate the functionality of the system and more importantly, its merits. The system was checked and validated using several test alignments and was found to be acceptable. The resulting calculations during the system's application to the test cases were quite accurate and showed a great degree of consistency with the base maps. Thus, the developed system should provide highway designers and planners an easy-to-use, versatile and efficient tool in performing the tasks of highway location and route selection.

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