The Use and Value of a Geodetic Reference System

Research Study by University of Maine at Orono

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FEDERAL GEODETIC CONTROL COMMITTEE

The Federal Geodetic Control Committee (FGCC) comprises 10 Federal departments and independent agencies involved in geodetic surveying. Under provision of Bureau of the Budget (now Office of Management and Budget) Circular No. A-16, revised 1967, titled "Coordination of Surveying and Mapping Activities," the Committee coordinates planning and execution of geodetic control and related survey activities of Federal agencies. The goal is to assure that the needs of the Government and the public at large are met expeditiously and economically with available resources.

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Executive Summary

This report applies a benefit cost framework to the issue of identifying and assessing economic value arising from utilization of a geodetic reference system. The findings indicate that investment in utilization of a geodetic reference system yields a large stream of benefits to an agency or jurisdiction that typically requires accurate, compatible, spatial information for decision-making. The major portion of benefits occurs with the use of spatial information based on a geodetic system by secondary and tertiary users. These users have the need to combine or integrate information and data originally produced for narrow-based primary purposes.

In the context of economic value, a geodetic reference system can be viewed as an input to a production process. The outputs of this process are spatial information products with the attribute of universal compatibility. Universal compatibility allows users of the information products, beyond those responsible for their initial production, to combine or integrate across information products independently of the original purpose for which the information was produced. In contrast, spatial information products based upon other reference systems possess only a limited and site-specific degree of compatibility. Such data products would be independent and only capable of being combined or integrated by secondary and tertiary users at an added cost. Use of a geodetic reference system, by imparting universal compatibility, avoids these costs. The avoided costs represent a major source of economic benefits.

A geodetic reference system can be characterized as a set of land positions whose spatial relationships are known. Such a system has several distinctive features: (1) density; (2) accuracy; (3) spatial extent; (4) use of a common language, essentially mathematical, to describe the relationships; and (5) operational effectiveness in the distribution of system data to potential users.

There are problems in identifying and measuring the benefits arising from utilization of a geodetic reference system. It is understood that such a system may be used in several ways to provide information to decision makers. However, there is a need to develop a methodology that makes it possible for a potential investor, such as a local government, to estimate the benefits generated from an investment to promote greater utilization of a geodetic reference system. Many potential investors are not interested in surveying and mapping activities, per se. For them, the question of economic value relates to the question of how a geodetic reference system can satisfy their broader and more complex needs for spatial information. This study answers that question.

Land planning and development decisions in both the private and public sectors require vast amounts and types of information for risk assessment. Such decision-making requires accurate and, most importantly, highly compatible data. These requirements create conditions that lead to an investment in the means of obtaining such information. This information transfer process includes, as one of the means, a geodetic reference system.

The contribution which a geodetic reference system alone makes to a land information system is the provision of universal compatibility to the resulting spatial information products. The demand for universal compatibility generates a stream of benefits attributable to the geodetic reference system. The system itself, regardless of its technical capabilities, does not generate any benefits. Benefits occur only if a demand exists for the product obtained from its use—universal compatibility.

Each time spatial information products based on a geodetic reference system are used in a manner that meets the needs of a decision maker, a measurable economic benefit is generated. This measurable benefit is the avoided cost of expensive, ad hoc measurements that would otherwise be necessary to allow the decision maker to combine individual information products. These cost savings are a benefit attributable to investment in utilization of the existing system.

The avoided costs of ad hoc measurements can be measured. The measurement requires identification of major activities and decisions that require universal compatibility in spatial information products and the rates at which these activities and decisions occur. Each decision generates an economic benefit (an avoided cost). The total benefit is found by aggregating the cost savings across all such decisions.

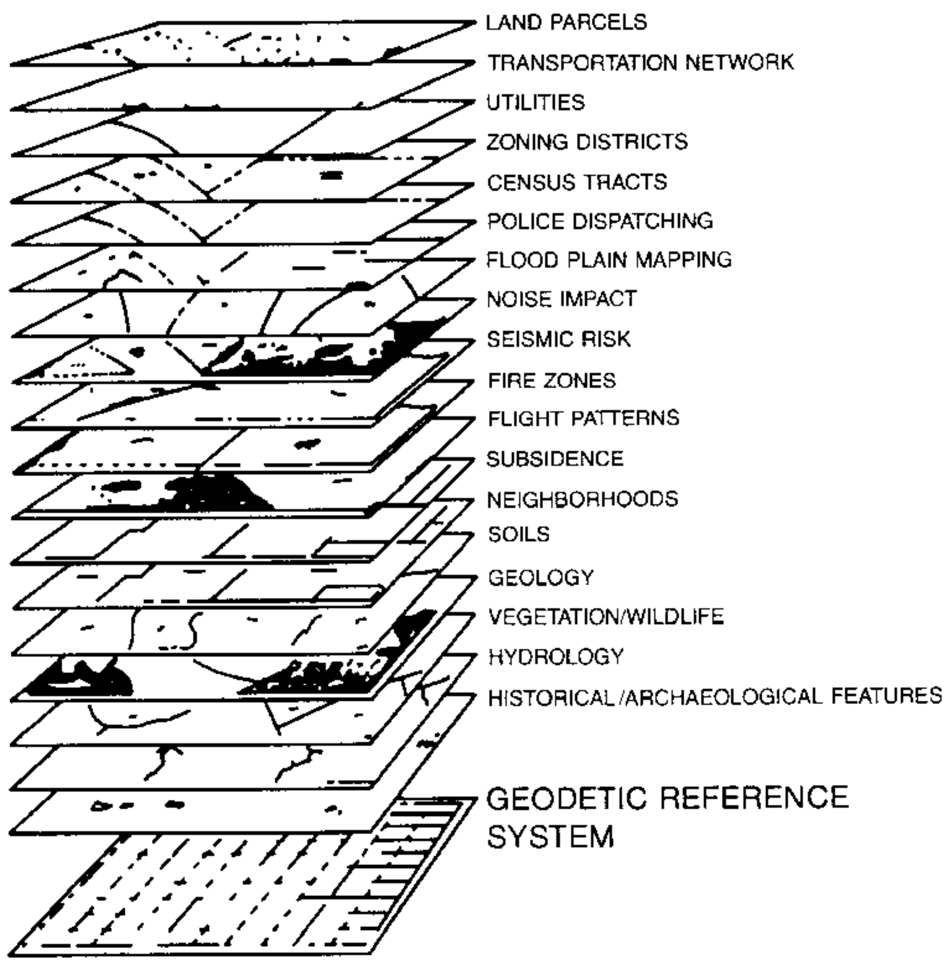
The concept of avoided costs as a source of benefits from investment in the use of existing information is demonstrated by case study observations. These observations indicate a variety of practices, some of which do or do not take advantage of the benefits derivable from the system.

We have identified a specific type of activity as the basis for applying the model and estimating the benefit cost relationship. In this activity, decision makers require accurate and universally compatible data. We have accepted the decision-making standards for accuracy and compatibility as used by personnel in the case study activity. We recognize that others may have different standards. However, the test activity has developed an information transfer process based upon these standards. Therefore, it provides an opportunity to measure the benefits obtained by the use of universally compatible spatial information.

The agency serving as the case study maintains records of past decisions that utilized universally compatible data. As a result it was possible to estimate the benefit stream. To some extent, this agency is an exception. Other agencies typically do not keep records of the type necessary to determine the sort of benefits generated.

On the basis of our case study observations, we estimate the ratio of benefits to costs to be at least in the range 1.7 to 4.5. These values are very conservative estimates, in part because some data are missing. They clearly demonstrate that positive net benefits arise from utilization of a geodetic reference system.

These results suggest that combined Federal and local efforts be directed toward identifying and supporting local agencies that seek to improve the quality of their planning and development information by using data based on a geodetic reference system. These agencies should be provided with institutional as well as technical support and guidance in obtaining greater utilization of existing geodetic reference systems to support land information systems.



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I. The Proper Role for Benefit Cost Analysis

A fundamental characteristic of any economy is the condition of scarcity—resources or factors of production are limited. As a consequence, a society must develop some mechanism for deciding which products and services will and will not be produced. Choices must be made and resources allocated among alternative uses. In the face of scarcity, the concern is that the pattern of resource use should be consistent with economic efficiency. In simple terms, the efficiency principle means that resources should flow to producing those products for which consumers have the strongest preferences relative to the opportunity costs of production.

A. Benefit Cost Analysis

The theme of economic efficiency in using scarce resources applies to the production of both private and governmental goods. In the case of private products, markets serve as the decision-making mechanism for deciding what will and will not be produced. The willingness of consumers to make expenditures reflects the benefits received from consuming various amounts of a good, and costs are reflected by the schedule of costs incurred at various levels of output. The interaction of the benefit and cost phenomena establishes the market price or value of the product with resource allocation being determined by demand and supply forces. In this way, the price system associated with the use of markets serves as a mechanism for calculating the benefits and costs of alternative uses of scarce resources.

Production of governmental or public products and services presents an entirely different situation in terms of how a society decides upon production levels. Governmental products are essentially different from private goods. Private goods are consumed individually while governmental products are consumed collectively. In the case of a public product, it is technically infeasible to exclude anyone from consuming the product once it is produced, and as a result, anyone can consume it without payment. National defense is commonly used to illustrate a public good.

Because exclusion is impossible, markets cannot be used to determine the efficient amount of resources to be allocated for production of public products. Some alternative mechanism must be used. Benefit cost analysis is commonly used in such situations to guide the decision-making process. As such, it serves as a replacement for the benefit cost analysis performed by the market in the case of private products. The basic aim of any benefit cost analysis of a government program is to determine if benefits exceed costs. If so, the use of scarce resources in the program is consistent with the social goal of economic efficiency.

B. Common Misconceptions about Benefit Cost Analysis

Benefit cost analysis is often seen as an attempt to substitute mechanical methods for reasoning in administrative decision-making. Benefit cost analysis makes no decisions, nor is it an algorithm which produces a number that solves all decision-making problems.

The essence of benefit cost analysis can be described quite simply. It provides a framework for organizing one's thoughts and a way of structuring the decision process. Such an analysis calls for explicitly listing all pros (benefits) and cons (costs) of an action, placing a weight (value) on each, and assessing the net value of the action. The contribution of the benefit cost approach to public expenditure analysis is that decision makers are forced to consider all factors—the quantifiable and nonquantifiable—in making decisions. As a result, implicit factors often become explicit. The decision process tends to focus more directly on critical elements, and orderliness and structure are imposed on the decision-making process.

In its proper use, benefit cost analysis often makes decision-making more difficult because it usually identifies a larger number of relevant effects that must be considered in any decisions. In addition, decision makers are often called upon to assign weights to specific benefit and cost streams that are basically nonquantifiable. While benefit cost analysis can be a valuable tool, it is not properly viewed as a substitute for the need to make decisions. Those familiar with public sector decision-making can certainly point to cases where such analysis is either not used or is buried in an avalanche of political forces. This does not mean benefit cost analysis cannot be of value—only that the real world operates with much friction.

C. Economic Value of Using a Geodetic Reference System

Economic value is a demand-initiated concept. In assessing economic value, a geodetic reference system (sometimes referred to as a geodetic or global control system) is properly viewed as an input, which, in combination with other inputs, is capable of producing various outputs or products. Economic value of the reference system is derived from the level of demand for these outputs. If no demand existed, no economic value could be assigned to the reference system. In other words, because a geodetic reference system is available and numerous products based on the system are technically possible, it does not automatically lead to the conclusion that public expenditures designed to densify and maintain the system and/or to promote greater usage of the system represent an economically efficient use of resources. Such a conclusion requires an assessment of the magnitudes of benefits and costs. Any economic value of the geodetic input will flow from the demand for or the amount users are willing to pay for the outputs obtained by using the system.

The purpose of this project is to assess the benefit and cost streams resulting from use of the existing geodetic reference system. We are not assessing whether public expenditures should be made to establish such a system. While density and accuracy may vary, the point is that a geodetic reference system exists in all areas of the United States. Expenditures to create a geodetic reference system have already been made; these are the result of past decisions. The only relevant decisions for benefit cost analysis are those that are prospective. The relevant prospective decisions are concerned with whether or not expenditures should be made to utilize the existing geodetic system. The project is guided by the principle that economic value is a demand-initiated concept. The significance of this point is fundamental and, while often appearing to be an "academic" point when first presented, it has major implications for an assessment of economic benefits. The following implications flow from this point:

- A geodetic reference system, by itself, has no inherent economic value.
- One must look away from the system itself for any economic benefits.
- It is necessary to identify the products or outputs that are uniquely dependent upon such a system.

The fundamental implications are pursued in the context of an analytical framework presented in the next chapter.

II. Analytical Framework for Evaluating the Geodetic Reference System

This chapter develops the critical elements of the analytical framework used to identify and quantify economic benefits arising from the investment in utilization of a geodetic reference system. The essential elements include the following: (1) the role of demand in creating economic value, (2) the unique outputs or products derived from the reference system, (3) the principle of avoided costs, and (4) the demand for compatibility. This framework represents a major departure from past attempts to assess the economic benefit of a geodetic reference system.

A. Concepts and Definitions

The geodetic reference system is often loosely defined as a set of marked points whose relative locations are known. The system possesses the following features:

- A collection of permanently marked and maintained points.
- Coverage of an extensive area.
- A spatial relationship of known accuracy.
- Relationships expressed in a common mathematical language or in a language translatable into other languages.
- Universal availability of geodetic information.

Geodetic information is used for many purposes including military security and geophysical science applications. Although this study primarily addresses the utility of a geodetic reference system for civil applications, it is recognized that such a system provides benefits for military applications. The assessment of cost benefits derived from military applications is difficult because of the inherent complexity in assigning a dollar value to the worth of an adequate national defense. The details of military applications are often classified and, therefore, not available for public distribution and analysis. Although these factors preclude an in-depth analysis of military applications for this report, there are two major factors which should be noted: (1) Military applications are global in nature and receive large benefits in the production and use of a global reference system; the requirement for a global reference system has been promulgated by defense interests for many years. (2) A global geodetic reference system is essential for successful development and deployment of modern weapons systems which require both positioning and/or navigation information for their operation. These factors are beyond the scope of this investigation, but a valuation structure for these uses is attainable in much the same manner as shown in table 2 (page 5).

Our focus is on (1) engineering and construction activities, and (2) management of information for land planning and development purposes.

B. The Demand Element—The Theory

A product has economic value only if a demand exists for the product. Likewise, any inputs used to produce outputs have economic value only if a demand exists for the outputs. In simple terms, the theoretical basis for economic value lies in the economist's concept of the demand curve.

It is important to distinguish between the meaning and source of economic value and its measurement. The value of a product is based upon the utility obtained from consuming various amounts of the product. The amount of money consumers are willing to spend to acquire various amounts of the product provides a measure of this value. When a consumer voluntarily exchanges money for a product, the amount expended represents a minimum measure of the value (utility) to the consumer. Thus, value arises from the demand for the product, and the level of expenditures provides a basis for measuring this value. Expenditures reflect economic value, but do not cause value.

The demand curve illustrated in figure 1 indicates the specific quantities of a product that consumers are willing and able to purchase at various prices. The price reflects the marginal value to consumers of acquiring incremental units. In turn, the price the consumer would offer for a specific unit, indicated by the height of the curve, indicates the level of utility gained. For example, in figure 1 consumers would purchase the quantity Q_1 units at the price P_1. In order to induce consumers to purchase one additional unit, to purchase the total quantity Q_2, price must decrease to P_2. The price, P_2, indicates the maximum price, or the marginal valuation, consumers place on the additional unit Q_1Q_2. The marginal value of successive units can be identified by repeating this process. For example, the total value of the quantity Q_1Q_3 is represented by the area Q_1ACQ_3.

To appreciate the implications of the benefit cost analytical framework, the following points should be emphasized:

- The source of economic value lies in the concept of utility.

- The demand relationship expresses the level of utility.
- Price measures, or reflects, but does not cause economic value.

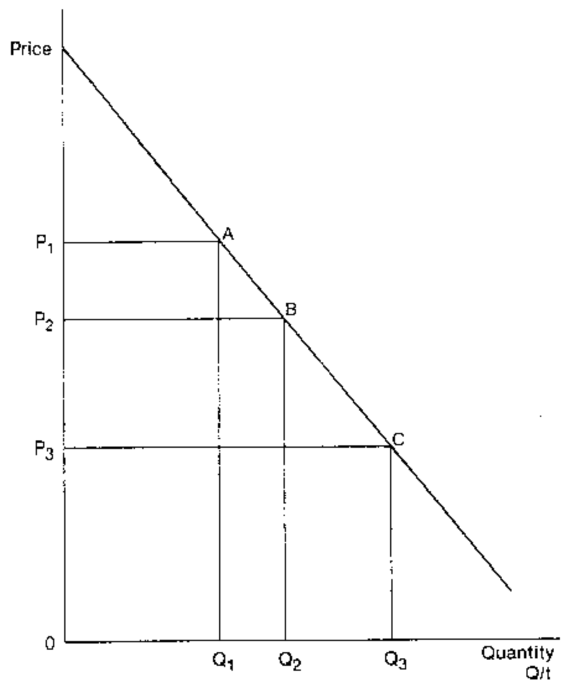


Figure 1.—The demand relationship.

C. The Demand Element—Applying the Theory

The theoretical notion of the demand relationship can be applied to the focus of our effort—an assessment of the benefit cost relationship associated with use of a geodetic reference system. Application of the concept requires the following:

- A precise definition of the unique product(s) flowing from the system, and
- Measurement of the amount (price) users would be willing to offer for amounts of these products.

In the case of a private good, such as an automobile, the task is relatively straightforward. In cases involving a public or governmental product, such as a geodetic system, the principles remain applicable, but their applications involve additional complexity.

1. A Fundamental Change in Thought and Approach

Adoption of the notion of value as being a demand-initiated phenomenon implies an approach that is very different. For many individuals, it involves a fundamental reorientation in thought. For example, discussions of economic value often incorrectly assume that value arises from production, i.e., the supply side. Implicit in these discussions is the premise that if you can do it, then it is worth doing. This reasoning often is present in arguments proposing production of a product simply because production is technically possible. This thinking is inconsistent with the notion of demand as the source of economic value. Its results are unreliable and do not serve the interests of policy makers.

With the emphasis on demand, the starting point of the analysis involves determining the products or outputs whose production is uniquely tied to the availability of the geodetic input.

2. Defining the Output from a Geodetic Reference System

It is necessary to establish a clear distinction between local and global systems as well as the outputs that each system can yield. As used here, local control refers to a reference system established for a specific site or project often with little or no emphasis on maintenance. A local control system serves two purposes: (1) to provide accurate measurement throughout the specific site, and (2) to create local compatibility across the measurements for the site and throughout the specific project to its completion. Thus, local control is site- and project-specific with its creation and maintenance tending to be short term and mainly relevant to an agency's specific mission and yielding local compatibility. In this sense, a local control system serves a limited and narrow function. A geodetic system can do all of the above but, in addition, it has the ability to do other things. The distinction is very important.

a. Spatial Information Products and Compatibility—The Joint Product Relationship

A geodetic reference system, while having a certain commonality with local systems, has the ability to yield certain unique products. Table 1 illustrates the relationship between reference system inputs and the resulting outputs.

TABLE 1
The input-output relationship by type of reference system

Input	*Output*
Type of reference system	Spatial information products
Local	Local compatibility
Geodetic	Universal compatibility

The common element in table 1 is that either type of system—local or global—has the capability of yielding spatial measurements or, in our terminology, spatial information products.

However, spatial information products based upon a geodetic reference system possess an additional and unique attribute. The individual products can be related to each other across all sites with a high degree of accuracy. We characterize this attribute as universal compatibility. Use of a geodetic system means that all resulting information products are based upon a common datum and, rather than having their compatability restricted to a local site or project, possess a universal compatibility. Universal compatibility is the condition which means that various spatial information products, representing positional location of natural and cultural features, can be related to each other with a high degree of accuracy. Such compatibility allows secondary and tertiary users to take two spatial information products that may have been produced by different individuals for totally unrelated primary purposes, such as the location of a river and an electric transmission line, and accurately depict their relative positions in a single map. (For further discussion see appendix A). Universal compatibility across spatial information products is the unique output or product resulting from use of a global control system.

While universal compatibility is often not a critical need for primary users of spatial information, it is a major need for a large and rapidly growing group of secondary and tertiary users. Such users often must be able to integrate or combine large amounts of spatial information products that may flow from a variety of sometimes unrelated, primary activities. As we will see later, it is from the secondary and tertiary users of spatial information that the demand for universal compatibility and, hence, economic value arises.

Past attempts at benefit estimation have focused on horizontal and vertical measurements as information products. We do not see this as the unique output from the global reference system. The major reason is that such a system is generally not necessary to generate spatial information products, per se. Technically, the measurements can be produced by using a local control system, usually at lower cost. It is difficult to make a convincing case that the production of spatial information products requires a geodetic reference.

b. Local vs. Universal Compatibility—An Illustration

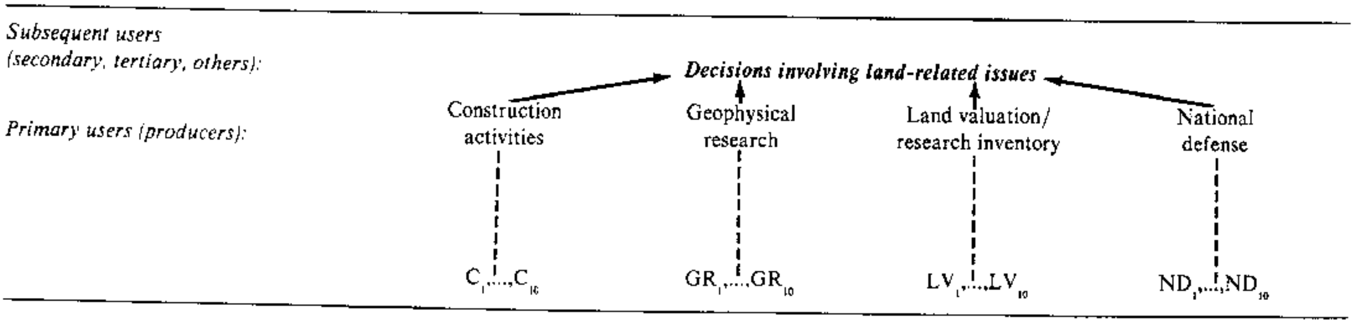
The following section expresses and illustrates the essence of the analytical approach employed in this project. At this point, we have established the demand for universal compatibility across spatial information products as the source of economic value attributable to a geodetic reference system. In addition, the major source of this demand has been identified as coming from groups of secondary and tertiary users of spatial information. Table 2 shows this configuration. Its usefulness in understanding the generation of economic value attributable to the geodetic input cannot be underestimated.

Table 2 illustrates a variety of applications, and is not intended to be a complete representation of usage. The four columns of the table indicate primary activities and/or organizational entities that generate and/or utilize spatial information products. Although the material is arranged vertically, we recognize that, in reality, there are overlaps and connections between the four activities. As a means of simplifying the exposition, we have assumed that, in each primary activity, ten spatial information products are produced. For example, in the case of construction activities, $C_1,...,C_{10}$ represents the individual information products used in decision-making for construction.

Our observations as to how real world needs for spatial information are satisfied can be illustrated by reference to table 2 and the construction column. The typical pattern is that spatial information needs for construction activities, represented by $C_1,...,C_{10}$, are produced in a manner and context mainly, if not solely, determined by the primary mission—construction. This should not be surprising. The typical highway department produces the necessary information by using a local reference system capable of yielding the degree of accuracy and compatibility required for its purposes. Consequently, information products $C_1,...,C_{10}$ will be compatible but only for the specific site or project. This scenario tends to be repeated in the other cases. Individual activities or organizations generate the type of spatial information needed for their specific mission, which means that such data tend to be compatible on only a local basis. Each primary activity has little need to draw upon spatial information products generated by others. In other words, each primary activity tends to be insulated and has little reason to be concerned with what we describe as universal compatibility. This is a logical outcome of an organizational structure. The need for universal compatibility does not tend to be a pressing concern within a specific primary activity.

The demand for universal compatibility arises mainly from a set of activities and decisions that require vast amounts of diverse types of spatial information cutting across a large number of primary activities. These uses represent secondary or tertiary uses of the original information products generated within each primary activity. In table

TABLE 2
Relationship between primary producers and users of a geodetic reference system and demand for universal compatibility in spatial information



2, the columns under "Decisions involving land-related issues" list the need of secondary and tertiary users for utilizing spatial information products generated from various primary activities. The ability to integrate and combine these products requires the presence of universal compatibility.

In practice, conflicts often emerge in planning the production of spatial information with the attribute of universal compatibility. Primary activities often produce spatial information only sufficient to meet immediate needs with little or no consideration of secondary or tertiary usage. Our focus is on the demand for compatibility arising from decisions of nonprimary users as indicated in table 2. This is the origin of the demand for a geodetic reference system to make spatial measurements. The spatial information generated by the system ensures that the needs of those operating within a single activity or organization will be met and, most importantly, the information products generated by each activity can be subsequently utilized by secondary and tertiary users.

When a geodetic reference system is used to produce information products $C_1,...,C_{10}$ and $LV_1,...,LV_{10}$, etc., users needing to combine data from each set can proceed without additional adjustment or expenses. For example, if a secondary user needed an information product defined as C_2LV_8 use of a geodetic system ensures that the two elements can be easily combined with a high degree of accuracy.

While local compatibility may be totally adequate for decisions in a single primary activity, users at a higher level of aggregation who must be able to relate independent sets of information would find that the data cannot be used in existing form. These users require the presence of universal compatibility—a characteristic imparted by use of a geodetic reference system to make site or project specific measurements.

Thus, the unique product is universal compatibility. Previously, we emphasized that economic value flows from the demand for the output or product. In this context, the benefits attributable to the investment in a geodetic system will flow from the demand for universal compatibility. The following major points have been made:

- The economic value of a geodetic reference system is found in the unique product it yields.
- The unique product is universal compatibility.
- Demand for universal compatibility arises mainly in the case of secondary and tertiary users of spatial information products.
- Agencies and organizations that initially produce much of the spatial information tend to have little concern for the need of universal compatibility by secondary and tertiary users.

D. Land-Related Decisions—The Process

Land planning and development activities have a number of phases, each requiring a significant number of decisions. The process appears to be divided into a small number of phases, each ending in a major decision. Within each phase is a subset of decisions requiring spatial information products, enabling decision makers to assess risks. This type of land-related decision-making is depicted in figure 2 as the origin of the demand for universal compatibility.

Figure 2 begins with the need for spatial information products having universal compatibility. Decision makers must assess the adequacy of existing data files for decision-making. If existing files were originally based upon a geodetic reference system, the most likely answer is yes, and further data collection costs are not necessary. In the case of a negative response, either because the data do not exist or the data are not based upon a geodetic system, the decision maker's needs can only be satisfied at additional cost. The point that the failure to base spatial information products on a geodetic system can cause secondary and other users to incur additional costs to meet their needs is crucial. The fact that initial use of such a system leads to avoidance of these costs will be seen as a basis for quantifying economic benefits.

Finally, the following points are emphasized:

- The demand for universal compatibility by those who are not surveyors, mappers, or geodesists is extensive.
- This demand, arising from a vast number of land-related decisions, appears to be expanding.

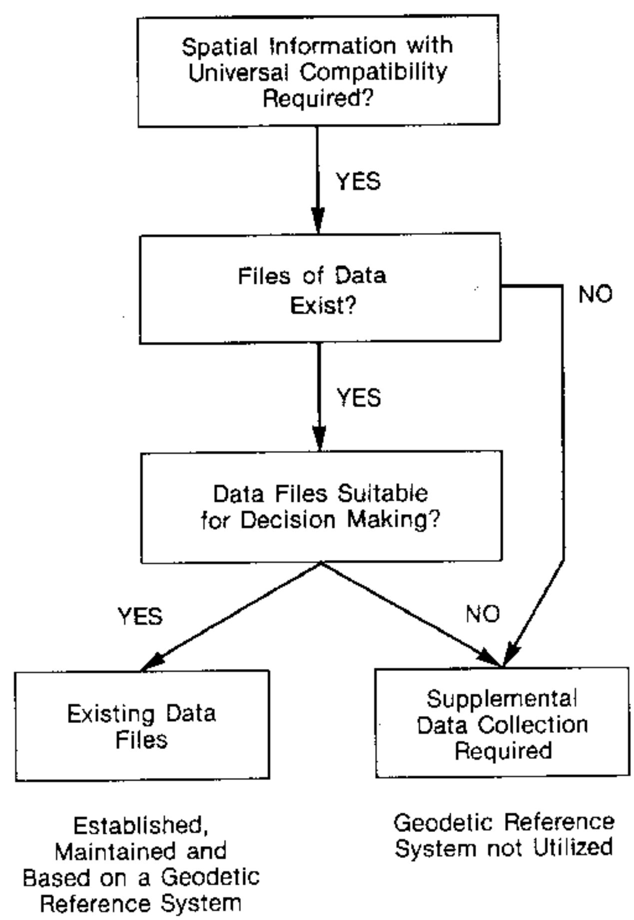


Figure 2.—The land-related decision process.

- These decisions require the integration or combination of large amounts of diverse information.
- Integration of such information can be accomplished without additional cost when a geodetic reference system is the basis for the information.

The following section discusses how the use of a geodetic reference system leads to cost avoidance (benefits).

E. Avoided Costs: The Benefit Stream

Measurement of economic value is reflected by the amount of money consumers would be willing to expend to acquire various amounts of a product. In the case of a private product, market transactions provide the basis for quantification of value or benefits and the demand relationship can be estimated. In the case of a governmental product, such as a geodetic reference system, the principle is the same, but market transactions are not available to serve as a means of identifying the demand curve. Alternative means must be used to quantify the benefit stream flowing from the system.

1. The Basic Principle

Our analytical approach rests upon a basic principle: the benefits generated from a government operation can be represented by the costs avoided as a result of the operation. These savings are properly interpreted and treated as benefits. The rationale, in terms of demand and expenditure, is that one would be willing to pay an amount equal to the cost savings in order to obtain the savings. The magnitude of the avoided costs, while not reflecting the complete demand relationship, represents a minimum estimate of economic benefits.

The principle of avoided costs can be applied to our research interest—estimating the economic value of using a geodetic reference system. Assume that a particular decision must be made and that it requires spatial information indicating the position of three physical features. Most importantly, the decision requires the three pieces of spatial information to be combined and expressed in a manner that allows the user to relate each feature to the others by placing the information on a single map. In other words, the three pieces of information must be universally compatible and capable of being placed in a single information file.

The manner by which a geodetic system leads to cost savings (benefits) is illustrated by contrasting two situations: (1) the three pieces of information mentioned above exist and are based upon a geodetic reference system; and (2) the information exists, but each information product is based on a separate and unrelatable reference system. In the first case, universal compatibility exists. But in the second situation the information products lack universal compatibility. The needs of the decision maker can only be satisfied by incurring additional costs to attain the required compatibility. However, these additional costs are avoided in the first situation where a geodetic reference system was originally used to generate the three information products. Thus, they represent part of the benefit stream attributable to a geodetic reference system. The avoided costs are properly viewed as a minimum estimate of the benefit stream.

2. Implications of the Benefit Cost Framework

The following discussion attaches a more operational meaning to the framework. However, we want to emphasize that use of a benefit cost framework to assess the value of a geodetic system leads to a dramatic change in the traditional perspective. In this context, the system is viewed as an input with its economic value dependent upon the demand for its output.

The perspective of previous studies, such as those conducted by Philip Johnson[1] and Duane Brown[2], viewed a geodetic control system as a self-contained unit with no systematic search for the unique ouputs obtainable from the system. This led to a limited search for economic benefits. In Johnson's analysis, the major benefit resulting from greater density of the system was identified as the savings in traverse time and lower costs in bringing control into a specific site. Such savings are important, but require careful interpretation as to whether they represent an economic benefit.

In our model, traverse time is viewed as simply another input or cost of using the reference system to produce an output. Any cost saving due to greater density simply reduces the denominator of the benefit cost ratio, i.e., reduces the cost of producing the output. In other words, a saving in traverse time is not an output of a geodetic system and these cost savings are not properly viewed as benefits. The input-output framework leads one to focus on the output (universal compatibility) as the point at which benefits are created. Prior analysis, by failing to distinguish between inputs and outputs (supply and demand elements), failed to identify the most important sources of benefits (secondary and tertiary users) attributable to a global reference system. Our framework incorporates the findings of Johnson and Brown, but changes the perspective from a point-specific focus to a focus on a system and the demand for the system output.

3. The Policy Issue Under Discussion

The basic issue is not whether a geodetic control system should be created, nor whether the existing system should be densified to some specific level. A global system already exists in every area of the country. The density of the existing system may vary regionally but a system exists. The point is that the expenditures to create a geodetic system are, in

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[1] Philip C. Johnson, A Measure of the Economic Impact of Urban Horizontal Geodetic Control Surveys, M.S. thesis, Cornell University, 1972, 113 p.

[2] Duane C. Brown, Densification of urban geodetic nets, *Photogrammetric Engineering and Remote Sensing*, 43, 1977, 447-467.

every sense of the word, a sunk cost. The expenditure is history.

The relevant costs for policy debate are those that can be controlled, namely the costs of maintaining and using the system. The basic issue focuses on the benefits and costs resulting from utilization of the existing system. What are the magnitudes of the benefits arising from using the system to produce universal compatibility and the costs incurred to obtain this output? The magnitude of benefits relative to costs indicates whether the expenditures represent an efficient use of scarce resources.

F. Summary

This chapter defines the critical elements of the analytical framework used to identify and assess the benefits arising from the existence of a geodetic reference system. The following major points have been established:

- Economic benefits arise from the demand relationship.
- Universal compatibility is the unique product obtained by use of a geodetic reference system.
- Universal compatibility allows secondary and tertiary users of spatial information products to integrate individual products without additional expense.
- The relevant policy issue concerns the benefits and costs of using an existing geodetic reference system, not whether such a system should be created.

The remaining chapters describe the results of an application of the preceding framework to assess the actual flow of benefits and costs in a particular case study.

III. Case Studies in the Production and Use of a Geodetic Reference System: Observations and Conclusions

Case studies are designed to examine concepts and theories. The concept to be examined is that of an information transfer process. Specifically, these case studies are designed to examine the process by which agencies convert investments in a geodetic reference system into information that satisfies their needs and the needs of land planners, developers, and decision makers. Stated alternatively, the goal of these case studies is an understanding of the process by which a geodetic reference system is created, used, maintained, and promoted.

A. Introduction

This report covers four case studies in three categories. Each category emphasizes a major land activity which relies upon data from a geodetic reference system. The three categories are highway construction, local and regional planning (including the activities of a regional planning commission and a county mapping agency), and private land development. These choices were based upon a priori assumptions about land activities that are important and likely to generate use of a geodetic reference system.

The case studies consider a variety of land related activities. For example, highway construction involves both production and use of reference system information. By contrast, private land development emphasizes use of an existing system. Local and regional planning generates as well as uses reference system information.

Several factors were examined in each case study. These include the following:

1. Important activities that lead to creation of a geodetic reference system.
2. Decision makers.
3. Quality of information required by decision makers.
4. Quality and nature of the geodetic reference system.
5. Information required by planners, developers, and decision makers.
6. Alternative sources of required information.
7. Products that depend on the reference system.
8. Use of the system by people other than those who established it.
9. Incentives to maintain the system.
10. Incentives to disseminate information about the reference system.

The case studies vary in the extent of their constituencies. Highway construction, defined for purposes of this study to extend through completion of the design phase, generally involves a narrow constituency from several public agencies with some public involvement. In contrast, planning involves a broad constituency from both the public and private sectors. Private land development concerns a constituency which tends to be narrow, mainly in the private sector, with public agencies involved at some stage of the process.

The case studies are also specific examples of the information transfer process. They elucidate the relationship between geodetic control information producers and control information users. They reveal patterns by which control information, produced in one activity, such as highway construction, is used or ignored in other activities. Appendix B discusses these case studies in detail.

B. Summary of Case Study Findings

The examination of the information transfer process concept reveals several characteristics unique and yet common to each case study as may be seen in the following findings:

1. Planning, development, and construction activities involve several phases by public agencies, private companies, and individuals. Each phase is characterized by a major decision and by demands for spatial data of greater accuracy and compatibility as the activity progresses towards completion.
2. Land-use activities require a variety of land data to satisfy the regulatory and environmental process. This process generates the most significant demand for land data and information.
3. Land data are usually obtained from a variety of sources. These data must be accurate and compatible to a degree that satisfies public or private decision makers.
4. Decision makers rely on two land data sources. One source is the existing data files; the other is supplemental field measurement. The ad hoc field measurement process is universally regarded as labor intensive and expensive.
5. Organizations often establish control for site-specific accurate measurement and data compatibility when their primary mission is facility construction. These organizations eventually confront the task of

integrating their site-specific information with information held by others in the course of the regulatory and environmental process.

6. Organizations that produce a facility or product as their primary mission find it difficult to divert resources to programs that (a) emphasize the integration of site-specific control into a geodetic reference system, and (b) effectively promote the general use of systems they have established. Therefore, they and others are unable to exploit fully the opportunities afforded by the original investments.

7. Organizations concerned with extensive land planning and development perceive creation and maintenance of a geodetic reference system as a significant and often essential aspect of their regular activity.

IV. The Value of a Geodetic Reference System: Methods

Land data and information are used at all levels of government and in the private sector. The demand for data and information is part of the process of land planning, development, administration, and investment. This process requires the assessment of risks associated with decisions involving land use.

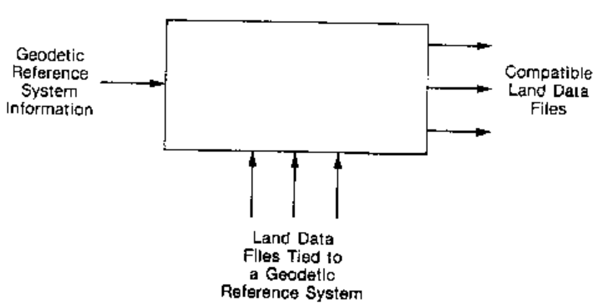
A. Introduction

The demand for land data and information to satisfy a risk assessment establishes an information transfer process. In some instances the transfer process results in the establishment of a geodetic reference system.

The satisfaction of a demand for data and information is the necessary element in a method that measures the benefits of investment in a geodetic reference system. The demand for data and information gives value both to the data and information and to essential ingredients, such as a geodetic reference system which contributes to the existence of the data and information.

It is necessary, but not sufficient, that a geodetic reference system contribute to the satisfaction of land data and information demands. For the geodetic reference system to have value it must provide an essential ingredient which is only obtainable at greater cost by other means.

A geodetic reference system designed to produce compatible files of land data in an information transfer process is represented as follows:



The attributes of a geodetic reference system are:

1. Density
2. Accuracy
3. Spatial extent
4. Use of a common spatial language
5. Operational effectiveness

The attribute which a geodetic reference system alone contributes to existing land data is the means to achieve compatibility of otherwise independent data files. A geodetic reference system imparts compatibility to spatial data that extend over an extensive area. Thus, investment in a geodetic reference system is for the purpose of satisfying a demand for existing, spatially extensive, accurate, and compatible data.

The benefits of an investment in a geodetic reference system can be identified and measured when the system provides compatible land data files at a cost less than provided by other methods. If these files exist and are compatible because of the geodetic reference system, then a benefit is derived when the avoided cost of obtaining compatibility by expensive ad hoc processes is greater than the cost of creating and maintaining the files.

Each local jurisdiction (State, region, county, municipal) and each Federal agency make planning, development, and investment decisions based on their own standard of acceptable data quality for "good professional planning." The standards depend upon the characteristics of the jurisdiction or individual or agency. These characteristics include tradition, population size, population heterogeneity, growth, wealth, and other factors. What matters is that each has a particular standard. At worst, some rely on available data of unknown or poor quality. Others demand accurate data of known compatibility before decisions are made.

Whatever the community or agency standard of data quality, there is an existing information or geodetic reference system. If the system is limited in extent or quality, then it provides few benefits in the form of avoided field measurements. Data are obtained ad hoc.

When a community or an agency demands low risk decisions based upon good data and information, then the question of investment in a geodetic reference system is necessary as well as appropriate.

The issue for each community, agency, or citizen is the following: what is the most effective means to achieve a desired standard of good planning if good planning means decision-making based upon accurate, compatible data? What investment in an improved geodetic reference system is justified by the avoided costs when decisions can be made from existing data files rather than by ad hoc field measurements?

B. Measuring Benefits: A Model

Measuring the benefits of a geodetic reference system begins with an inventory of major planning, development, and construction activities which create a demand for compatible, accurate spatial information. These activities typically include the planning and design phases of construction projects, watershed and flood hazard management, and local and regional land use planning and development by the public and private sectors.

Measurement requires determination or prediction of the rate R_i of various major planning and development activities. R_i is the rate of a major activity, typically on an annual basis.

Each activity is characterized by several phases, each of which requires compatible data for decision-making. For example, the first phase of a watershed management plan seeks to identify alternative actions, each alternative described at the same level of detail, and concludes with the selection of one alternative. If the jurisdiction chooses to proceed, a second phase follows consisting of characterization of the alternative to a degree sufficient to acquire regulatory permits and provide the basis for physical construction. Each phase of a major activity consists of a set of decisions requiring spatial information.

Finally, those land-planning and development decisions which require compatible land data based upon a geodetic reference system must be identified and distinguished from decisions which do not depend on such a system. For purposes of our model, a decision is considered to either require or not require compatible data produced from the system-dependent files. Thus the rate of land-related decisions that depend on compatible data is:

$$\sum_{i} R_i \left[\sum_{jk}\sum C_{jk}\right]$$

where C_{jk} = 0 for decisions which do not depend on compatible data,
= 1 for decisions which depend on compatible data based on a geodetic control system.

The terms i, j, k index the activities, phases, and decisions, respectively.

Decisions which do not require compatible data from the files generated by an investment in a geodetic control system (e.g., $C_{jk}=0$) are characterized as follows:

1. Decisions made from available data files produced by agencies other than the agency which invested in the control and data system. Data produced by other agencies (e.g., U.S. Geological Survey Quadrangle Maps) provide benefits to many users. These benefits can be ascribed to the investments made to produce these products. However, a jurisdiction is interested in decisions that utilize compatible data produced from its investments.
2. Decisions which require the ad hoc collection of data. These decisions require data with accuracy and compatibility greater than the jurisdiction considers to be a reasonable basis for decision-making. The attitudes of the citizens and officials have placed an upper limit on the quality and compatibility of data that will be obtained and maintained systematically.
3. Decisions based on land data that do not require compatible data. There are land features that are measured accurately and used without reference to other features. If topography is used for decision-making without reference to other features, then there is no demand for a geodetic reference system to support compatibility of topographic measurements with measurements of other features.

For these classes of decisions, no benefits in the form of avoided costs can be attributed to the incremental investment in a geodetic reference system by a jurisdiction. These decisions do not rely upon the reference system.

Decisions based on files of existing data made compatible through a geodetic reference system form the class of decisions for which $C_{jk}=1$. It is these decisions which generate benefits because they are made without further need to collect data by expensive, ad hoc field measurements.

The benefits of a geodetic reference system, measured by its ability to avoid ad hoc measurements, are compared with the costs of the system. These include the costs for creation and maintenance of the reference system itself and for the field measurements necessary to make existing data compatible. These latter costs exist because there are chosen limits to the system's density and accuracy which make field measurements necessary in order to achieve compatibility when data files are updated.

The model for evaluation of the investment in a geodetic reference can be summarized as follows:

$$\textbf{Benefits/Costs} = \frac{\sum \left(\begin{array}{c}\text{Costs to create data compatibility, which}\\ \text{are avoided because of the geodetic}\\ \text{reference system}\end{array}\right)}{\sum \left(\begin{array}{c}\text{Costs to create, maintain, and use the}\\ \text{geodetic reference system, which makes}\\ \text{data compatibility possible}\end{array}\right)}$$

The numerator in this expression is actually a double summation. The interior summation takes into account all the avoided measurement costs for those decisions within each activity requiring compatible data.

There are three specific cost-generating factors in the denominator. They are the cost to create, maintain, and use a specific geodetic reference system.

The first term in the denominator is a sunk cost. The annual investment value of the sunk cost approaches zero as the lifetime of the system increases. The decision to create and maintain a geodetic reference system is part of the decision to plan with accurate, compatible data. If data are to be available when needed, then there must be a geodetic reference system which is maintained.

The second term represents the periodic investment necessary to maintain the geodetic reference system.

The final term in the denominator depends upon the system density and accuracy. Each system, because of its characteristics, imposes unavoidable field measurement costs when the files of data are created and maintained for future use. The greater the reference system density and accuracy, then the less the cost of creating data file compatibility. Increased reference system density and accuracy are not seen as a benefit but represent lower costs of operating an information system that satisfies the demand for decision-making data.

C. Testing the Model

The methodology has been tested in an area that invested in a geodetic reference system and uses it to sustain an information system for local planning and development. The area has the following characteristics:

- It is comprised of a regional planning commission encompassing several counties and municipalities.
- It is within the Public Land Survey System.
- It encompasses more than 2,000 square miles.
- It has an economy reasonably balanced between industry, commerce, and agricultural activity.

Many of the local jurisdictions within the area have:

- resurveyed, remonumented, and established geographical coordinates for a significant proportion of the Public Land Survey System corners and quarter-corners.
- used the resurvey maps to prepare large scale maps for an extensive portion of the area.
- developed accurate, compatible data files based on the geodetic reference system.
- used existing, compatible data files for land planning and development decisions.
- developed common regional standards of data quality for decision-making.

The area is balanced economically in that there are important industrial and commercial activities as well as extensive agricultural areas. There is a major city with more than one million people and several smaller cities with more than 100,000 people. Population growth and economic development are moderate.

While the area is typical in many ways, it is not typical in the degree of reliance on good data for land planning and development decisions. Many local governments have invested in a geodetic reference system according to an area-wide common standard and produced spatial information products with the prospect, often realized, of avoiding costly ad hoc field measurements.

Officials and citizens in the test area distinguish between "local control" and a regionally coordinated geodetic reference system. Local control is site- or project-specific, often not maintained, and the basis for site-specific accurate measurement and site-specific data compatibility, with little concern for compatibility with data from other sites. Often local control is a basis for the typically vertical activity in an agency or corporation.

The regional geodetic reference system is considered to be "global" in the sense that it is the basis for accurate data files that are compatible over the region. The area-wide or "global" system is seen as a basis for satisfaction of horizontal demands that extend across agencies.

The attitude towards and use of spatial information based on a geodetic reference system throughout a region of several counties engenders ideal circumstances for a test of the model.

The valuation methodology has been applied to the case study jurisdiction. The process involved steps applicable to any jurisdiction or agency that considers investment in land information and the requisite geodetic reference system.

D. Application of the Model to a Test Area

Application of the valuation model and data gathering involves the following:

1. Identify major activities in the jurisdiction that require extensive and/or accurate spatial information for land decision-making and the rate of these activities.
2. Characterize the decisions that are a part of the activity. Identify decisions pertaining to land features that are made with accurate, compatible data.
3. Identify those decisions that require a combination of land feature data.
4. Identify the features for which the jurisdiction maintains existing files of accurate, compatible data that can be combined without further significant measurement into a spatial information product that satisfies community standards for decision-making.
5. Estimate the avoided costs of field measurement each time a satisfactory combination of compatible data files is used for decision making instead of an ad hoc field measurement to establish compatibility.
6. Estimate the costs of reference system maintenance and the costs imposed because the chosen system density and accuracy require field measurements to maintain compatibility among existing files.

For the case study area the regional planning commission director identified the following as major activities which are frequent and/or require accurate, compatible data:

- Land-use and community development plans
- Watershed and related water studies
- Facility construction, especially highway construction

Land-use and community development plans project future land use based upon current conditions, projected changes in population and uses of land, and the physical capacity of the land. The process requires several distinct combinations of land feature data. For example, the suitability of soils for various uses is a question that arises frequently in planning and is answered by a specific combination of land feature data drawn from existing, compatible files.

Land-use and community development plans require answers to a list of questions and the combination of features relative to each question as shown in the following table:

Land-use and community development plans

Question	*Features*
Topography and surface drainage	Topography Wetlands Roads Buildings Sewers (sanitary and storm) Water supply
Soil suitability	Soils Parcel boundaries Buildings Topography Wetlands
Existing land use	Parcel boundaries Land cover (woodlands, etc.) Wetlands Soils
Zoning	Parcel use Environmental corridors
Community utilities	Water supply Sewers (sanitary and storm) Wetlands
Community facilities	Parcel boundaries Boundaries for schools, parks, etc.
Roads	Roads Geodetic reference system
Property	Parcel boundaries Building locations Easements

For watershed and related water studies the goal is to plan for flood hazard management and to mitigate drainage problems in consideration of community and regional and land-use plans.

The following features are routinely considered and data combined from existing files for a watershed study:

Topography
Surface water
Soils
Land use
Land cover—woodlands, etc.
Natural areas—wildlife habitat, etc.
Water supply
Sewers (storm and sanitary)
Community facilities
Wetlands
Roads
Wastewater sources
Parcel boundaries
Building location
Easements
Precipitation
Population

For facility construction, especially highway construction, several issues arise. These include centerline location, grade and topography, right-of-way location, parcel boundary location, land use, building location, natural areas, and environmental corridors. Several of these issues are resolved by appropriate combination of accurate, compatible data.

Highway construction is not the responsibility of the regional planning commission or local governments. State and Federal agencies involved in this process within the test region rely extensively upon the files of accurate, compatible data created and maintained by the commission and local governments. However, these highway agencies have not typically maintained records of both the land feature data combinations and the source of these data for the various decisions that are made. Thus, we are unable to include this stream of decisions in the benefit analysis based upon existing data made compatible as a result of the geodetic reference system. We are assured by State highway department people that such data are used, but they do not have the retrospective records that indicate quantitatively the use of such data. Thus the estimate of the benefits of the geodetic reference system is low because it lacks the contribution of avoided costs associated with highway construction.

The benefits of a geodetic reference system are obtained when: (1) decisions require spatial information products that are an accurate combination of land feature data, and (2) a combination of land feature data from existing files is made without considerable resort to field measurements. The benefits are therefore the avoided costs of field measurements necessary to create the desired compatibility of land feature data.

The costs of a geodetic reference system are those for establishment and maintenance. In addition there are costs imposed by the system because the specific choice for density and accuracy results in field measurements necessary to maintain compatibility between existing data files.

E. Data Collection

The calculation of avoided costs generated by an information system built upon a geodetic reference system is based upon a comparison with the situation where land feature maps or files exist but are not compatible (or are not compatible to the degree desired) because they are not tied to a geodetic reference system. In this situation two possible types of ad hoc measurements must be made. These differ because an independent existing file, which is tied to its own control system, involves one of the following circumstances:

1. The original control is no longer available because it was not maintained or was specifically designed not to be permanent; or
2. The original control is available (as in the use of site-specific control), but is not tied to the geodetic reference system.

Both circumstances require field measurements in order to establish compatibility. The former situation involves more measurement than the latter. Thus, the benefits from a geodetic reference system constitute a range which depends upon the mixture of circumstances that exists in a jurisdiction regarding the control systems upon which the existing files were built.

Consider existing topographic data that were generated from local control data rather than from geodetic reference system data. It is now desired to combine the topographic data with other land feature data. There are two possible circumstances:

1. The original local control is gone because it was not maintained or was temporary by design. The topographic features must now be integrated into the ground configuration. This requires the activities of ground survey, aerial photography, and computation and drafting based upon a photogrammetric model.
2. Some portion of the original local control remains. The necessary tasks are then to connect the remaining local control to the geodetic reference system by ground control and to recompute and draft the results to produce the new spatial product. It is typically not necessary to repeat the photogrammetric modeling.

Jurisdictions in the test area rely upon the existing, compatible data to avoid the cost of field measurements. The cost of these avoided measurements must be estimated. Estimates are made for both of the situations described above. These situations represent the upper and lower limits of the avoided costs. The upper limit is the avoided cost if the jurisdiction had data files but control was no longer available. The lower bound is for the situation where all the independent files are tied to the local control system.

Estimates of the avoided costs of field measurement are made for the test area based upon the following resources:

1. Identification by local personnel of major activities that require and use existing compatible data.
2. Estimates by local personnel of the annual rates of major activities in the area.
3. Planning documents as retrospective records of actual data use.
4. Planning documents and interviews with local officials to determine decisions made with spatial information.
5. Interviews with surveyors, mappers, and photogrammetrists to estimate the cost of avoided field measurements that would be necessary to produce compatibility of the existing data.

The general problem of estimates is illustrated by the example of topographic data. For the limiting case where topographic data exist (often in the form of a topographic map) but nothing remains of the local control used to generate the data, measurements must be made that tie the topographic data to the geodetic reference system. All data must be tied to the system. This problem occurs in the process of ground survey, aerial photography, modeling and plotting. For the limiting case where the topographic data exist and some or all of the local control remains, measurements must still be made but less effort is required. Although no aerial photography is required, ground surveying and some computation and redrafting are necessary.

We have estimated the avoided costs of obtaining compatibility for the set of independent, compatible files typically maintained and used by jurisdictions in the test area. Clearly there is a range of estimates that depends upon the measurement techniques employed and the accuracy desired. We have assumed the use of current, standard surveying and photogrammetric techniques. In addition, we have assumed the high standards of data accuracy and compatibility demanded by the jurisdiction that serves as our example. An indication of these standards is given by the fact that the area has established the geographical coordinates of corners in its Public Land Survey System to an accuracy corresponding to traditional second-order standards. The jurisdictions typically prepare base and thematic (land feature) maps for the decision-making process.

The following table contains cost estimates using methods described in the example for topographic data and applying the standards of the test area. Appendix C provides further explanation.

Estimated cost of making land feature data compatible (Costs expressed in $/sq. mile)*

Feature	*Original control destroyed*	*Cost*	*Original control recoverable*	*Cost*
Topography	Aerial photography	$200	Ground survey	$400
	Plot (model)	1,200	Compute, draft	400
	Ground survey	400		$800
		$1,800		
Roads	Aerial photography	200	Ground survey	400
	Plot	200	Compute plot	200
	Ground survey	400		$600
		$ 800		
Sewers (storm and sanitary	Ground survey	400	Ground survey	200
	Compute and draft	100	Compute and draft	100
		$ 500		$300
Parcel boundaries (Registry work done)	Ground survey	2,600	Ground survey (compute)	100
	Graphics	200	Graphics	200
		$2,800		$300
Building location	Aerial photography	200	Ground survey	400
	Plot	600	Compute, plot	200
	Ground survey	400		$600
		$1,200		
Easements	Ground survey	2,600	Ground survey	200
	Compute, graphics	200	Compute, graphics	200
		$2,800		$400
Soils**	Graphics, plotting	$ 200	Graphics, plotting	$200
Wetland				
Land uses				
Environmental corridors				
Surface water				
Ground water				
Land cover				
Others				

* Cost estimates are concensus figures based on industry fee schedules.

** These and other features are ambulatory. The major effort to maintain these files is field measurement. The indicated values are the avoided compatibility costs when data about features are regularly maintained in compatible form.

For land-use and community development plans, the following combinations of land feature data are routinely made within the test area jurisdictions:

Land-use and community development plans
(Costs expressed in $/sq. mile)

Decision	Features combined	Avoided costs: High	Avoided costs: Low
Topography and surface	Topography	$1,800	$800
	Wetlands	200	200
	Roads	800	600
	Buildings	1,200	600
	Sewers	500	300
Soil suitability	Soils	200	200
	Parcel boundaries	2,800	300
	Buildings	1,200	600
	Topography	1,800	800
	Wetlands	200	200
Existing land use	Parcels	2,800	300
	Land cover	200	200
	Wetlands	200	200
	Soils	200	200
Zoning	Parcel use	200	200
	Environmental corridors	200	200
Community utilities & facilities	Water supply	500	300
	Storm sewers	500	300
	Sanitary sewers	500	300
	Wetlands	500	300
	Parcel, park and school boundaries	2,800	300
	Roads	800	600
Property	Parcel boundaries	2,800	300
	Buildings	1,200	600
	Easements	2,800	400
Total avoided costs, including all decisions and combinations		$26,900	$9,300

Each combination for a particular decision must be considered even though features appear several times in the entire process. The process demands a set of independent decisions, each involving an independent set of combinations. These independent decisions are used in decision making with the ultimate goal of a land use plan. Because each combination must be made independently, it thus generates an independent set of avoided costs.

For watershed studies, a single combination involving a large number of features must be made. This list and the avoided costs follow:

Watershed studies
(Costs expressed $/sq. mile)

Features	High cost	Low cost
Topography	$1,800	$800
Surface water	200	200
Ground water	200	200
Soils	200	200
Land use	200	200
Land cover	200	200
Environmental corridors	200	200
(e.g. natural habitat)	200	200
Water supply	500	300
Sewers—storm	500	300
Sewers—sanitary	500	300
Community facilities	2,800	300
Wetlands	200	200
Sewers	200	200
Roads	800	600
Wastewater sources	200	200
Precipitation	200	200
Parcels	2,800	300
Population	200	200
Buildings	1,200	600
Easements	2,800	400
	$16,100	$6,300

For facility construction, especially highway construction, no data were available because records are not maintained which would have allowed a calculation.

F. Calculation of Benefits and Costs

We are now able to calculate the avoided costs of field measurements to create compatibility for the major activities. These avoided costs are the benefits from utilizing the geodetic reference system.

The director of the regional planning commission estimates that the commission prepares land-use and community development plans for local units of government at a rate of about 36 square miles per year.

Watershed studies are done for entire watersheds and project conditions for a 15- to 20-year period. Based on the number of watersheds completed and their area, the commission prepares studies at a rate of 120 square miles per year.

Benefits = Σ (avoided costs for planning, watershed, and construction activities)

$$\text{Benefits} = [(\text{rate})\ (\text{avoided costs for planning activities}) + (\text{rate})\ (\text{avoided costs for watershed activities}) + (\text{rate})\ (\text{avoided costs for construction activities})]$$

$$= [(36\ \text{mi}^2/\text{year})\ (26{,}900/9{,}300\ \$/\text{mi}^2) + (120\ \text{mi}^2/\text{year})\ (16{,}100/6{,}300\ \$/\text{mi}^2) + \ldots]$$

The costs of using the system consist of two terms: geodetic reference system maintenance costs, and the unavoided costs of creating compatibility imposed on the information system because of the choice of density and accuracy for the reference system.

Geodetic reference system maintenance costs are estimated from data obtained from the county surveyor in a county that has resurveyed, remonumented, and coordinated the Public Land Survey System corners and quarter-corners. Corners are connected to the first-order National Geodetic Survey network. Based on data provided by the county surveyor, the costs of maintaining the coordinated corners is approximately $80 per square mile per year. Not all of these maintenance costs are direct public costs. About two-thirds is borne by public and private groups identified by the planning commission, the county surveyor, and others responsible for corner destruction. The commission and the surveyor take positive action to monitor actions that lead to reference system damage and recover restoration costs from offending parties.

The costs of using the system imposed by the density and accuracy of the reference system can be estimated. This can be done because the jurisdiction maintains the reference system and periodically updates dependent files. The updating process involves aerial photographs, feature idenfication, and plotting. Ground activities are unnecessary except those minimally necessary to flag ground points. We estimate these avoided costs as $2,000/mi² for each updating process, which typically occurs in 5-year intervals.

The geodetic reference system established to support these planning and related decisions now covers about 1,344 square miles. Thus:

$$\text{Costs} = \begin{pmatrix}\text{reference system}\\ \text{maintenance costs}\end{pmatrix} + \begin{pmatrix}\text{unavoided use}\\ \text{costs}\end{pmatrix}$$

$$= (1{,}344\ \text{mi}^2)\ (\$80/\text{mi}^2) + (1{,}344\ \text{mi}^2)\ (1/5)\ (\$2{,}000/\text{mi}^2)$$

Finally, the ratio of benefits to costs is:

$$\frac{\text{Benefits}}{\text{Costs}} = 4.5/1.7\ (\text{upper limit}/\text{lower limit})$$

These estimates of the benefits of investment in a geodetic reference system to support land decision-making are low for several reasons. First, data are unavailable for the process of transportation facility development. Second, records are unavailable for retrospective analysis of data utilization by local government at local levels. We have relied entirely on records based on efforts made on behalf of local governments by the regional commission. Missing data can only be obtained prospectively, based upon new recordkeeping.

G. Summary and Conclusions for the Test Area

A methodology designed to measure the benefits of investment in a geodetic reference system has been developed. The analysis reveals that the context for obtaining the benefits is the demand, especially but not exclusively, at local levels of government for accurate compatible data in the process of land planning and development. The geodetic reference system provides the means of making available existing data files that can be combined in various ways to satisfy information needs without resorting to expensive, ad hoc field measurements. These avoided efforts generate the stream of benefits.

A mathematical model has been applied to a test area. Jurisdictions in the area have invested in a geodetic reference system, developed land information based upon the system, and used the information in decision-making for land- related activities.

The results of an application of the model to a test area demonstrate large benefits compared to the costs of the system. These positive net benefits are conservative; they include only a portion of the actual benefits generated because complete records are not maintained. If these additional benefits were to be included, then the full extent of the value of investment in a geodetic reference system would be revealed.

V. Summary and Recommendations

This study develops and applies a benefit cost analysis to the question of whether public investment in a geodetic reference system represents efficient use of resources. The context for that question involves the process of land planning and development. This process reveals the following points which are critical to a discussion of a measure of the value of benefits derived from investment in a geodetic reference system.

A. Summary

1. **A geodetic reference system requires a demand for information dependent upon the system.**
Both the development of support for a geodetic reference system and a measure of its value depend upon the timely and efficient satisfaction of the demand for spatial information that satisfies the needs of land-planning and development decision makers. Measurement of value places emphasis upon a demand for information which depends upon a reference system. Emphasis is thus placed upon identification and measurements of benefits rather than solely upon reduction of costs.
2. **A geodetic reference system is not the same as "control."**
The demand for a geodetic reference system is not the same demand as required for site specific control. Control is the basis for accurate land measurement. It can be generated and used for a specific project. A geodetic reference system also provides the basis for site specific, accurate, land measurement. However, it is incorrect to assign benefits to a geodetic control system when site specific measurements can be accomplished with alternative, less expensive means such as project-specific control.
3. **A geodetic reference system is "global" rather than "local."**
A geodetic reference system provides spatial information extending over an area larger than that typically associated with a specific project. It is the spatial extent of the system—its use of a common mathematical language to describe the spatial relations— that makes the geodetic reference system "global" rather than merely local.
4. **Local activities create the most significant demand leading to a geodetic reference system.**
Government agencies, especially those at the local level, whose activities are deeply involved with the planning and development process, form the constituency for a geodetic reference system.
5. **Mutual needs and benefits occur at all levels of government.**
There are Federal agencies concerned with land management and development which require accurate and compatible data over spatially extensive areas. Thus, there is a mutuality of interests at all levels of government in the development of land data and information systems based upon geodetic reference systems.
6. **A geodetic reference system means compatibility.**
The measurable contribution which a geodetic reference system makes to the satisfaction of land planning and development demands is the ability to provide compatibility to independent land data and information. When a geodetic control system is used to produce compatible spatial information, then the benefits of the system are measured by the avoided cost of field measurement necessary to relate otherwise incompatible information. The avoided costs can be calculated by any agency that requires land information.
7. **Benefits of a geodetic reference system far exceed the costs.**
The measurable benefits of a geodetic reference system are considerable when compared to the costs. This is clear from the limited data available. Those who benefit from the system typically keep poor records of the use of system dependent information. The missing data further enhance the conclusion that many agencies can benefit from investment in a geodetic control system.

B. Recommendations

1. **Support agencies whose activities demand compatible data.**
Support local government agencies that use a broad range of compatible data for land decision-making. Examples include regional and local planning departments, local planning boards, county executive departments, and consortiums of such departments. Provide assistance to agencies whose role extends beyond mere production of a geodetic reference system and into the use of spatial information products that depend upon the system. These are the agencies

concerned with the demands for system dependent information, and thus provide the greatest demand for a geodetic reference system.

2. **Develop a prospective study that reveals the full extent of the considerable benefits of a geodetic reference system.**
Develop and support a prospective study of the value of investment in a geodetic reference system. Application of the methodology described in this project was made retrospectively based on remaining records of recent decision-making. A prospective investigation is needed not only to reveal more fully the true extent to which spatial information products are actually used, but also to provide the basis for more complete records of that usage.

3. **Provide intergovernmental mechanisms to facilitate the use of geodetic control information by all users.**
Ensure that investment in a geodetic reference control system is accompanied by mechanisms that guarantee the operational effectiveness of the system. Operational effectiveness exists when a broad community of users has convenient access to geodetic reference system information. Avoid circumstances where one or a few agencies effectively hold geodetic reference system information in a confidential or proprietary manner that limits access to that information by others. Avoid dependence solely upon promotion of geodetic reference systems by producers at the local level. Local producers of a geodetic reference system are almost invariably technical and engineering personnel. They are not in departments concerned with the use of spatial information products for land planning and development. Promotion of a geodetic reference system requires the cooperation of local government in a program designed to ensure general community use of the system before support and assistance is given to a producer department. These efforts must be directed to nontechnical departments are well as technical ones. Where cooperative efforts are made with single purpose departments (such as highway, public works, mapping), ensure that the geodetic reference system and products generated by these departments are integrated into the broader local government planning activities.

4. **Develop an advisory service to aid local governments in reaping economic benefits in land decision-making provided by a geodetic reference system.**
Develop a geodetic reference system advisory service. Objectives of this service include the following: liaison with local government agency personnel; identification of local governments willing to make institutional changes that lead to identification of existing files of compatible data; and development of criteria for local government actions leading to effective use of investments in a geodetic reference system including institutional aspects of local government. Advisory service personnel must include those whose professional expertise covers operational functions of local government agencies as well as technical matters.

VI. APPENDICES

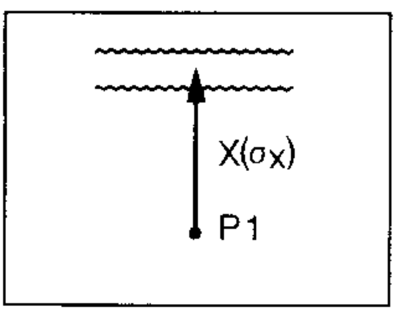
APPENDIX A

Merging Independent Sets: The Concept of Universal Compatibility

Universal compatibility is a feature of independent data that makes it possible to combine the data into a single information product with a measurable accuracy. The combination of independent data introduces an uncertainty which is independent of errors in the original measurements. This uncertainty varies inversely with the compatibility of the initial measurements.

Compatibility is an attribute of independent data which has a range of values. The variability of compatibility is illustrated by the example of a combination of two maps, each an independent representation of a land feature.

MAP 1



In map 1, the location of a river with respect to an identifiable feature, P1, appears as the distance x. The distance x has an estimated standard deviation of σ_x, which represents the uncertainty associated with a measurement of x in the field. The estimated error of σ_x is a result of inherent errors in the data collection and the process of mapmaking.

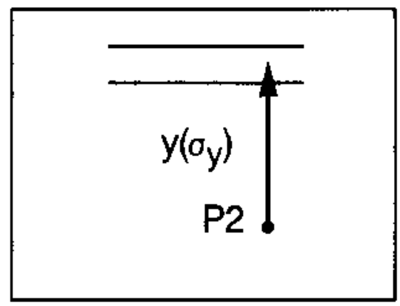
Map 2 represents the location of a highway with respect to an identifiable feature, P2. The degree of uncertainty is shown as σ_y.

P1 and P2 may be reference datums with respect to which the two features are measured.

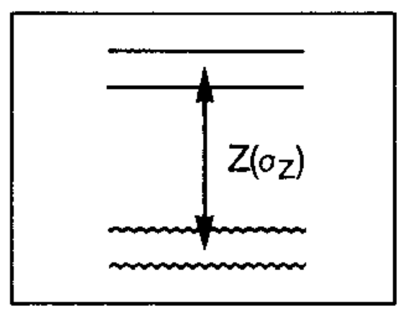
Map 3 represents the combined spatial information product resulting from the overlay of maps 1 and 2. It illustrates the creation of a single information file, depicted here in the form of a map, from the independent data sets.

A planning decision may be based on the distance of a point on the highway to a point on the river, a distance and error represented by $z(\sigma_z)$ in the spatial information product, map 3.

MAP 2



MAP 3



The estimated error in a measurement of z from the overlay depends not only on σ_x and σ_y, but also on a factor which represents how well one may "relate the two independent pieces of information." This factor is the degree of compatibility. Compatibility is expressed mathematically as a function of σ_{P1-P2}, the estimated error in distance between the datums for the two independent maps. Thus, $\sigma_z = f(\sigma_x, \sigma_y, \sigma_{P1-P2})$.

The two representations can be combined with a measurable accuracy if the spatial relation between the two datums is known. If the distance between the two datums is well known (e.g., σ_{P1-P2} is small), then the two representations can be combined in a single map with a "high compatibility."

Land features may be measured and represented with respect to a single point (or a few points) or they may be measured and represented with respect to a network of points with the characteristics of a geodetic reference system. In either case, these datums or basis points can be assembled into a geodetic reference system. This occurs when the spatial relationships of the basis points are established for the purpose of creating compatibility.

APPENDIX B

Case Studies

State Department of Transportation
Regional Planning Commission
Mapping Services Division of a County Government
Private Land Development

Appendix B provides a detailed discussion of our observations as to the production and use of a geodetic system in several agencies. The observations cover both primary and other uses of such a system.

A. State Department of Transportation

This case study concentrates on the activities of a state highway department in the southern part of the country. The specific focus is on the agency's role in the following activities: (1) establishment and use of a control system during the course of a specific project, (2) reuse of the control system established for a specific project, and (3) promotion of control-system use by others.

These activities were analyzed in terms of a specific highway project. The political process led to a decision to build a highway between two areas. Our interest begins with the department's entry into the process to develop alternatives, focus on one or a few of these alternatives, and develop the detailed design sufficient for final public approval and construction.

1. General Characteristics of the Project

The project involved widening and rebuilding an existing section of highway. A portion of the adjacent street pattern was incorporated into the project. The area encompassed by the project was urban with high land values. Both commercial and residential uses of the land were present.

The total cost of the project including construction is in the $4 million range with Federal funds accounting for 70 percent of the total. Estimates are that the primary control costs for purposes of mapping and centerline placement, etc., represent one-half of 1 percent of total costs. The highway department emphasized that the estimate tends to vary across projects because of variation in the density of the National Geodetic Survey (NGS) network.

The project was characterized as representative of construction in urbanized areas. The project encompassed an historic district with residents who are historically oriented. This created a need for a special set of spatial information products in order to assess the project's impact on the historical area. At the beginning of the project, the condition of the existing control system was described as poor. The first-and second-order control at this location was very limited. In addition, the original control work on the highway, done in 1960, was not reliable for the new construction.

The project encompassed three phases of activity:

Phase I: Establishment of a set of potential corridors and the selection of a specific corridor;

Phase II: Description of the selected corridor in sufficient detail to meet design requirements and to obtain the various permits needed for construction; and

Phase III: Construction phase.

The production and utilization of control and spatial information products during phases I and II were closely examined. Phase III, the actual construction, was not considered.

2. Use of Spatial Information Products

Each phase of the highway project has decisions which require spacial information. Focusing on phases I and II of the highway project, we have identified these decisions, the type of spatial information required, and the resulting need for control. The decisions have been grouped into three categories: (1) ownership/boundary features, (2) engineering problems, and (3) regulatory/environmental issues. Observations and findings are given separately for the individual phases of the project.

3. Types of Spatial Information

Tables B1 and B2 list specific spatial information products required during this particular project. They are grouped according to the three general categories and presented separately for phases I and II. It should be recalled that phase I decision-making involves identifying a set of possible corridors and progressing to the point where a specific corridor is selected. Phase II decision-making starts with the identified corridor and ends where all design aspects are completed and the requirements arising from the permit/regulatory process are satisfied. At completion of phase II, the project is ready for the construction phase. As pointed out previously, our focus does not extend beyond phase II. Table B1 lists the types of spatial information needed for decisions during phase I.

TABLE B1
Phase I: Selection of corridor

Types of spatial information utilized		
Ownership/Boundary	*Engineering*	*Regulatory/environmental*
Boundary (property and highway)lines	Centerline location	Land use patterns
Easement locations	Drainage area	Storm water drainage
Property values	Earthwork	Historic preservation area
	Electric and gas	
	Transmission	
	Pipelines	
	Bridges	
	Roads and streets	
	Topography	
	Railroads	

The information needs of this project are considered typical for highway projects, except for information concerning the historic preservation area affected by the project. Part of the need included information about property values in the area. Our discussions with Department of Transportation (DOT) officials indicated during phase I that no formal input was received from their Right-Of-Way Office. However, in selecting the corridor decision makers were sensitive to the property damage issue and attempted to minimize damages. This required an indication of property boundaries and values from sources outside the DOT. Large-scale accuracy and data compatibility were not required.

The use of engineering information in phase I was generally for identifying the gross factors associated with alternative corridors. The need was simply to identify the factors that would be involved with alternative corridors, not to characterize these factors in great detail. Information as to centerline location was used as a basis for the reference of other project-specific spatial information.

Phase II requires spatial information to bring the project through the design stage and satisfy permit and regulatory requirements. Table B2 lists spatial information utilized in phase II.

In phase II there are differences in the types of spatial information required for decision-making. The major differences occur in the case of regulatory/environmental information with the need for information indicating air quality and noise levels.

While the spatial information products used in the two phases of the project were basically the same, there are other important differences. These are discussed next, but

TABLE B2
Phase II: Completion of design requirements and permit process, excluding actual construction

Type of spatial information utilized		
Ownership/boundary	*Engineering*	*Regulatory/environmental*
Boundary lines	Centerline location	Air quality
Building location	Drainage	Historic preservation areas
Easements	Earthwork	Noise levels
Frontage	Electric and gas	Noise levels
Property values	Transmission lines	
Object location	Pipelines	
	Bridges	
	Roads and streets	

it should be noted that they arise because of fundamental differences between phase I and phase II. In phase I, the functional purpose of spatial information is to identify the gross factors and features of the possible corridors.

4. Characteristics of the Spatial Information

We observed three important characteristics of the spatial information that varied considerably across the first two phases of the project. They are (1) the amount of information necessary for decision-making, (2) the degree and accuracy of the information, and (3) the typical source of the information. Each is discussed below.

In terms of the amount of information required at each phase of the project, an assessment, based on a three point scale ranging from low importance to very important, is given in table B3. In phase I, ownership/boundary information and engineering information are assessed as being important in terms of the amount of information needed to make decisions. In phase II, some change in relative importance is observed as engineering information becomes very important and environmental/regulatory information is assessed as important.

TABLE B3
Relative importance of spatial information categories in terms of the amount of information required for decision-making

Information category	*Low importance*	*Important*	*Very important*
Phase I:			
Ownership/boundary		X	
Engineering		X	
Environmental/regulatory			X
Phase II:			
Ownership/boundary		X	
Engineering			X
Environmental/regulatory		X	

Table B4 assesses the relative importance of spatial information in terms of the degree of accuracy and quality required for decision-making. There is a major difference in the need for accuracy and quality across the two phases. Accuracy and quality have little importance in making phase I decisions, but in phase II decisions the opposite is the case as accuracy needs of ownership/boundary and engineering information are assessed as very important. This difference derives from the fact that phases I and II differ in the nature of the decisions that are made.

It became clear that the regulatory and environmental process imposes considerable demands for spatial information. The process, which enters near the end of phase II, requires that project-specific data gathered earlier in the highway development stage be combined with data from other sources. Whatever data accuracy and quality are established for the specific project, it must result in products that contribute to success in the regulatory and environmental permit process.

TABLE B4
Relative importance of spatial information categories in terms of the degree of accuracy and quality required for decision-making

Information category	*Low importance*	*Important*	*Very important*
Phase I:			
Ownership/boundary	X		
Engineering	X		
Environmental/regulatory	X		
Phase II:			
Ownership/boundary			X
Engineering			X
Environmental/regulatory		X	

In terms of the usual sources of the spatial information used to make decisions during the two phases, two observations were noted. One, the DOT makes an effort to reduce the use of field parties to obtain spatial information. The driving force is the need to minimize expensive labor costs in the face of budgetary pressures. This has led to a shift from field work towards increased reliance on design map activities in obtaining spatial information. This represents the substitution of capital-intensive for labor-intensive methods of obtaining spatial information.

Two, the sources of the spatial information differ markedly across the two phases. The difference is evident in table B5. In the case of phase I decisions, the required spatial information was, with limited exception, obtained from existing sources. No field work was utilized in obtaining the information. In contrast, field work was the usual source of the information required to make decisions during phase II of the project.

5. Establishment and Utilization of Control

During the course of the highway project, the DOT made expenditures for additional control. While the project involved expansion and reconstruction of an existing highway, the original control simply was not usable. Investment was made for vertical as well as horizontal control. This additional control was based on spatial-information needs arising from phase II decisions.

TABLE B5
Usual source of spatial information

Information category	*Existing sources*	*Field-generated*
Phase I:		
Ownership/boundary	X	
Engineering	X	
Environmental/regulatory	X	Limited
Phase II:		
Ownership/boundary		X
Engineering		X
Environmental/regulatory		X

The demand for additional control was determined by the need to accurately measure and locate the centerline of the corridor. The DOT's operating procedure in the early stages of the project was to install sufficient control to locate the centerline, establish coordinates, and relate to the centerline all spatial information generated or used during the project. This procedure contrasts with one where accuracy and density of the control system are improved as the need for accurate measurements increases during the various phases of the project. The DOT procedure is to install the maximum control anticipated during the course of the project when a corridor is chosen from among the alternatives. Typically, centerline location requires the greatest spatial accuracy, and therefore determines the control expenditure. Other spatial information is tied to this line with the result that all of the project-specific information is placed on a common datum. This ensures that project-specific observations are compatible and negates the need for field measurements to eliminate problems.

The project involved approximately $2,000 for installing the required supplemental control. Four permanent points were set to second-order accuracy, with points related to the NGS network. The decision to tie control points to a national datum reflects standard operating procedure of this DOT. This procedure adds to project cost, but is justified on two grounds. One, it provides a convenient check on the accuracy of spatial-information used during the project and the avoided costs of field work to solve problems. Two, the DOT expects cost savings when activities are conducted in this area in the future.

Maintenance of permanent control is the sole responsibility of the DOT. Maintenance decisions are based upon the value of stations to the highway department. The policy is not to maintain systematically individual stations. Maintenance costs are not included as part of the budget for the original project that generated the stations, but were allocated from the department's general fund. The agency judged its maintenance efforts to be reasonably effective even though points are lost each year. The loss rate was estimated to be less than 5 percent annually.

The DOT considers maintenance of the control system as providing the means of avoiding costs of future reconstruction activities. Large savings on an absolute cost basis are expected to result from the use of the feature of a common datum to generate compatible spatial information and provide easier access to the records.

6. Utilization of Control

Benefits of control expenditures rest upon future utilization of the system. In this manner, expenditures for a geodetic control system represent an investment, while the costs that are avoided when the system is utilized in the future represent a benefit or return on the investment. The highway department itself will return to use a set of control points when it reconstructs or expands a highway. Such reconstruction and expansion do not typically occur at a frequent rate for a particular highway segment. The question then is whether it is efficient to invest in a geodetic control system throughout a locality, region, or State for the sole purpose of future highway reconstruction or expansion.

The magnitude of the benefits depends upon the extent to which control established for a project is subsequently used. This depends, in part, on how those who install the control view promotion and utilization by other agencies and private users as a major responsibility. Our observations indicate that the DOT restricts its efforts to establishment of control for highway construction and reconstruction purposes without specific promotion efforts. The use of geodetic control by others is not part of the DOT's primary mission, and would require devoting scarce resources to these latter activities.

Full utilization of the control system necessitates that someone, usually the agency responsible for installing the control system, documents and disseminates information or makes the system operational, i.e., creates information about the control system. Our case study attempted to assess the extent to which the DOT engaged in this activity.

The DOT is concerned with the relation between its control-based information and other land data used during highway activities. This occurs when the department seeks construction permits through the regulatory and environmental process. The need is to merge highway data with a variety of resource and environmental data and to present the results for public scrutiny.

The DOT conducts a set of activities designed to promote future use of the control system. Information packages, describing the primary network and indicating the location of stations, are prepared for department district offices as well as for the DOT control office. Informal procedures are followed in disseminating information beyond the DOT. Information is provided to local surveying associations and county engineers. The information is not regularly sent to regional planning agencies. DOT officials indicate that private users contact them for information about the control system. Such requests are estimated to average 8-10 per week and in 65-70 percent of the cases involve vertical control. The DOT does not keep systematic records of these requests. There are no personnel in the agency with specific responsibility to disseminate information about the network and to promote its utilization.

It is important to note that the number of requests for information is not a reliable method to indicate the extent of use of the control system. The DOT, as is true of Federal agencies such as NGS, has no way of identifying how often control data are actually used by requestors. In addition, there is no way to identify cases where the primary recipient of the data provides the information to someone else for use in generating spatial information.

The agency perceives few advantages to itself from providing documentation of the control system to others. In fact, it perceives a disadvantage from even the current low level of dissemination activities, which obviously increase demand for scarce employee time and are somewhat of a nuisance.

7. Findings

A highway construction or reconstruction activity has several phases, each with many decisions that demand spatial information. The following findings apply to the highway department case study:

The first phase involves the establishment of alternative corridors and the selection of a primate candidate. Typically data are available from existing sources in the form of files and maps at small scale representation. Accuracy and compatibility demands are not high at this time.

Control is established at an accuracy and density sufficient to satisfy the most demanding need anticipated throughout the activity, usually for centerline measurement and location. This control will be used as a basis for project-specific data collection, combination, and representation.

The regulatory and environmental process appears in a later phase and requires project-specific data be related to resource and environmental data, much of which is not generated by the department. Both departmental data and information from other sources must be combined to yield products that are sufficiently accurate and compatible to satisfy the demanding requirements of public hearings that are part of the regulatory process.

Control generated by the department is capable of being introduced into the local, regional, and state control systems because geographic coordinates are obtained. However, the opportunities made possible by this work are not fully exploited. This is because the department has resources which must be devoted to its primary activity, the construction and reconstruction of highways. It is unable to promote effectively the development of geodetic control systems and must rely on others at local levels of government to take responsibility for distributing geodetic control information among the community of users.

The department itself can benefit from a more developed geodetic reference system. Demands for making its own project-specific data campatible with other data can be more effectively satisfied if geodetic reference systems are established.

The justification for permanent control of high accuracy for specific projects is the stream of avoided costs when the control is reused. There are incentives to minimize the cost of data-gathering in the form of labor intensive field measurements. Reuse of project-specific control by the highway department has not occurred to a significant degree because this control is a recent addition and highway reconstruction is an infrequent activity.

B. Regional Planning Commission

The activities of a regional planning commission located in the midwestern part of the county were considered as a case study. The planning commission includes several counties, a city with a metropolitan population of more than one million, several smaller cities, suburban areas, and extensive rural areas with productive, valuable agricultural activity.

The agency's role in the following activities were considered:

1. Establishment of a geodetic control system in the region.
2. Use of a geodetic control system to create products that satisfy the demand for land information.
3. Promotion of geodetic control system use subsequent to its installation.

1. General Characteristics of the Regional Planning Commission

The case study regional planning commission is a legal creation of both the State and the constituent counties. The commission was created in 1960 due to local initiative under provisions of a State enabling act. The executive director of the commission since its formation is a surveyor, engineer, and planner.

The creation of the commission preceded significant Federal support for local planning. As a result the commission received power under its State law to levy a property tax. It also obtains revenues from Federal sources (such as the planning support provided under Section 208 of the 1982 Amendments to the Federal Water Pollution Control Act) and from the sale of various data processing services to substituent counties and towns.

The following are stated objectives of the planning commission:

1. Collect, analyze, and disseminate the planning and engineering data necessary for answers to social and economic questions in the region.
2. Make and adopt advisory plans for physical development of the region (a legal duty of the commission).
3. Serve as a center for coordination of planning activities in the region.

The regional planning commission acts not only to fulfill its legal obligation to prepare advisory plans, but also to establish and maintain those files of land data and information that contribute to the completion of its legal obligation. In addition, the commission exercises significant influence over the planning and data-gathering activities of its substituent counties and local governments.

The planning commission influences surveying and mapping throughout its region. Local regard for the professional practice of the commission and its director results in the regional commission often being hired by the local governments to develop local plans, an activity which is not a legal duty of the regional commission. The regional commission also prepares specifications and guidelines for local level surveying and mapping, or provides technical assistance in the preparation of specifications. The commission frequently reviews work done for local governments by private contractors.

The result of this activity is that the regional planning commission contributes to the existence of common standards and practices in surveying and mapping extensively across several counties and vertically across various government levels. In effect, surveying and mapping in the region at all levels of government are done with the guidance (perhaps a stronger word should be approval) of the commission. These practices appear to be the result of a balance between what is perceived to be appropriate for sound professional planning and the constraints of regional and local government budgets.

2. Type of Spatial Information

The regional planning commission prepares spatial products for regional planning. Recurring activities in the regional planning process emphasize the need for the following information: land use, transportation, sanitary and sewage lines, park and open space, watershed and water supply, housing, soils, drainage and flood control, and environmental corridor.

For regional planning purposes maps are currently prepared at scales of 1"=400' and 1"=200' (2' contours). The 1"=400' are ratioed and rectified aerial photos. The commission plots the geodetic control system points which are identified on the photos. The 1"=200' maps are line drawn products. Photographs are obtained for updating base maps every 5 years. Thematic material is updated according to planning needs. The geodetic control system is regarded as essential to the updating process when there are extensive changes in the land.

Local levels of government are responsible for the acquisition and preparation of spatial information products for local planning. The work is done either by private contractors or by the regional planning commission as a contractor. When the work is done privately, it is usually performed according to commission standards. The greatest demand is for information for town land-use planning and for comprehensive physical development. In addition to that required for regional planning, information is also needed about buildings, parcels, redevelopment actions, parks, and neighborhoods.

Local maps are typically at a scale of 1" = 100', occasionally larger for special purposes. They become, effectively, sophisticated plots and are used for plan implementation in the form of zoning and official maps.

The remarkable element within the county and town mapmaking is the degree to which the regional commission effectively promotes common standards for spatial products. If a county or town seeks help with planning from the regional commission, the commission requires the local government to prepare the spatial information products and the control necessary for sound planning decisions.

3. Spatial Information Products and Control

Investment in land data and a control system is determined by perceived planning needs. The recurring and extensive nature of regional and local planning provides the demand for information that drives investment in land data and in a geodetic control system.

Officials in the case study jurisdiction describe planning as an iterative process. Both local and regional project development and planning progress from the idea to the construction phase. Each phase requires an increase in the accuracy of information and the scale of data representation. Over time, the successive cycle of area-wide and local planning is accompanied by demands for greater attention to the specific impacts of an activity. Regulatory and environmental requirements are the primary causes of these changes. These demands require increasingly accurate and compatible land data.

The regional planning commission promotes the establishment of a geodetic reference system as a means of coping with changes in the planning process. The purpose of the system is to provide the basis for spatial information products which are both essential to the planning process at the local as well as regional level and also expensive to produce as needed.

Development of the geodetic reference system began when there were two independent control systems. These were the science-based National Geodetic Survey (NGS) first-order network and the law-based Public Land Survey System (PLSS). The NGS stations were widely distributed, often in relatively inaccessible places, and with data in a form not useful for the typical surveyor. The PLSS system had deteriorated through nonmaintenance and the points were not related in a scientific way. The result was that no region-wide system existed which could be used systematically for the production of spatial products.

The regional planning commission supported the establishment of a geodetic reference system on an extensive basis throughout the region. The criteria was a geodetic system suitable for satisfaction of all reasonable planning needs within the area. The mechanism chosen was the integration of the best features of the two existing systems, the scientific elements of the NGS network with the legal character of the PLSS.

A geodetic reference system has characteristics of density and accuracy, as well as spatial extent, a reference language (coordinates), and operational effectiveness. Density of the integrated NGS/PLSS system was fixed by the decision, successfully encouraged by the regional planning commission to resurvey, remonument where necessary, and attach State plane coordinates to the corners, quarter-corners, and center points of the PLSS. The question of accuracy was fixed by the decision to determine State plane coordinates for all these corners according to current third-order, class I standards. These decisions were based on the professional judgment that this geodetic reference system supports reasonable demands for land regional and local planning data.

Investment in and establishment of this geodetic system is a function of the individual counties and towns. The standards are set by the commission. If a local government seeks the help of the commission in local planning, the commission requires the local government to first invest in data and products of the geodetic reference system for sound planning. The local governments have been willing to make these investments not only on the basis of the needs for current planning, but also on the basis of recurring and future planning data needs.

Local boards accept the need for maps. They accept the idea that decisions about the geodetic reference system, data gathering, and mapmaking cannot be left ad hoc to the hired photogrammetrists, engineers, and surveyors. The boards now seek to avoid single purpose expenditures that do not leave permanent control.

These efforts, begun in the 1960's, have caused two of the seven counties in the commission to invest their resources in the resurvey, remonumentation, and coordination of all their PLSS corners and in base maps for local planning. Throughout the region as a whole, 50 percent of all corners have been coordinated and 40 percent of the base maps prepared as of the end of 1983.

4. Use of Spatial Information Products

The spatial information products are used in an iterative, multiphase planning process. This process is illustrated by the example of a watershed management plan for a river basin that straddles two counties. The counties chose the regional planning commission as the agency to prepare the plan. The commission, as is its standard policy, required completion of the geodetic reference or control system and the base mapping (1" = 200', 2' contours). The rationale is that the geodetic control system and mapping are essential for sound, professional planning to meet both the immediate need and anticipated, future needs. The positive response from the counties consisted of complete funding of the geodetic control system and the mapping where that was incomplete, as well as the planning activity.

The plan was regarded as a first phase analysis of alternatives for control of river flow. The geodetic control system and mapping were completed in 1979, the first phase plan in 1983. The first phase plan described alternatives for rechanneling flow and diking along certain river sections.

Further development of the alternatives and actual implementation of one of the river basin alternatives will require spatial information at greater detail and accuracy. If the files of information are available at greater detail, and if that information is compatible, then future investments in data gathering and processing to create compatibility will be avoided. The investment in a geodetic control system in connection with the first phase plan makes it possible for the commission and/or counties to include the appropriate data as a part of its regular data gathering activity.

The project illustrates that the demand for spatial information products is considered a part of an iterative process. Each stage of a particular plan or development proposal requires more detailed and accurate information. Consideration of the recurring and anticipated regional and local demands for appropriate and timely information leads to increased quality and compatibility in the data files that are collected and maintained.

5. Maintenance

Maintenance of the geodetic reference system is a responsibility shared by the regional commission and the county and local governments. Money is available from the regional commission general fund, the budget of the rejuvenated office of the county surveyor (the regional commission director serves as county surveyor in one county), and local government budgets.

About 20 percent of the corners are inspected each year in all areas of the region. Losses are about 1 percent per year. This appears to be less than the national average.

The regional commission has designated personnel to respond to requests for spatial information, including requests for information about the geodetic control system. Precise records of requests are maintained.

Information is gathered and disseminated systematically. The commission is known by interested professionals and others as the information repository. Recipients include county surveyors, city engineers, State departments of transportation and natural resources, and the National Geodetic Survey. Annual reports, newsletters, talks, and reports provide information directly to private surveyors and engineers.

6. Findings

Regional and local planning consists of several phases including development of alternatives, choice among alternatives, and finally design and construction. Not all proposals pass through all the phases if the choice is not to continue further development. However, each phase requires data and information to answer the questions which arise.

Regional and local planning requires various combinations of land feature data. These combinations must present spatial products to the planner and decision maker that satisfy their needs to make choices and assess the risks associated with particular decisions.

The demand for data and information in the planning process is one which can be satisfied either by files of compatible data or by ad hoc project-specific data collection. The frequent demands for compatible data in the planning process across a spatially extensive area and across many agencies and governments are for those conditions which suggest the creation and use of existing compatible files.

The regulatory and environmental process demands compatible data from many agencies, governments, and private sources. This process occurs with a frequency suggesting that much of the data be available rather than generated ad hoc.

Standards for the information used in planning processes vary by jurisdiction. However, each jurisdiction can measure the cost of investment in a priori data against the cost of ad hoc data collection whatever its decision-making standards.

Planning agencies at all levels of government encounter a large portion of the demand for spatial information. They are also in a position to lobby for and, in some cases, impose standards for data used in planning, environmental, and regulatory decision-making. They are in a position to promote establishment, maintenance, and use of a geodetic reference system through uniform, voluntary standards and specifications for local government offices.

A geodetic control system is viewed by a planning agency as a building block for a variety of frequently requested spatial information products. The points in the system are those distributed throughout a spatially extensive region rather than within specific sites.

C. Mapping Services Division of a County Government

We have investigated as a case study the mapping division of a county government in an Atlantic coastal State. The county is within the metropolitan area of a large eastern city. It has experienced a large population growth in the last 20 years. Land values are high throughout the area. The county is more concerned with the effects of this recent urban growth rather than the prospect of future large population changes.

The mapping division is responsible for provision of base maps that represent natural features such as topography, streams and lakes, and culture features such as roads, highways, and railroads. The scale of these base maps is 1"=200'. The division is also responsible for the creation and maintenance of thematic maps. The thematic maps include watersheds, flood hazard areas, land use (including subdivisions), land cover, etc. These are created utilizing the base maps. The mapping services division is active primarily in areas of the county outside the towns. The division provides property mapping for the towns.

Development of base and thematic maps and the control system to support it began in 1968. This effort was in response to the rapid growth of population. Impetus came specifically from the planning office of the county government. That sector and others, both in county government and private, required more precise information about topography and streets than that provided by the USGS Quadrangle Sheets. They also sought spatial information products that could provide measurements as accurate as those obtained from routine field measurements (i.e., distances from products that were better than could be obtained by means other than "exceptional" surveying). The general objective was to avoid labor-intensive site investigation in the early phases of a project. Specifically, there was a desire to avoid external contracts for preliminary field work.

The mapping services division (or rather its predecessor in the pre-1968 period) sought advice from a variety of potential users with county government about mapping needs. As a result the emphasis was placed on orthophotographic mapping rather than production of a line prepared product. Eventually, the problems of users who could not see objects on the orthophoto maps led to production of line drawn maps.

Base maps for the county were prepared in the period 1968-72. The first- and second-order control throughout was extended as part of the mapping program. More than 500 new, permanent second-order control points were established based on 57 first-order points. This number was greater than that considered minimally necessary for the proposed mapmaking in anticipation of alternative and future needs. Support for the program came from the county and the cooperative program of the National Geodetic Survey.

The products from the 1968-72 period remain the basic material for mapping in subsequent years. Thematic material is updated according to the availability of information. For example, a new subdivision is placed on the appropriate thematic map based on information provided in the subdivision plot.

The mapping service products are generally accepted as reliable by a community of users in the county government and the private sector. It is understood by users that "reasonable professional practice" stands behind the products. Nevertheless, there appears to be a sense of accumulated errors during the updating process.

The county has decided to invest in new orthophotographic base maps. The current demand is overwhelmingly for updated planimetrics. This will be satisfied by stereo orthophotographic techniques.

County officials in several agencies see the benefits of these new products in terms of the regular avoidance of field labor costs. These agencies estimate that the savings in avoided field work for site planning based on the proposed new map products will be $250,000 annually (1983 dollars). These savings would pay for the orthophoto mapping costs in 1½ years.

The geodetic reference system to support this mapping activity is the system of 57 second-order control points established in the 1968-72 period. These points were originally established at a cost of about $2,000 per point (1969 dollars). Current costs are estimated at $4,000 per point. These points have generally been maintained, at county expense, mostly from the survey budget of the public works department. Some points may be missing. Almost all are in place according to estimates. For mapmaking, the only costs are flagging costs, estimated to be $100 per point.

In addition to the 57 points established during the 1968-72 period, the county department of public works has added approximately 500 points throughout the county in the subsequent period. These points, whose positions are known generally to second-order accuracy, are site-specific additions as public works projects are carried out.

Data for these points have been adjusted by the National Geodetic Survey. Although information is available both from the NGS and the county public works department, it has not been widely disseminated and made operational by the county.

Use of the reference system points by others is not well known to the mapping services division. The division does not keep records of requests for information about the control points. It is estimated that the rate is one request per day. The county cannot choose specific control points and determine how many surveys and plans have been made in reliance on a particular control point because the county work records are not arranged for such an analysis. Thus it is not possible to estimate the avoided costs associated with the existence of the control system.

Reviewing this case study we can summarize as follows:

A geodetic reference system was established in the county more than 12 years ago as support for base mapmaking. The demands placed on county agencies for planning and land use decision-making led to this investment. It was believed then, and continues to be the belief now, that the expensive cost of labor-intensive site investigation can be avoided in the early stages of a project if information is available.

Reuse of the entire geodetic reference system is now planned for the first time since its establishment. Again the use is for base mapmaking. Records indicating the use of the system by others are not maintained systematically by the mapping services division or other divisions of county government.

The value of investment in a geodetic system is measured by the avoided costs in field measurements provided to planners and decision makers by the highly regarded spatial information products.

D. Private Land Development

Private development of land is examined as a case study in the use and value of a geodetic control system. This type of development involves individuals or corporations seeking to find, acquire, and develop a site for a specific use.

1. Land Development Activities

Several of the following activities may occur simultaneously. Several depend crucially upon the availability, quality, and compatability of land data. We are interested in how they depend on these attributes:

- The decision to acquire and develop a site for a specific use.
- Identification of alternative sites.
- Characterization of alternative sites.
- Selection of a site from the alternatives.
- Acquisition of financial support for acquisition and development.
- Purchase of the site (or an option to purchase).
- Further site characterization, including title and boundary security.
- Satisfaction of lending, regulatory, and environmental requirements.
- Design and construction.

The activities were examined by means of interviews within a private company in a northeastern city. The company acts in several capacities: as a source of general information about land features, values, and community attitudes about development; as a surveyor; as a data collector; and finally, as a data analyst and advocate before permit-granting public agencies. In effect, the company acts as an information broker serving both the client developer and the public agency in the development process. It provides professional expertise in the collection, interpretation, and presentation of a variety of spatial information.

The information aspects of the land development process were examined by means of an example—the selection, purchase, and development of a site for an industrial building in a metropolitan area. The process begins with identification of desirable jurisdictions or neighborhoods. This requires information about land value, zoning, physical characteristics such as soil and topography, and roads and traffic. This analysis seeks to provide potential sites. The information requirements are not high in spatial accuracy and compatibility. The information demands may be characterized as more qualitative than quantitative. The demands are typically satisfied from existing sources (such as USGS Topographic Maps) and thematic products produced from these maps. The object is to characterize areas rather than sites with respect to features such as floodplains and watersheds, traffic, value, parcel locations generally, and other spatially extensive features. The scale is typically 1:24000.

These products are used to choose a site or a small number of sites. A more detailed preliminary site analysis then follows. Typically data are obtained at an accuracy and compatibility appropriate for representation at a scale of 1:5000. The object is to characterize the site geology, highway capacity, valley cross sections, transmission facilities, etc. If data are not available, they may have to be obtained by measurements.

Once a single site is selected and acquired (or an option acquired), it must be further characterized. This site-specific work is typically performed with data appropriate for a 1:1200 or 1:600 scale map product. The activities are those necessary to establish specific design alternatives, determine ownership and boundaries, obtain the information necessary to satisfy environmental and regulatory requirements, and prepare for construction. This effort requires data significantly more precise than that required in the earlier phases. The specific goals are to satisfy the lender, secure ownership and boundary, obtain regulatory and environmental permits, and prepare site plans for the architect and construction engineer.

2. The Demand for Spatial Information

The land information company sees land development as a process that requires land data and information of increasing accuracy and compatibility as site development proceeds through its various phases. These increases are considered to be an outcome of Federal, State, and local regulations from the 1970's, designed to control activities which abuse the environment of common resources. The company does perceive a retreat from these regulations that generate a conflict between private rights and public interest.

The demand for spatial information often becomes the demand required to obtain a permit. The land information broker, acting for a developer, confronts the problem of many applicable permits at public agencies in several governments. These include, but are not limited to, the following: wetlands protection, air quality regulation, environmental policy acts, water pollution control acts, local zoning codes, floodplain and watershed protection, site plan reviews, historic and scenic area protection, access and utility, right-of-way improvement, curb cuts, road opening, sewer connections, and special tax rates.

It is the perspective of the land information company personnel that many conflicts in the "war" between private right and public interest occur as a result of area regulations. The problems involve jurisdictional limits and the probability of change. Their view is that the informational basis for resolution of these conflicts is generally inadequate.

Ultimately, a demand is placed upon someone, often the surveyor or land information specialist, to say something like "I certify that all regulations are satisfied." This demand may come from the lender, regulatory authority, developer, or a combination of these people.

Regulations affecting the developer fall into two classes: those that regulate activities, such as discharge permits, and those that regulate areas. Regulations that control areas contain descriptions of the area in the form of measurements, which may appear on maps, and in the form of words. The words typically refer to some physical feature as the basis for the regulated area. Examples are a dune, wetland, ordinary high water mark, and a flood hazard area. These areas may appear on maps. But unlike the areas described by the measurements, their location on the ground depends on the meanings given to the words, usually by the law.

The descriptions and representations of regulated areas create a dilemma for the surveyor, surveyor-engineer, civil engineer, and other land information specialists. These professionals receive an education that tends to place a preference on accurate measurement of the land and representation of features on maps and digital products as the most reliable media for portraying resources and their boundaries. However, regulated resource areas described by words (and represented on maps) make reasonable reconciliation between the location of the physical feature on the ground with its location as represented on the regulatory map or product difficult if not impossible. Most critical is the fact that resource mapping for the regulatory process is rarely tied to the land tenure framework, the individual parcel.

To the land information broker, the struggle does not appear to be over land use but over data. Is the parcel in the regulated area? Is a permit required? Is the area wet? Is the land high enough? The task for the information broker is to gather, analyze, and present data in a package that satisfies the decision maker's demands for accuracy and compatibility.

Private land development is a process with several phases, each with many decisions that require spatial information products. Private development depends upon publicly established sources of spatial reference and information, especially in the early phases of a development. The publicly available sources of compatible information provide benefits to the private developer in the form of avoided field measurement costs.

The regulatory and environmental process requires private developers to gather, analyze, and present spatial information to public agencies. This information is obtained by the developer either from existing sources, public or private, or by field measurement.

The regulatory and environmental process requires the private developer to assemble a variety of spatial products, each product designed to satisfy a specific regulatory or environmental question and each containing a specific combination of land data features.

APPENDIX C

Estimation of the Avoided Costs of Field Measurements

The field measurement costs avoided because independent files of data are made compatible as a result of a geodetic reference system can be estimated. These estimates are specific to a particular area and jurisdiction. They depend upon the quality of information that a jurisdiction requires to assess the risks associated with land development or investment.

A jurisdiction that requires accurate, compatible data and information for risk assessment is assumed to be willing to pay for that information in two ways: one method is to pay for the information as it is needed by ad hoc measurements; the other is to anticipate the demand and provide for the information by systematic, a priori means. If a jurisdiction chooses to anticipate the demand for data and to provide for that data systematically, then it avoids the costs of obtaining data of the same quality and compatibility as needed. The jurisdictional standards of data quality and compatibility for risk assessment must be applied to the estimates of avoided costs. Where standards are high, then estimates must assume the use of techniques that yield data which meet the standards.

The test area has high standards of data quality. Planning depends upon data that are appropriate for maps of scale 1:1200. Thus estimates of the avoided costs associated with making topographic data compatible with other data assume measurement, computation, and representation techniques sufficient to yield a topographic map of this scale. Similar assumptions apply to estimates of the avoided costs associated with other features.

The following definitions and underlying assumptions form the basic rationale for estimating the cost of field measurements necessary to make land feature data universally compatible.

Universal compatibility—The attribute that allows various data to be combined to yield products with measurable quality in the representation of spatial relations.

Independent data—Data without the spatial compatibility attribute that allows the data to be combined with other data to yield a combined product (a spatial information product) with measurable accuracy and precision.

Compatible data—Data files that have the attribute of compatibility such that a combination yields a product that represents spatial features with a measurable and known accuracy.

The basic rationale for estimating costs involves the use of spatial data (topographic, road, parcel, wetland, etc.) which are often independent because:

1. They are measured using site-specific control that has totally disappeared because the control was not maintained or because it was specifically designed to be temporary; or
2. The data are measured with respect to site-specific control, all or part of which remains but has not been tied to a larger, global, system.

These two situations require different ad hoc field measurements. In the latter case, field measurements are required which tie the existing control to the geodetic reference system. The land feature data were measured with respect to the existing site control. Therefore, compatibility is achieved when the field measurements tie the remaining control to the reference system and a recomputation and representation of the data are achieved.

In the former case no site control remains. The land feature data remain as a map or file. But the data are not related satisfactorily to anything on the ground because the control is gone. In this case, the field measurements consist of the entire process of survey, monumentation, coordination, feature measurement, data compilation, and representation. The costs of creating compatibility are significantly greater than in the circumstances where a portion of the site control remains.

We have estimated the field measurement costs for each of the data files used in the test activity for each situation. The following assumptions are made:

1. Each estimate is based on a per square mile basis.
2. The geodetic reference system to which field measurements of the features must be tied is that of the Public Land Survey System for which the corner, quarter-corner, and center corner locations have been surveyed, monumented, and coordinated to an accuracy corresponding to third order, class I.
3. The quality of field measurement and compatibility is according to standards of the test area. These standards are apparently high compared to those typically demanded by governments and agencies. Therefore, the cost of measurement is based on the assumption that the location of highway, topographic, parcel, building, and other features will be measured with

an accuracy appropriate to representation, for example, on a map of scale 1:2400 or even 1:1200 according to national map accuracy standards.

4. Data files are measured and maintained as separate files. Often, for example, roads and topographic data are obtained by a common aerial photographic technique and maintained and represented in a single representation. We assume that these features are handled independently in a land information system. This assumes a desire to maintain timely, compatible information about roads and topography independently. If a road is altered, we assume that changes are measured independently of other features and made compatible by ties to the geodetic reference system. This assumption looks forward, without neglecting current practice, to the time when spatial data will, more often, appear as digital data.
5. Some land features are typically not measured or represented with great accuracy or precision, even though they are often used in conjunction with accurately measured data. For example, the locations of different soils or watershed boundaries are subject to an interpretation or definition, which limits the accuracy of a typical data file or representation of these features. The result is that the field measurements necessary to make the files compatible are the same under the two circumstances described above.