FIFTH EDITION

ROUTE SURVEYING AND DESIGN

CARL F. MEYER
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Preface

The fifth edition of *Route Surveying and Design* is characterized by a reframing and updating of the chapters on surveying and design procedures. Each of the last three editions contained one new chapter written to cover evolving developments in field and office methods. As a result, there was a tendency to consider the material as frozen in a time frame, being either "traditional," "recent," or "new." In truth, however, all the methods described had their ideal place of application, depending on the nature and scope of the project.

The approach of a fifth edition gave the opportunity to revise the foregoing chapters by eliminating the "time frame" chapter titles. Instead, all the material, whether formerly thought of as "old" or "new," is now treated under method or job titles. At the same time, new material has been added and older material updated.

It is a privilege to introduce Professor David W. Gibson as coauthor of the fifth edition. He is solely responsible for the writing in Chapters 10

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through 13. In addition, he has lent valuable assistance in reviewing and suggesting improvements in the other chapters.

Chapters 1 through 9 contain numerous small changes intended to clarify and improve on the former treatment. Worthy of special mention is a new treatment of compound curves, which takes advantage of frequently used surveying procedures that are "hard wired" into some desk-top calculators or are available as prerecorded program cards that can be inserted into some pocket calculators.

Users of the end-of-chapter problems will be glad to find all new problems with answers given to most of them.

CARL F. MEYER
DAVID W. GIBSON

East Los Angeles Interchange. (Courtesy of California Division of Highways.)

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Part I
BASIC PRINCIPLES

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Chapter 1
Route Location

1-1. Introduction

This chapter comprises an outline of the basic considerations affecting the general problem of route location. The material is nonmathematical, but it is necessary for a clear understanding of the purposes served by the technical matters in the remaining chapters of Part I. Specific practical applications of these basic considerations to the location of highways, railroads, and other routes of transportation and communication are given in Part II.

1-2. Route Surveying and Systems Engineering

Route surveying includes all field work and requisite calculations (together with maps, profiles, and other drawings) involved in the planning and construction of any route of transportation. If the word *transportation* be taken to refer not only to the transportation of persons but also to the movement of liquids and gases and to the transmission of power and messages, then route surveying covers a broad field. Among the important engineering structures thus included are: highways and railroads; aqueducts, canals, and flumes; pipe lines for water, sewage, oil, and gas; cableways and belt conveyors; and power, telephone, and telegraph transmission lines.

Though this definition of route surveying distinguishes the subject from other branches of surveying, it is assumed that projects involving route surveys have considerable magnitude. There will usually be definite termini a fairly long distance apart. In such a situation the surveys serve two purposes: (1) to determine the best general route between the termini; (2) to find the optimum combination of alignment, grades, and other details of the selected route. To accomplish these purposes requires not only expert survey technique but also experience in the *art of engineering*. This combination of creative planning, surveying, and design is a good example of what is called *systems engineering*.

1-3. Relation of Project to Economics

Every route-surveying project involves economic problems both large and small. *By far the most important question is whether or not to construct the project*. Essentially, this decision is based on a comparison of the cost of the enterprise with the probable financial returns or social advantages to be expected. In some cases the question can be answered after a careful preliminary study without field work; in others, extensive surveys and cost estimates must first be made.

However simple or complex the project may be, it is rarely possible for the engineer alone to answer this basic economic question. To his studies must be added those of the persons responsible for the financial and managerial policies of the organization. In the case of a public project the broad social, environmental, and political objectives also carry weight.

The engineer responsible for conducting route surveys is not solely a technician. In addition to his indispensable aid in solving the larger economic problems, he is continually confronted with smaller ones in the field and office. For example, the relatively simple matter of deciding which of several methods to be used in developing a topographic map of a strip of territory is, basically, an economic problem that involves survey, terrain, and equipment and personnel available.

1-4. Relation of Project to Design

Design problems in route location are closely related to route surveying. Some matters of design must precede the field work; others are dependent on it. For example, in order that field work for a proposed new highway may be done efficiently, the designers must have chosen—at least tentatively—not only the termini and possible intermediate connections but also such design details as the number of traffic lanes, width of right-of-way, maximum grade, minimum radius of curve, and minimum sight distance. On the other hand, considerable field work must be done before the designers can fix the exact alignment, grade elevations, shoulder widths, and culvert locations to fit the selected standards safely and with the greatest overall economy. The relationships between modern route surveying and design are described in detail in Chapter 11.

1-5. Basic Factors of Alignment and Grades

In route location it is usually found that the termini and possible intermediate controlling points are at different elevations. Moreover, the topography and existing physical features rarely permit a straight location between the points. These circumstances invariably require the introduction of vertical and horizontal changes in direction; therefore, grades, vertical curves, and horizontal curves are important features of route surveying and design.

Curvature is not inherently objectionable. Though a straight line is the shortest distance between two points, it is also the most monotonous—a consideration of some aesthetic importance in the location of scenic highways. The device of curvature gives the designer limitless opportunities to fit a location to the natural swing of the topography in such a way as to be both pleasing and economical. Excessive or poorly designed curvature, however, may introduce serious operating hazards, or may add greatly to the costs of constructing, maintaining, or operating over the route.

Steep grades are likely to have the same effects on safety and costs as excessive curvature. It should be emphasized, nevertheless, that problems of curves and grades are ordinarily interrelated. Thus, on highway and railroad location it is often the practice to increase the distance between two fixed points in order to reduce the grade. This process, known as "development," necessarily adds to the total curvature. It is not always a feasible solution, for added curvature may be more objectionable than the original steep grade.

The aim of good location should be the attainment of consistent conditions with a proper balance between curvature and grade. This is especially true in highway location, owing to the fact that each vehicle is individually operated and the driver often is unfamiliar with a particular highway. Many highway accidents occur at a place where there is a sudden and misleading variation from the condition of curvature, grade, or sight distance found on an adjacent section of the same highway. To produce a harmonious balance between curvature and grade, and to do it economically, requires the engineer to possess broad experience, mature judgment, and a thorough knowledge of the objectives of the project.

1-6. Influence of Type of Project

The type of route to be built between given termini has a decided influence on its location. As an example, the best location for a railroad would not necessarily be the most suitable one for a power-transmission line. A railroad requires a location having fairly flat grades and curves. Moreover, there are usually intermediate controlling points such as major stream and highway crossings, mountain passes, and revenue-producing markets. In contrast, power is transmitted as readily up a vertical cable as along a horizontal one. Grades, therefore, have no significance, and river and highway crossings present no unusual problems. Where changes in direction are needed, they are made at angle towers. Consequently, the alignment is as straight as possible from generating station to substation.

1-7. Influence of Terrain

Character of the terrain between termini or major controlling points is apt to impress a characteristic pattern upon a route location, particularly in the case of a highway or a railroad. Terrain may be generally classified as *level*, *rolling*, or *mountainous*.

In comparatively level regions the line may be straight for long distances, minor deviations being introduced merely to skirt watercourses, avoid poor foundations, or possibly to reduce land damages. On an important project, however, the artificial control imposed by following section lines or other boundaries should not be permitted to govern.

In rolling country the location pattern depends on orientation of the ridges and valleys with respect to the general direction of the route. Parallel orientation may result in a *valley line* having flat grades, much curvature, frequent culverts and bridges, and fill in excess of cut; or it may permit a *ridge line* having simpler alignment and drainage problems. To connect two such situations, and also when ridges are oblique to the general direction of the route, there may be a *side-hill line*. This has the characteristics of uniformly rising grades, curvature fitted to the hillsides, and relatively light, balanced grading.

Where ridges and valleys are approximately at right angles to the general direction of the route, the typical pattern that results may be called a *cross-drainage line*. There the location of passes through the ridges and of crossings over major streams constitute important controlling points between which the line may be the side-hill type. Generally, a cross-drainage line involves steep grades, heavy grading with alternate cuts and fills, expensive bridges, and curvature considerably less than that on a valley line.

Mountainous terrain imposes the severest burden upon the ingenuity of a locating engineer. No simple pattern or set of rules fits all situations. Short sections of each type of lines previously described must be inserted as conditions require. "Development," even to the extent of switchbacks and loops, may be the only alternative to expensive tunnel construction.

1-8. The Basic Route Survey and Design System

Figure 1-1 indicates the basic route survey and design system that has been successfully used in this country for most projects. Although these operations vary with different organizations, and particularly with the nature and scope of the project, a typical outline of the field and office work is represented.

1-9. Importance of the Reconnaissance

Second in importance to the primary question—whether or not to build the project—is selection of the *general route* between the termini. This is usually determined by *reconnaissance.*

The statement by Wellington,* "*The reconnaissance must not be of a line, but of an area,*" is a most apt one. Extent of the area depends, of course, on the type of project and nature of the terrain, but the area must be broad enough to cover all practicable routes joining the termini. Of particular importance is the need to guard against the natural tendency to favor an obviously feasible location. It is possible that country which is covered with tangled undergrowth, or otherwise rough for foot travel on reconnaissance, may hide a much better location than available in more settled or open territory.

With regard to the importance of the "art of reconnaissance" and attitude of an engineer toward it, nowhere will more effective comments be found than in Wellington's classic treatise. Though written by that author in 1887 for the instruction of engineers on railroad location, the following statements are timeless in their application to all types of route location:

> . . . there is nothing against which a locating engineer will find it necessary to be more constantly on his guard than the drawing of hasty and unfounded conclusions, especially of an unfavorable character, from apparent evidence wrongly interpreted. If his conclusions on reconnaissance are unduly favorable, there is no great harm done—nothing more at the worst will ensue than an unnecessary amount of surveying; but a hasty conclusion that some line is not feasible, or that further improvements in it cannot be made, or even sometimes—often very absurdly—that no other line of any kind exists than the one which has chanced to be discovered—these are errors which may have disastrous consequences.
>
> On this account, if for no other, the locating engineer should cultivate . . . what may be called an optimistic habit of mind. He should not allow himself to enter upon his work with the feeling that any country is seriously difficult, but rather

* Reprinted by permission from *Economic Theory of the Location of Railways* by A. M. Wellington, published by John Wiley & Sons, Inc., 1915.

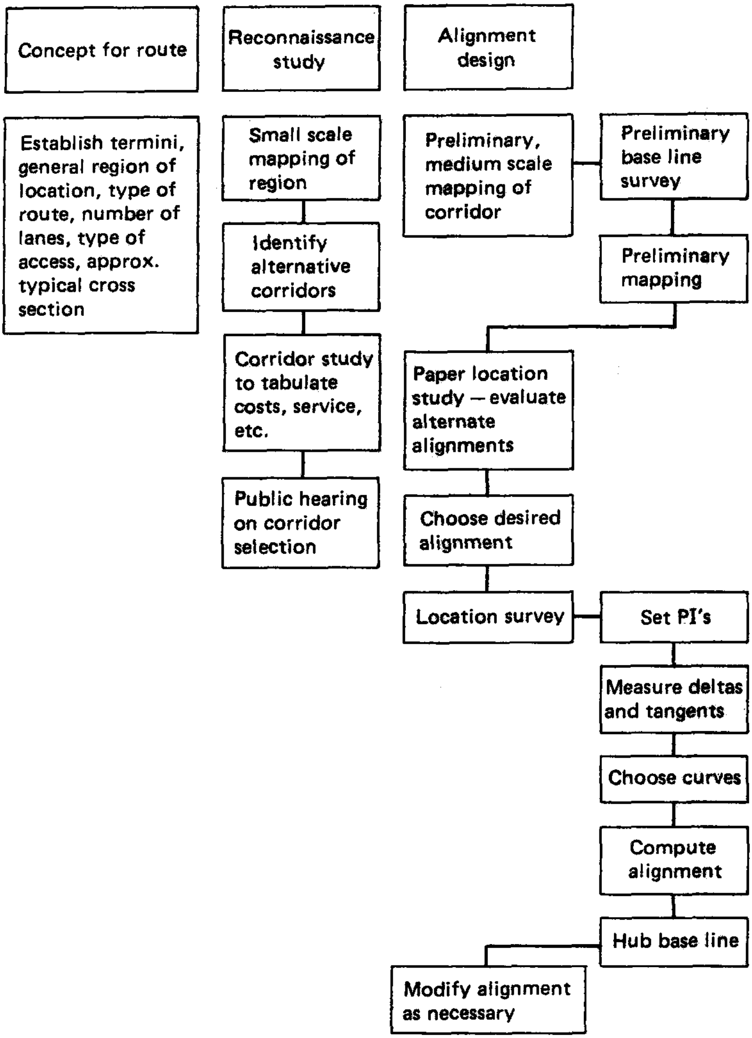

Figure 1-1 The basic route survey and design system.

that the problem before him is simply to find the line, which undoubtedly exists, and that he can only fail to do so from some blindness or oversight of his own, which it will be his business to guard against.

For the reason that there is so much danger of radical error *in the selection of the lines to be surveyed* (or, rather, of the lines not to be examined), it results that THE WORST ERRORS OF LOCATION GENERALLY ORIGINATE

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