# 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

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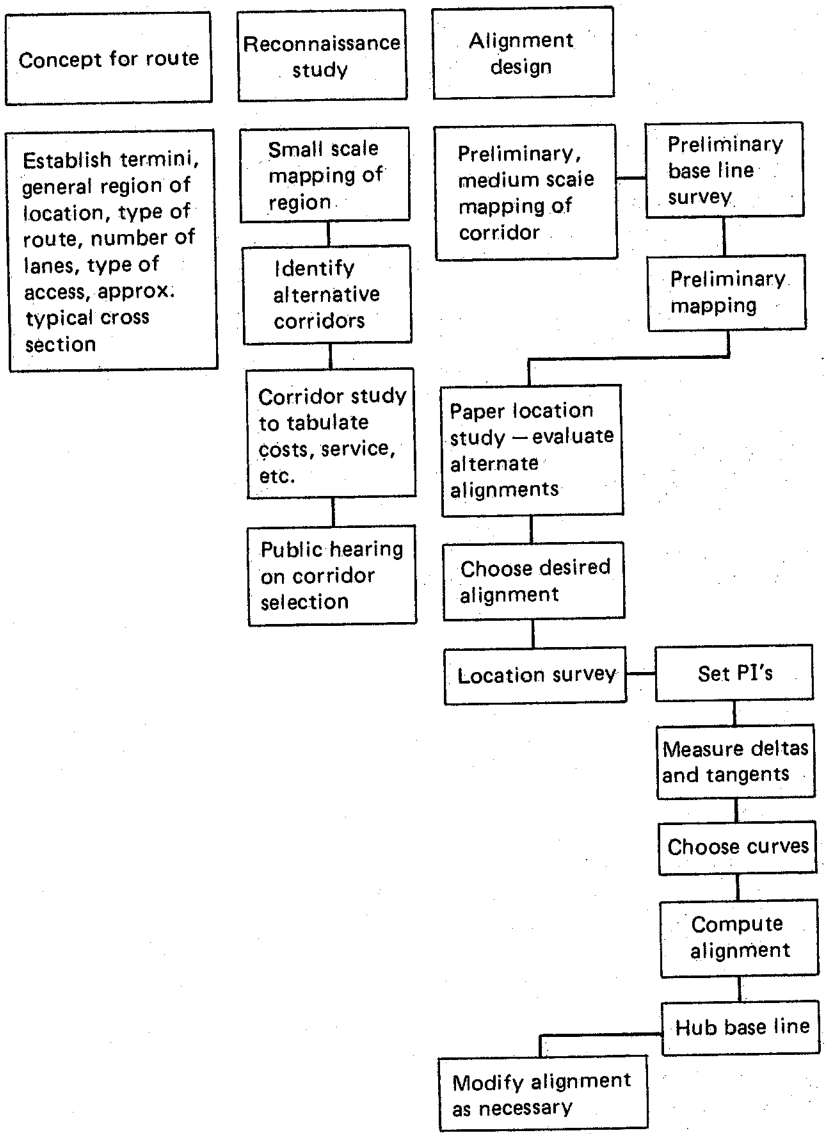


Figure 1-1 The basic route survey and design system.

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



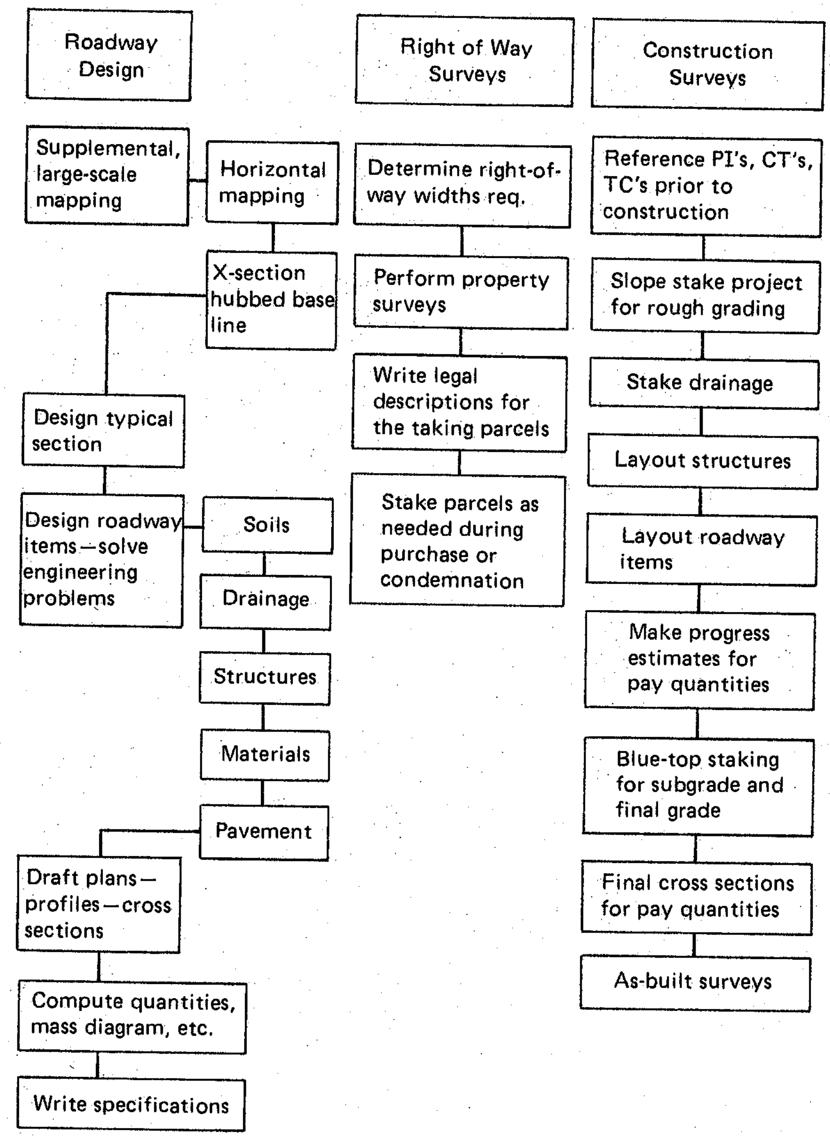


Figure 1-1 (*continued*)

IN THE RECONNAISSANCE. This truth once grasped, the greatest of all dangers, over-confidence in one's own infallibility, is removed.

If, as often happens, the reconnaissance is entrusted to one engineer, he should have mature experience in the promotional, financial, and engineering aspects of similar projects. It is not enough that he be an experienced locating engineer, for such a man is likely to concentrate upon the purely physical possibilities of a route. Furthermore, he should be able to sense the significance of present trends and their probable effect upon the future utility of the project and realize when to seek a specialist's advice in such matters.

## 1-10. Purposes of Preliminary Surveys

A preliminary survey follows the general route recommended in the reconnaissance report. The most important purpose of such a survey is to obtain data for plotting an accurate map of a strip of territory along one or more promising routes. This map serves as the basis for projecting the final alignment and profile, at least tentatively. Enough data are also obtained from which to make an estimate of earthwork quantities, drainage-structure and needed right-of-way. Taken together, these data permit compilation of a fairly close cost estimate.

Preliminary surveys differ greatly in method and precision. Invariably, however, there is at least one traverse (compass, stadia, or transit-and-tape) which serves as a framework for the topographical details. Elevations along the traverse line and tie measurements to existing physical features are essential. Accurate contours may or may not be needed, the requirement depending on the type of project.

Detailed methods of running preliminary surveys including photogrammetric methods will be found in Chapter 11.

## 1-11. Proper Use of Topography

On new locations of routes over which grades are particularly important, an accurate contour map is indispensable. Relocation of an existing route, such as a highway, may sometimes be made by revising the preliminary survey directly on the ground. The method, termed "field location" or "direct location," is not recommended for a new line. It is true that some engineers seem to have uncanny ability for locating a satisfactory line—though not necessarily the best one—by direct field methods. Such a natural gift is not to be belittled, but it should be subordinated in difficult terrain to careful office studies aided by a contour map.

The primary purpose of a contour map is to serve as a basis for making a "paper location" of the final center line. On such a map the locating engineer is able to scan a large area at once. By graphical methods he can study various locations in a small fraction of the time required for a field party to survey lines on the ground. Furthermore, he is not subject to the natural optical illusions that often mislead even the most experienced engineer in the field. An added advantage of the contour map, provided it is extensive enough, is to supply visible evidence that no better line has been overlooked.



It is possible, however, to put too much reliance upon map topography. Particularly to be avoided is temptation to control the work from the office by making such a meticulous paper location, even to the extent of complete notes for staking all curves, that the field work of final location becomes a mere routine of carrying out "instructions from headquarters." A contour map, no matter how accurate it is, cannot impress upon the mind as forcibly as field examination such details as the true significance of length and depth of cuts and fills; nature of the materials and foundations; susceptibility to slides, snow drifting, and other maintenance difficulties; or the aesthetic values of a projected location. At best, the map facilitates making what might be termed a "semifinal location," which is to be further revised in minor details during the location survey.

## 1-12. Function of Location Survey

The purpose of the location survey is to transfer a paper location, complete with curves, to the ground. It is too much to expect that this ground line will conform to the paper location in every detail. Almost certainly there will be minor deviations, resulting usually from errors in the preliminary traverse or in the taking or plotting of the topography. An exact agreement does not assure excellence of the location; it merely proves the geometric accuracy of the field and office work. Consequently, regardless of the "fit" with the paper location, the engineer should be constantly on watch for opportunities to make those minor adjustments in alignment or grades that only close observation of the field conditions will reveal.

When staked, the final location is usually cross sectioned for closer determination of earthwork quantities. In addition, tie measurements to property lines are made to serve for preparing right-of-way descriptions, and all necessary field data are obtained to permit detailed design of miscellaneous structures.

## 1-13. Relation of Surveying to Engineering

Before we leave these basic considerations to study the technical aspects of route surveying, it should be pointed out that surveying and mapping, as ordinarily practiced, are not engineering; they are merely methods of obtaining and portraying data needed as a prelude to the design and construction of engineering works.

During study of the chapters that follow, it will be natural for the students to concentrate on geometrical and instrumental techniques. However, the course in Route Surveying will not reach its potential value unless it is more than drill in field and office practice. Students stimulated by the instructor's examples and illustrations, should attempt to look beyond technical details and gain some insight into the factors that lead to the conception of a particular project. Knowledge of those factors will give them a better appreciation of the engineering surveys—their planning, the controlling specifications, and the usefulness of the data to the designers.

To be of the greatest usefulness, without being unduly costly, surveys, maps, and computations should be only as complete and accurate as needed for the ultimate job. For some purposes utmost accuracy is required. For others, extreme niceties are too costly and time-consuming; they may be replaced by approximate methods and short cuts. As an example, much time is often wasted in "exact" calculation of yardage estimates prior to construction, only to find that shrinkage, compaction, overbreak, or stripping allowances change the estimated quantities by large amounts. This is not to imply that grading calculations may always be done by approximate methods. Accuracy is invariably required, for example, in determination of yardage for payment to contractors. One trait of a good engineer is his judgment of the degree of precision required in obtaining data and computing values for use.

Surveying and mapping are essential prerequisites to engineering design for mass transportation. In designing a large transportation project, extensive surveying operations are involved in the early reconnaissance, detailed preliminary and location surveys, and all the work leading to the preparation of topographic maps, profiles, cross sections, and other working drawings. If to these there are added the construction layout and "as-built" record surveys, it is apparent that a large portion of the total engineering costs is absorbed by surveying and mapping.

In contrast to the leisurely pace of highway construction in the early part of this century, wherein the ordinary piecemeal survey served the purpose, we now have vast and costly projects. Noteworthy among these are the heavily-traveled California Freeways and the toll highways in Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Ohio, Indiana, Florida, and several other states. Even these are dwarfed by the Interstate Highway System. Already conceived is the proposed Mississippi River Parkway, for which map reconnaissance of 50,000 square miles has yielded over 8000 miles of alternate routes. Survey and mapping methods must be selected to keep pace with the advanced design and construction techniques used on such vast projects.

Applications of photogrammetry and new automated devices are given in Chapters 10, 11, and 12. These represent advances in route surveying and design that save time and reduce interest charges during construction of a major project.

In fitting surveying and mapping into the plans for a transportation project, saving in time by use of shortcut methods should not be achieved at the expense of reduction in ultimate required accuracy. Time saved by short cuts in control surveys, for example, may be lost many times over in transferring the paper location to the ground or in monumenting the right-of-way.



During construction, one field change caused by poor original surveys may delay the work longer than the time saved earlier by shortcut survey methods.

By observing the ultimate accuracies needed in the various phases of a project and adopting well-planned methods of surveying and mapping, even at the expense of some extra time, the whole project will have a firmer base around which design and construction operations can be planned. This kind of surveying and mapping is necessary for route location in systems engineering.