GUIDELINES FOR SELECTING A COST-EFFECTIVE SMALL HIGHWAY SIGN SUPPORT SYSTEM

RESEARCH REPORT 3254-4

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Contract DOT-FH-11-8821

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College Station, Texas

Submitted to

Federal Highway Administration
Implementation Division
Office of Development
Washington, D. C.

by

Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

GUIDELINES FOR SELECTING A COST-EFFECTIVE SMALL HIGHWAY SIGN SUPPORT SYSTEM

by

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16. Abstract

Guidelines are presented to assist transportation agencies select a sign support system. Three major elements are addressed in the guidelines: safety, design, and economics. An economic analysis procedure was formulated whereby the present worth of initial and annual costs of a given support system can be computed and compared with costs of other systems. The procedure was used in an example to analyze the relative costs of available support systems for small sign installations. A limited sensitivity analysis was also performed to evaluate the influence of input parameters on costs.

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FOREWORD

This report was prepared as a part of DOT Contract No. FH-11-8821, entitled "Cost Effectiveness of Small Highway Sign Supports". The contract began July 1975 and was completed September 1978.

The basic purpose of the contract was to develop objective criteria and methodologies to assist transportation agencies in the selection of a cost-effective sign support system. Four tasks were required: (1) survey existing practices; (2) evaluate the crashworthiness of widely used support systems and promising new systems; (3) develop methodologies whereby candidate systems can be evaluated on a cost-effective basis; and (4) to the extent possible, identify the relative cost effectiveness of current systems. Results of this phase of the contract are presented in the following reports:

1. "State of the Practice in Supports for Small Highway Signs", Ross, Hayes E., Jr.; Buffington, Jesse L.; Weaver, Graeme D.; and Shafer, Dale L.; Research Report 3254-1, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, June 1977. (To be published by FHWA)

2. "Survey of Current Practice in Supports for Small Signs -- Documentation of Data Reduction and Information File", Ross, Hayes E., Jr., and Schafer, Dale L., Research Report 3254-2, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, April 1977.

3. "Crash Tests of Small Highway Sign Supports", Ross, Hayes E., Jr.; Walker, Kenneth C.; and Effenberger, Michael J.; Research Report 3254-3, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, September 1978. (To be published by FHWA)

4. "Guidelines for Selecting a Cost Effective Small Highway Sign Support System", Ross, Hayes E., Jr., and Griffin, Lindsay I., III, Research Report 3254-4, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, September 1978. (To be published by FHWA)

5. "Cost Effectiveness of Small Highway Sign Supports -- A Summary Report",Ross, Hayes E., Jr., Research Report 3254-5F, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, September 1978. (To be published by FHWA)

Subsequent to the initial contract, additional work was conducted under contract modifications. This included the crash test evaluation of rural mailboxes and the crash test evaluation of selected small sign supports using subcompact automobiles. Results of this work are published in two reports:

6. "Crash Tests of Rural Mailbox Installations", Ross, Hayes E., Jr., and Walker, Kenneth C., Research Report 3254-6, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, October 1978. (To be published by FHWA)

7. "Crash Tests of Single Post Sign Installations Using Sub-Compact Automobiles", Ross, Hayes E., Jr., and Walker, Kenneth C., Research Report 3254-7, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, October 1978. (To be published by FHWA)

Also developed under the contract was a narrated, documentary 16 mm movie in which a general overview of the small sign support problem is presented. Included in the movie are summaries of the crash tests described in Research Report 3254-3. Copies of the movie entitled "Small Sign Supports" can be obtained by contacting the

Office of Development
Implementation Division
Federal Highway Administration
Washington, D.C. 20590

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I. INTRODUCTION

I-A. General

Roadside signs are a vital part of any highway or street system. Numerous types of signs are needed to convey a wide array of information to motorists. Within the 50 state highway systems alone, there are in excess of ten million roadside sign installations. Millions more are used within county and city jurisdiction. Approximately 75 percent of these are small single support installations. A wide variety of support systems are used in small sign installations.

Many of these installations are replaced annually due to accidents, vandalism, and normal wear. It is not uncommon for a state transportation agency to spend 20 percent or more of its annual maintenance budget on small signs. Cities and counties commonly spend an even larger percentage.

In the past, small single-post sign installations were not a significant hazard to motorists. Most could be ridden down by the larger autombiles that used to be prevelant. Breakaway bases were used on many of the larger installations that would not yield or bend over on impact. However, the trend is now toward smaller automobiles and some sign installations that were safe a few years ago are no longer acceptable today.

These observations underline the significance of small signs in terms of economics and safety. Recognizing this significance, and the absence of objective guidelines and information, the Federal Highway Administration undertook this study. Its basic objective is to provide state-of-the-art guidelines and criteria for those responsible for the selection of safe and cost-effective sign supports. Four major tasks were required to achieve this objective.

First, a survey was conducted to determine the state of the practice in small sign supports. A comprehensive questionnaire was sent to federal, state, county, and city transportation agencies. Follow-up phone calls and personal interviews were made with selected transportation officials to fill voids in the questionnaire data. From the survey, the researchers determined the types of small sign supports being used, their design characteristics, and the costs to install and maintain the supports. Detailed results of the survey are presented in Research Report No. 3254-1 (1). Research Report No. 3254-2 (2) documents the way in which the raw survey data were coded and stored.

The second major task involved an evaluation of the impact performance or crashworthiness of widely used small sign support systems and promising new sign support systems. This was accomplished through a comprehensive full-scale crash test program. Results of these tests are presented in Research Report No. 3254-3 (3). Appendix A of this report contains a summary of the crashworthiness of small sign supports.

In the third phase of the study, guidelines were developed whereby candidate sign support systems could be evaluated on a cost-effectiveness basis. Chapter III of this report contains the formulation of these guidelines with their attendant requirements, assumptions, and limitations.

The final phase of the study was aimed at quantifying the cost-effectiveness of the various support systems now available. To the extent possible, this was done in Chapter IV of this report.

I-B. Scope

Guidelines presented herein have application to both new and existing sign support systems and can be used by federal, state, county, and city transportation agencies. They provide an objective means of evaluating the various sign support systems available for new installations and/or to retrofit and maintain existing installations. These guidelines are not intended as operational warrants for sign installations, that is, they do not establish the need for signing itself.

The guidelines are not limited by type or size of sign installations. However, the supporting data on safety, design, and costs are limited to small, single and in some cases multiple post installations having sign panel areas up to approximately 15 ft^2 (1.4 m^2).

II. SELECTION GUIDELINES

II-A. General

Figure II-A-1 presents a basic evaluation procedure suggested for use in selecting a support system. For a candidate system, the first item that would normally be evaluated is its impact performance characterisitcs. If it does not meet current standards it is not acceptable. Impact behavior may not be a critical factor to city and county agencies due to lower operating speeds on streets and arterials. However, there are a number of support systems which have acceptable behavior for a wide range of impact speeds. Further discussions of impact behavior are presented in Section II-B. The next factor to consider is the system's design characteristics. There may be some characteristics which render the system unacceptable to a given agency. Further discussions of this factor are presented in Section II-C. If the system satisfies these first two conditions, an economic analysis is necessary to rank the system. A detailed procedure for the economic analysis is given in Chapter III.

II-B. Safety Standards

Prime consideration should be given to systems which offer the least hazard to the motorist. Appendix A contains an evaluation of the impact performance of widely used support systems, as well as promising new systems. Reference should be made to Appendix A as to the acceptability of a given system.

Current safety criteria for sign supports are intended primarily for relatively high-speed facilities. There are no widely accepted safety criteria for city streets or low-speed roadways. Nonetheless, it should be

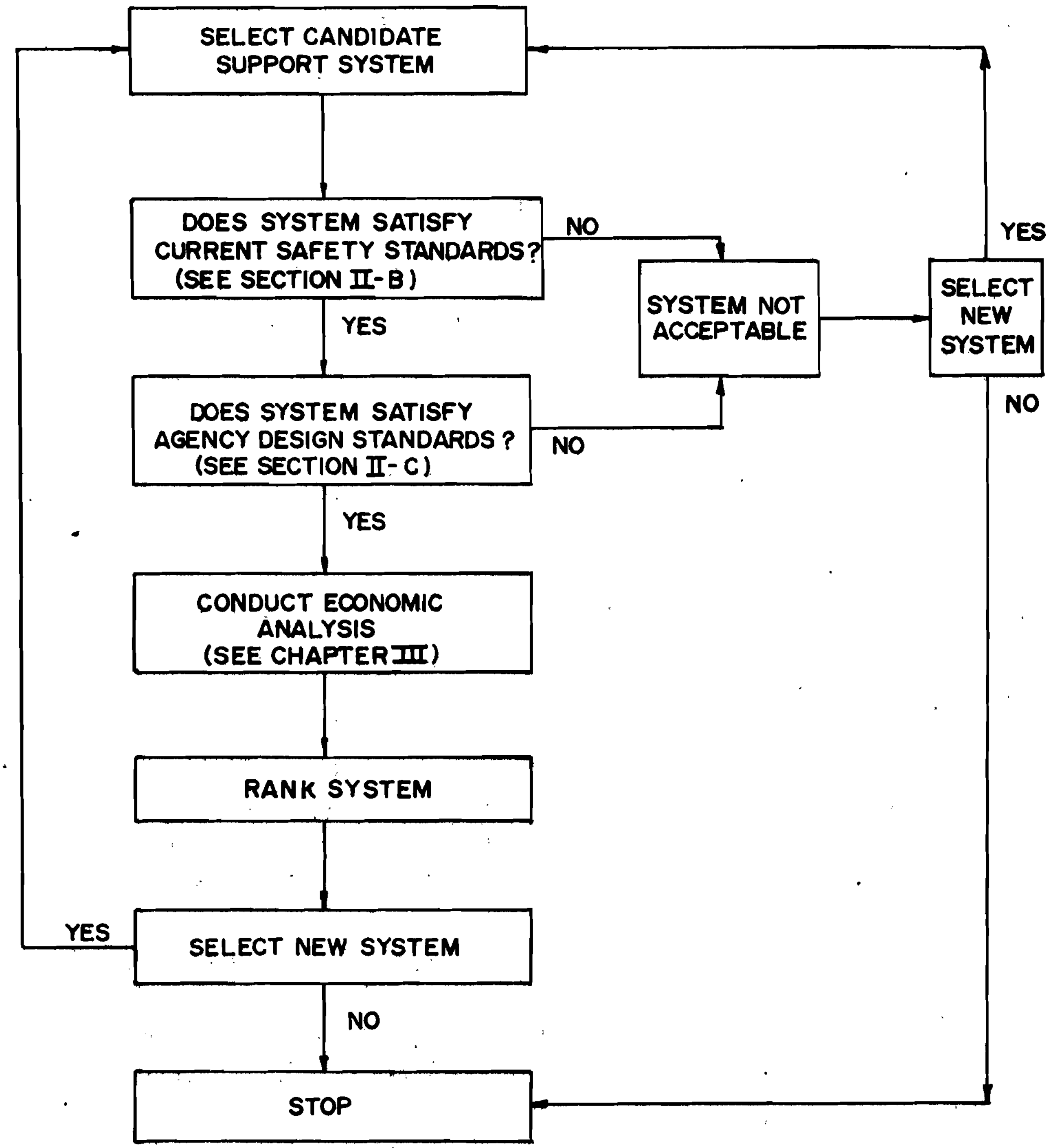

FIGURE II-A-1. SIGN SUPPORT EVALUATION PROCEDURE.

a goal of county and municipal agencies to achieve a level of safety comparable to that for state agencies. It is noted that the critical impact speed for many sign support systems is within the approximate range of 10 mph (16.1 km/h) to 30 mph (48.3 km/h).

II-C. Design Standards

Figure II-C-1 contains a suggested checklist for evaluating the design characteristics of a candidate sign support system. Item one is essential in the evaluation process. The remaining items, not necessarily listed in order of importance, should be given consideration in the analysis of a candidate system. A discussion on each item in the check-list is given in the following sections.

II-C-1. AASHTO Specifications (4)

Most, if not all, state highway agencies pattern their sign support design standards according to AASHTO Specifications (4). Loads, allowable stresses, aesthetics, and functional requirements are all addressed in the Specification. It was not the purpose of this study to evaluate or recommend changes to these Specifications. *An agency should verify that a candidate system is in compliance with either the Specifications or the agency's specifications.*

It is the opinion of some highway officials that sign supports designed according to the AASHTO Specifications are often overdesigned and are therefore unnecessarily hazardous. To substantiate this observation, reference is usually made to the lack of any appreciable number of wind load failures throughout the country. Although the latter point appears

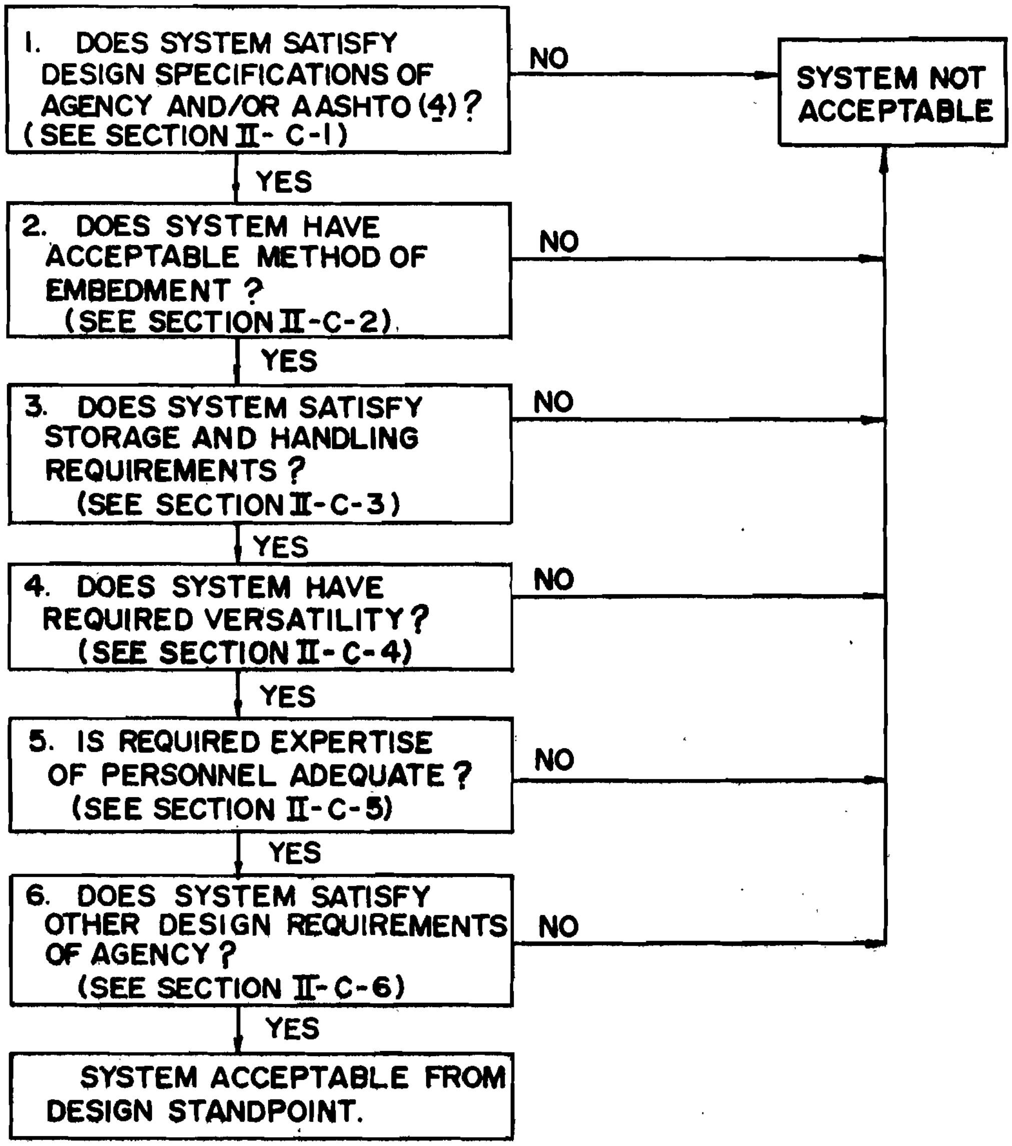

FIGURE II-C-1. EVALUATION OF SIGN SUPPORT DESIGN CHARACTERISTICS.

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[illegible]

equipment. Wood posts are commonly placed in a drilled or excavated hole, and the excavated soil is then backfilled and tamped around the post. Metal posts and wood posts are also embedded in concrete footings, which require a drilled or excavated hole.

Method of embedment for a given system has a direct relationship to the overall cost of that system. This can be taken into consideration in the procedures presented in the following chapter. In some instances, however, an agency may be constrained to the use of systems with a particular method of embedment. For example, in areas having predominately rocky terrain, support systems requiring a drilled or excavated hole may be impractical. Systems capable of being driven into the terrain may be the only acceptable alternative. In those instances, a candidate support system may be eliminated without the need for further analysis.

Another factor to consider is the relative ease and safety associated with the installation of a given system. For example, some state agencies require that the candidate system be capable of being embedded from ground level. Driving a full-length post can pose a hazard to sign crews, especially when one member is driving the post from above and another member is holding the post in place at ground level. It should be noted that powered equipment is available to drive full-length posts with the crew remaining at ground level.

II-C-3. Storage and Handling

Some agencies have centralized purchasing, storage, distribution, and installation of signposts. Others have centralized purchasing but the posts are delivered and stored at various districts or field operations.

District personnel install the supports. Required storage space and the labor and equipment needed to transport the posts should be considered in selecting a system, especially in the former case. Sign crews that are responsible for large areas, possibly on a statewide basis, must be capable of transporting a relatively large number of posts and the associated installation equipment. In those situations, the choice of a support system may be restricted to systems easily transported. However, an agency should not necessarily rule out a given system before analyzing the economics of all alternatives. Although a new support system may require the purchase of new equipment and possible expenditures for additional storage facilities, the net annualized costs for a given time period may be less than current costs. Guidelines for such an analysis are presented in Chapter III.

As a point of interest, a recent study (5) indicated that a centralized sign shop may be more cost-effective than decentralized shops. However, this finding pertained perimarily to fabrication and refurbishment of sign panels as opposed to sign posts.

II-C-4. Versatility

Small signposts are required to support a wide variety of sign panels and/or combinations of panels. It is not uncommon for four, five, or even more panels to be supported by a single post. Several panels may be attached to cross members which are fastened to the vertical post. Panels may be mounted back-to-back or at 90 degrees to each other. The ease and utility with which the post can be adapted to accommodate these various panel configurations should be considered. Consideration should be given to systems which can also be used for temporary signing in maintenance and construction zones.

II-C-5. Design Complexity

Well designed systems improperly assembled and/or installed may be of little benefit. Probability of assembly and/or installation errors increases as the complexity and number of parts of a system increase. However, it is difficult to quantify the effect that design complexity may have on the cost and design aspects of a given system. Judgment and past experience must be carefully used in evaluating these factors. Errors can be reduced by education of appropriate personnel. Education should not only include the "how to" but the "why" of various design features. Crash test films can be very helpful in demonstrating the importance of proper assembly and installation.

II-C-6. Other Factors

Following are other factors which should be given consideration in evaluating potential support systems:

Availability - An agency should have reasonable assurance that a candidate system will be available for both short-term and long-term deliveries.

Durability - An agency should have reasonable assurance that a candidate system will have the desired design life. Resistance to deterioration caused by environmental exposure should be investigated. As a matter of interest, there seems to be uncertainty among some highway officials as to what the design life of a support system should be. Many supports have relatively short lives since they are frequently knocked down, vandalized, stolen, or removed and/or replaced due to roadway improvements or changes in standards.

Aesthetics - There is some evidence that a motorist's perception of a sign support may be related to its color. For example, in limited observations by city officials, a round tube post with "high visability" yellow paint appeared to offer better delineation than galvanized or green painted posts. Significant reductions in knockdowns were noted when the yellow posts were installed. Although there are no objective criteria regarding signpost appearance at this time, the designer should stay abreast of any developments which may be forthcoming.

Torsion and sign flutter - Wind induced vibration or flutter of a sign panel occasionally presents problems, especially to single post installations. Flutter may diminish or obliterate the legibility of the sign. It may also cause structural fatigue failures in the sign panel and/or support post. If the support is embedded directly in the soil, flutter may create gaps between the support and the soil, diminishing the load carrying capacity of the sign support system.

Unfortunately, very little data exist on which objective guidelines can be established with regard to the flutter problem in single post signs. It is well known, however, that the tendency for the panel to vibrate or flutter in the wind is dependent on the torsional stiffness of the post. Torsional stiffness is directly related to the cross-sectional shape of the post and its modulus of rigidity. Closed shapes such as pipe, tubes, and solid sections (wood) are considerably more resistant to twisting than open sections such as W-shapes or U-posts. With regard to material, steel has a modulus of rigidity approximately three times that of aluminum.

While the torsional stiffness of the post itself is higher for a closed section, the torsional resistance of an open section post will usually be higher than that of a closed section post when both are embedded in soil. For example, anti-twist plates are commonly used on pipe posts to prevent twisting of the post in the soil.

Tests conducted at Youngstown State University (6) have shed some light on the vibration and fatigue problem of sign panels, at least those that are supported by steel U-posts or steel flanged channel posts. It was found that back-up plates between the panel-to-post connections are important to transmit the sign face loads to the post. It was also found that the panel-to-post bolt torques should be kept at a minimum value to maximize the strength of the sign.

III. ECONOMIC ANALYSIS

III-A. General

Discussed in the previous chapter were engineering or design factors involved in the decision process. This section will present the economic factors which should be considered when selecting the most appropriate sign support system for a given political jurisdiction or geographic region.

Cost-benefit analysis would seem to be the logical procedure for ranking candidate systems once it had been ascertained that the system was acceptable from a safety and design standpoint.

> "In a cost-benefit analysis the present and future benefits and costs associated with the system under consideration are determined and compared. Future benefits and costs are usually discounted at some rate to reduce them to present values. In order to compare them, both the benefits and costs must be expressed in common monetary units. They are usually compared either by computing the ratio of benefits to costs (the well known 'benefit-cost ratio') or by subtracting costs from benefits (the net benefits). Benefit-cost ratios greater than one or positive net benefits are usually considered as economic justification for the adoption of the system under consideration." (7)

The primary function of a small sign support is to position a sign panel so that the message contained thereon is communicated to the driving public. There is no question that in so doing it performs a very beneficial function. However, all candidate systems that satisfy the design requirements of Chapter II would presumably perform this function equally well and hence there would be no measurable differences in such benefits. There are, however, measurable differences in the cost of various systems which perform this function. A secondary function or benefit of a sign support system is to give way or yield during vehicular impact so that the striking vehicle and its occupants receive little if any damage. Safety would therefore be the primary benefit that would accrue to a given system. A cost-benefit analysis conducted to determine the most appropriate small sign support system for a given agency would consider both the present and future costs associated with the various sign support systems under consideration, and the present and future benefits associated with those systems. The system with the largest ratio of benefits to costs would be selected as the most appropriate system under consideration.

In reality, differences in benefits as defined above (safety) for various small sign supports that meet current safety standards (4) are relatively small and difficult to measure. The state of knowledge is not sufficient to allow one to define or predict levels of injuries that may occur from impact with a small sign support. Fortunately, results of recent crash tests with small single post installation (3,8,9,10) indicate the likelihood of injury, at least serious injury, will be small if a sign support meets current safety standards (4). With regard to vehicle damage, results from the referenced crash tests also showed that there was little difference in vehicle damage at low-speed impacts for various support types. Greater differences in vehicle damage occurred during high-speed impacts. In general, base bending or yielding posts inflicted more damage than posts that fractured or broke away. It is noted, however, that various size posts were evaluated in the referenced test programs and in general the damage was proportionate to the post size. Also, compact automobiles were used in the referenced test programs, as required (12). In essence, it is concluded that a sufficient data base does not exist from which one could objectively differentiate probable vehicle damage costs resulting from impacts with candidate support systems, considering the wide variety of vehicles and impact conditions that prevail on the streets and highways. These facts notwithstanding, an agency should place primary emphasis on the selection of a support system which minimizes the hazard the system represents to the motorists.

Because of the points enumerated in the preceding paragraph, a cost-benefit analysis of competing small sign support systems appears unfeasible at this time. As a consequence, the choice of an appropriate system reduces to determining the system with the lowest overall costs, including both present and future costs, provided the system satisfies the safety and design requirements outlined in Chapter II. The following section presents the formulas and procedures used to calculate the present and future costs of sign support systems.

III-B. Present Worth of Total Costs Associated with a System (6,11)

NOMENCLATURE

P_{TC} - Present worth of total costs associated with a system

IC - Initial costs

P_{AC} - Present worth of annual costs

AC - Annual costs associated with operating and maintaining the system

i - Compound interest rate

n - Period of analysis

C_A - Annualized cost of a system (i.e., annual operating costs plus capital recovery costs)

The present worth of all costs associated with a system is equal to the initial cost of the system, plus the present worth of annual operating costs. Or,

$$P_{TC} = IC + P_{AC} \qquad \text{(Eq. 1)}$$

If it is assumed that the annual costs (AC) associated with the system are uniform throughout the period of analysis (n) of the program, then the present worth of the annual costs (P_{AC}) associated with the program can be defined by the following expression:

$$P_{AC} = AC \left[\frac{(1 + i)^n - 1}{i(1 + i)^n} \right] \qquad \text{(Eq. 2)}$$

Substituting the right-hand sides of equation 2 into equation 1 produces the following equation:

$$P_{TC} = IC + AC\left[\frac{(1 + i)^n - 1}{i(1 + i)^n}\right] \qquad \text{(Eq. 3)}$$

For convenience, let

$$K_{PU} = \frac{(1 + i)^n - 1}{i(1 + i)^n} \qquad \text{(Eq. 4)}$$

Then equation 3 can be written as follows:

$$P_{TC} = IC + AC(K_{PU}) \qquad \text{(Eq. 5)}$$

Note that K_{PU} is referred to as the "present worth factor for a uniform series". Values of K_{PU} are given in Table III-B-1 for various combinations of "i" and "n".

The preceding paragraphs have shown how to calculate the present worth of the total costs of a project, program, or system. At this point the question might reasonably be asked: Why do we need to calculate the present worth of the total costs associated with sign support systems?

If all acceptable sign support systems had equal repair and maintenance costs and no salvage value, then the most appropriate system would be the one with the lowest initial cost. No present worth calculations would be required to determine the most appropriate sign support system. As a practical matter, however, different sign support systems do have different salvage values and maintenance/repair costs. If a given support system has a low initial cost, but high maintenance/repair costs, then that system may

TABLE III-B-1. PRESENT WORTH FACTOR - UNIFORM SERIES (K_{PV})

Service Life in Years (n)	Compound Interest (i) .04	.05	.06	.07	.08	.09	.10
1	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
2	1.8861	1.8594	1.8334	1.8080	1.7833	1.7591	1.7355
3	2.7751	2.7232	2.6730	2.6243	2.5771	2.5313	2.4869
4	3.6299	3.5460	3.4651	3.3872	3.3121	3.2397	3.1699
5	4.4518	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908
6	5.2421	5.0757	4.9173	4.7665	4.6229	4.4859	4.3553
7	6.0021	5.7864	5.5824	5.3893	5.2064	5.0329	4.8684
8	6.7327	6.4632	6.2098	5.9713	5.7466	5.5348	5.3349
9	7.4353	7.1078	6.8017	6.5152	6.2469	5.9952	5.7590
10	8.1133	7.7217	7.3601	7.0236	6.7100	6.4177	6.1446
11	8.7605	8.3064	7.8869	7.4987	7.1390	6.8052	6.4951
12	9.3851	8.8633	8.3838	7.9427	7.5361	7.1607	6.8137
13	9.9856	9.3936	8.8527	8.3577	7.9038	7.4869	7.1034
14	10.5631	9.8986	9.2950	8.7455	8.2442	7.7862	7.3667
15	11.1184	10.3797	9.7122	9.1079	8.5595	8.0607	7.6061
16	11.6523	10.8378	10.1059	9.4466	8.8514	8.3126	7.8237
17	12.1657	11.2741	10.4773	9.7632	9.1216	8.5436	8.0216
18	12.6593	11.6896	10.8276	10.0591	9.3719	8.7556	8.2014
19	13.1339	12.0853	11.1582	10.3356	9.6036	8.9501	8.3649
20	13.5903	12.4622	11.4699	10.5940	9.8181	9.1285	8.5136
21	14.0292	12.8212	11.7641	10.8355	10.0168	9.2922	8.6487
22	14.4511	13.1630	12.0416	11.0612	10.2007	9.4424	8.7715
23	14.8568	13.4886	12.3034	11.2722	10.3711	9.5802	8.8832
24	15.2470	13.7986	12.5504	11.4693	10.5288	9.7066	8.9847
25	15.6221	14.0393	12.7834	11.6536	10.6748	9.8226	9.0770
26	15.9828	14.3752	13.0032	11.8258	10.8100	9.9290	9.1609
27	16.3296	14.6430	13.2105	11.9867	10.9352	10.0266	9.2372
28	16.6631	14.8981	13.4062	12.1371	11.0511	10.1161	9.3066
29	16.9837	15.1411	13.5907	12.2777	11.1584	10.1983	9.3696
30	17.2920	15.3725	13.7648	12.4090	11.2578	10.2737	9.4269

$$\text{Tabulated Values} = \frac{(1 + i)^n - 1}{i\,(1 + i)^n}$$

be less advantageous than another system with high initial costs, but low maintenance/repair costs. In short, when agencies select a sign support system to fit their needs, they must consider not just the initial costs of the system but the costs they must meet throughout the period of analysis.

The most direct (but erroneous) means of determining the total costs is to add together the initial costs and annual operating costs of the system, and then subtract the salvage value of the program's component parts. This procedure is erroneous because inherent in such a procedure is the assumption that the value of money remains constant with time, which is not true. Disregarding inflation, ten dollars received today is more valuable than ten dollars received five years from now, by an amount equal to the interest ten dollars will yield over a five-year period. Conversely, a ten dollar transaction which will take place five years from now is equivalent to a lesser transaction today. Or in other words, cost transactions which will take place in the future must be discounted in value if they are to be compared directly to current costs. Equation 2 provides a formula for discounting the annual operating costs of a program throughout the period of analysis of the system*.

*This equation assumes that annual operating costs are constant throughout the period of analysis of the system.

III-C. Discussion of Required Input Parameters for Analysis of Candidate Systems

A procedure is presented in Section III-D for computing the total cost of a given sign support system for a given period of analysis. Discussed below are the input parameters that are required for this procedure.

III-C-1. Initial Costs (IC)

Additional equipment and/or storage facilities may be required if a new system is adopted. Costs of these items must be determined and included as initial costs. If the service life of these items is less than that of the support system, then future costs of such items during the service life of the support system must be computed and discounted to present worth.

Selection of a new system may also require additional time on the part of sign crews to become familiar with the system. To the extent possible, an agency may wish to estimate "start-up" or orientation costs which would occur if a new system were selected. Normally the orientation process would be accomplished within a year after adoption of the system, and the costs would therefore be included as part of the initial costs.

III-C-2. Annual Costs

For convenience, annual costs are subdivided into four parts: (1) those due to the annual purchase of support system component parts; (2) those associated with the installation of new signs; (3) those associated with the restoration of installations knocked down by errant motorists; (4) and those associated with other maintenance activities. The reason for the subdivision is twofold. First there are measurable differences in the cost of each of the four items for the various small sign support systems. Some systems have relatively low material costs but relatively high installation and maintenance costs. The converse is true for other systems. These differences could be easily overlooked or assumed negligible if annual costs were not subdivided. Secondly, most agencies will either have a good estimate of the required input data for each of the four subdivisions or be able to secure it from available sources.

It should be noted that the procedure outlined in the next section assumes that the component parts purchased annually, item 1, are used to perform items 2, 3, and 4 in the above mentioned subdivision. Hence, the last three items mainly involve labor costs to perform the respective functions and salvage value of reusable and damaged parts.

1. Purchase of component parts - One of the primary annual costs is the purchase of component parts of the support system, i.e., signposts, base posts (if used), footings (if used), and hardware such as fasteners, clamps, etc. Fabrication costs must be included where appropriate, such as breakaway systems with slip bases. Research Report 3254-1 (1) contains a summary of unit costs of various components of widely used support systems. Unfortunately, these costs are based on 1975 prices and should therefore be used with much discretion. At best, these data may be used to make gross comparisons of costs. *It is essential that current prices of component parts be obtained prior to conducting an analysis.*

When comparing the costs of candidate systems, it should be assumed that the same number of support systems will be purchased annually for each candidate system. In reality, fewer annual purchases will be required for systems with components that are reusable. For example, systems with break-away mechanisms will normally have reusable components after an impact whereas a wood post would not. However, to simplify the analysis procedure it was concluded that savings due to reusability of components could best be accounted for as salvage values (negative costs) in items 3 and 4.

2. Installation costs - A certain number of new sign installations are installed each year by agency personnel. An estimate of the number of such installations must be made. Man-hours of labor to install the various size installations should be estimated. Travel time to and from an installation would not normally be included since it would be independent of the support system. Average cost per man-hour of labor to install a new sign system must be estimated.

The above data may be obtained from existing records, from sign crews and maintenance personnel, from material suppliers, and from other agencies using the system in question. In the absence of such information, reference may be made to the estimates given in the next chapter and Research Report 3254-1 (1).

3. Collision maintenance costs - The following should be estimated for each candidate support system, considering damage caused by an average or typical impact:

(a) Man-hours to restore installation - This includes time necessary to remove and replace damaged parts or the time to straighten or refurbish damaged parts. Travel time to and from installation would not normally be included since in most cases it would be independent of the support system.

(b) Salvage value of components - Installation components may be salvaged for scrap and/or refurbished and reused. Value of the salvaged components less the labor costs to salvage them is the salvage value. As an aid in determining salvage value after a typical impact, an agency should estimate the probability of replacement of the various components for each candidate system. The sign panel sould be included as a salvageable item. As a matter of fact, it will usually be the most costly item of the installation, and its damage will typically be influenced by the type of support used. As a general rule, less panel damage will occur for posts which break away or fracture on impact than those which bend or yield without fracturing.

The above data may be obtained from existing records, from interviews with sign crews and maintenance personnel, from material suppliers, or from other agencies employing the system in question. In the absence of such information, reference may be made to the estimates given in the next chapter or Research Report 3254-1 (1).

Also required is an estimate of the number of installations that will be knocked down per year. Most state agencies have accident data coded such that the number of reported sign accidents per year can be determined. However, this will have to be supplemented from other sources since many, if not most, small sign impacts go unreported, i.e., no formal accident report is made. Maintenance management systems are also being adopted by many states, and these should greatly increase the data base needed to objectively evaluate systems.

4. Normal maintenance costs - All annual maintenance activities other than those associated with new installations or collision repairs are termed normal maintenance. This includes painting, repairing, and/or replacing vandalized installations, straightening posts in soil, replacing worn-out installations, and repairing and/or replacing installations damaged by storms. Costs associated with repair or replacement of the panel(s) only would normally be disregarded unless such costs are known to be related to the type of support system. Normal maintenance costs should be determined on a unit basis, i.e., for an average installation. Unit values of material, such as paint, and labor required to maintain an average installation are desirable. An estimate of the total number of in-place installations should be made.

Support system components replaced as a consequence of vandalism or damage from a storm may have a salvage value. The number of such replacements per year and their unit salvage value should be estimated. Presumably, a support system replaced as a consequence of being worn-out will have no salvage value.

The above data may be obtained from existing records, from sign crews and maintenance personnel, from material suppliers, and from other agencies using the system in question. In the absence of such information, reference may be made to the estimates given in the next chapter and Research Report 3254-1 (1).

III-C-3. Interest Rate

The following excerpt from Reference 13 is offered for consideration in selecting a discount or interest rate:

> "To summarize, if benefit and cost streams are expressed in constant dollars, a constant dollar discount rate should be used. If a current dollar discount rate is used (which includes the anticipated inflation rate), the benefit and cost streams must be inflated to current dollars also. The final choice of an interest rate or rates is up to the analyst or decision maker, but a rate of about four to five percent seems appropriate for projects of average risk evaluated in constant dollars. For simplicity, the constant dollar approach is recommended, but for projects for which the benefit and cost streams are in current dollars, the average anticipated rate of inflation should be added to the constant dollar discount rate. (To obtain the sum of two interest rates, add their product to their sum; for example, the sum of four percent and five percent would be (4% x 5%) + 9%, which equals 9.2%. To reverse this process and solve for a missing component interest rate, subtract the known component rate from the total rate and divide the result by one plus the known component rate. For example, the real rate of return that would total ten percent with a five percent rate of inflation is 4.76 percent. This is derived from: (10% - 5%) ÷ 1.05.)"

III-C-4. Service Life

Service life per se is not an input to the analysis procedure presented herein. However, the service life of a candidate system will have a bearing on its future costs. Specifically, normal maintenance costs of a system as discussed in Section III-C-2 will be directly related to its service life. In general, normal maintenance costs decrease as service life increases.

Service life will depend not only on the type of support but the geographic area in which it is being deployed. Service life of steel posts may diminish in areas near salt water or where salt is used for deicing and/or areas of high precipitation. Protective coatings of paint or galvanizing will obviously extend the service life of steel posts. Wood posts are also susceptable to shorter service lives when exposed to high moisture levels. Most agencies use pressure treated wood preservatives or paint to prolong the service life of wood posts.

In the absence of more definitive data, service lives for various posts may be obtained from the data in Research Report 3254-1 (1).

III-C-5. Period of Analysis

Selection of a period of analysis is arbitrary, however, an agency should keep in mind that implicit in the analysis procedure presented is an assumption of uniform or constant costs. If all future costs associated with each candidate system increased or decreased in the same proportions, the relative costs would remain unchanged, and the period of analysis would be immaterial. Such an occurrence is highly unlikely. As a consequence the analysis should be based on a relatively short period. Another consideration in selecting a period of analysis is how often it would be feasible for an agency to change its support system. It would obviously be unfeasible to change every year. A five-year period appears to be a reasonable value for analysis.

III-D. Outline of Procedure

Following is a step-by-step outline of the suggested evaluation procedure for a given candidate system. This procedure should be repeated for each system evaluated.

1. Determine initial costs (IC)($)

   (a) Determine cost of new equipment and/or storage facilities. (See Section III-C-1 for explanation.)

   Let C_E = cost of new equipment and/or storage facilities ($)

   (b) Determine "orientation" costs. (See Section III-C-1 for explanation.)

   Let C_O = orientation costs ($)

   Thus,

$$IC = C_E + C_O \qquad \text{(Eq. 11)}$$

2. Select an interest rate (i)

   (See Section III-C-3 for suggestions.)

3. Select a period of analysis (n) (years)

   (See Section III-C-4 for suggestions.)

4. Determine unit values of support system component parts

   (See Section III-C-2 for discussion of following variables.)

   Let N_P^k = number of posts of size "k" to be purchased each year for small sign installations

   Then, the total number of posts, N_P, to be purchased during year for small sign installation is computed by:

$$N_P = \sum_{k=1}^{m} N_P^k \qquad \text{(Eq. 12)}$$

Where m = number of different size posts to be purchased.

For a post of size "k", let

C^k_{SP} = unit price of signpost (\$/ft) (Should include fabrication costs if appropriate)

C^k_{BP} = unit price of base post (if used)(\$/ft) (Should include fabrication costs if appropriate)

C^k_S = unit price of sleeve (if used)(\$/ft)

C^k_F = unit price of footing if other than natural soil, such as concrete (\$/ft)

C^k_H = unit price of hardware (\$/post)

Note that the above unit prices will have to be determined for each post size purchased. For a signpost of size "k", let

L^k_{SP} = typical length of signpost (ft)

L^k_{BP} = typical length of base post (if used)(ft)

L^k_S = typical length of sleeve (if used)(ft)

L^k_F = typical length of footing (if used)(ft)

5. Compute annual cost of support system component parts (AC_P) (\$/year)

$$AC_P = \sum_{k=1}^{m} (N^k_P) \left[(L^k_{SP})(C^k_{SP}) + (L^k_{BP})(C^k_{BP}) + (L^k_F)(C^k_F) + (L^k_S)(C^k_S) + C^k_H\right] \qquad \text{(Eq. 13)}$$

6. <u>Compute annual cost of installing new systems</u> (AC_N) (\$/year) - (See Section III-C-2 for discussion of following variables.)

Let,

N_I^k = total number of new installations with posts of size "k" installed annually

H_I^k = number of man-hours typically required to install a system of size "k" (man-hours/installation)

C_I = unit labor cost to install a new system (\$/man-hours)

Then,

$$AC_N = C_I \sum_{k=1}^{m} (N_I^k)(H_I^k) \qquad \text{(Eq. 14)}$$

7. <u>Determine annual costs of collision repairs (AC_C) (\$/year)</u> - (See Section III-C-2 for discussion of following variables)

Let,

H_C^k = man-hours required to restore installations with posts of size "k" after typical collision (man-hours/collision)

C_C = unit labor cost to repair signs (\$/man-hr)

SV_C^k = salvage value of material after typical collision with post of size "k" (\$/installation/collision)

N_C^k = number of collisions involving installations with posts of size "k" annually

Now,

$$AC_C = (C_C) \sum_{k=1}^{m} (H_C^k)(N_C^k) - \sum_{k=1}^{m} (N_C^k)(SV_C^k) \qquad \text{(Eq. 15)}$$

where variables are as previously defined.

It should be noted that it is entirely possible that AC_C will be negative. In fact, the system becomes more cost-effective as AC_C decreases in the negative direction. However, this should not be interpreted to mean that collisions or accidents are in any way beneficial. Each accident will result in some degree of restoration and, at best, these repairs will be paid by the errant motorist. If not, there will be a direct cost to the agency. In either case there will be a cost to society. Equation 15 accounts for the cost of labor to repair damaged installations whereas Equation 13 accounts for the annual cost of support system components, portions of which are used to restore knocked down installations. Also, Equation 15 accounts for the salvage value of the entire installation, including the panel. In reality, the more negative AC_C is for a given system, the fewer will be the number of posts and panels purchased each year.

8. Determine annual costs of normal maintenance (AC_M) ($/year)

(See Section III-C-2 for discussion of following variables.)

Let,

H_N^k = man-hours per installation per year required to perform normal maintenance for post of size "k" (man-hrs/installation/year)

C_{MN}^k = unit cost of material, other than support components, used to maintain support system, such as paint for post size "k" ($/installation/year)

C_N = unit labor cost to perform normal maintenance ($/man-hr)

N^k = total number of in-place small sign installations having posts of size "k" within agencies' jurisdiction

N_{PN}^{k} = number of support systems with posts of size "k" replaced annually due to storm damage, vandalism, or theft

SV_{N}^{k} = salvage value of support system with posts of size "k" replaced due to storm damage, vandalism, or theft ($/installation)

Then,

$$AC_M = \sum_{k=1}^{m} (N^k)\left[(H_N^k)(C_N) + C_{MN}^k\right] - \sum_{k=1}^{m} (N_{PN}^k)(SN_N^k) \qquad \text{(Eq. 16)}$$

9. Compute present worth of annual costs (P_{AC}) ($)

$$P_{AC} = (AC_P + AC_N + AC_C + AC_M)(K_{PU}) \qquad \text{(Eq. 17)}$$

where AC_P is defined in Eq. 13, AC_N is defined in Eq. 14, and AC_C is defined in Eq. 15; AC_M is defined in Eq. 16, and K_{PU} is defined in Eq. 5.

10. Compute present worth of total costs (P_{TC}) ($)

$$P_{TC} = IC + P_{AC} \qquad \text{(Eq. 18)}$$

III-E. Example of Analysis Procedure

The following hypothetical example will be used to illustrate application of the procedure outlined in Section III-D.

1. Determine initial costs (IC) ($)

   (a) Adoption of the system would require purchase of three utility trunks and new driving equipment. Total cost would be $25,000. No new storage facilities would be required. Thus,

$$C_E = \$25,000$$

   (b) It was determined that the system could be adopted without appreciable start-up or orientation costs. Hence,

$$C_O = 0.0$$

   Thus,

$$\underline{\underline{IC = \$25,000}}$$

2. Select an interest rate (i)

$$i = 0.05 \text{ (or 5 percent)}$$

3. Select a period of analysis (n) (years)

$$n = 5 \text{ years}$$

4. Determine unit values of support system component parts

   It was determined that three different size posts would be needed. Hence,

$$m = 3$$

Further, it was determined that the following numbers of each size post would be needed:

N_p^1 = 20,000/year (small posts)

N_p^2 = 20,000/year (medium size posts)

N_p^3 = 10,000/year (large posts)

Thus,

$Np = 20{,}000 + 20{,}000 + 10{,}000$

or

$\underline{Np = 50{,}000/\text{year}}$

The following unit prices were determined for the various components:

POST SIZE (k)	SIGNPOST ($/ft)	BASE POST ($/ft)	FOOTING ($/ft)*	HARDWARE ($/post)
1	0.50	0.75	0.0	1.00
2	1.00	1.25	0.0	1.50
3	1.50	1.75	0.0	2.00

*Base driven in existing soil.

It was determined that typical lengths of the components would be:

POST SIZE (k)	SIGNPOST (ft)	BASE POST (ft)
1	10	3
2	12	3
3	14	3.5

5. <u>Compute annual cost of support system component parts (AC_P) ($/year)</u>

$$AC_P = (20{,}000)\left[(10)(0.5) + (3)(0.75) + 1.00\right]$$
$$+ (20{,}000)\left[(12)(1.00) + (3)(1.25) + 1.50\right]$$
$$+ (10{,}000)\left[(14)(1.50) + (3.5)(1.75) + 2.00\right]$$

$$AC_P = 165{,}000 + 345{,}000 + 291{,}250$$

or

$$\underline{AC_P = \$801{,}250/\text{year}}$$

6. <u>Compute annual cost of installing new systems (AC_N) ($/year)</u>

It was determined that

$$N_I^1 = 4{,}000/\text{year}$$

$$N_I^2 = 4{,}000/\text{year}$$

$$N_I^3 = 2{,}000/\text{year}$$

$$H_I^1 = H_I^2 = 1.5 \text{ man-hrs/installation}$$

$$H_I^3 = 2.0 \text{ man-hrs/installation}$$

$$C_I = \$5.50/\text{man-hr}$$

Thus,

$$AC_N = 5.50\left[(4{,}000)(1.5) + (4{,}000)(1.5) + (2{,}000)(2.0)\right]$$

$$\underline{AC_N = \$88{,}000/\text{year}}$$

7. <u>Determine annual costs of collision repairs (AC_C) ($/year)</u>

It was determined that

$H_C^1 = H_C^2 = 1.0$ man-hrs/installation

$H_C^3 = 1.5$ man-hrs/installation

$C_C = \$5.50$/man-hr

$SV_C^1 = \$3.00$/installation (average salvage value of installation using post of size "1")

$SV_C^2 = \$4.00$/installation (average salvage value of installation using post of size "2")

$SV_C^3 = \$5.00$/installation (average salvage value of installation using post of size "3")

$N_C^1 = N_C^2 = 15{,}000$/year

$N_C^3 = 7{,}500$/year

Thus,

$$AC_C = 5.50\left[(1.0)(15{,}000) + (1.0)(15{,}000) + (1.5)(7{,}500)\right] - \left[(15{,}000)(3.00) + (15{,}000)(4.00) + (7{,}500)(5.00)\right]$$

$$AC_C = 226{,}875 - 142{,}500$$

$$\underline{\underline{AC_C = +\$84{,}375/\text{year}}}$$

8. <u>Determine annual costs of normal maintenance (AC_M) ($/year)</u>

It was determined that

$H_N^1 = H_N^2 = 0.10$ man-hrs/installation/year

$H_N^3 = 0.15$ man-hrs/installation/year

$C^1_{MN} = C^2_{MN} = C^3_{MN}$ = \$0.25/installation/year

C_N = \$5.50/man-hr

$N^1 = N^2$ = 200,000

N_3 = 100,000

N^1_{PN} = 1000/year (number of installations using post of size "1" replaced annually due to storm damage, vandalism, or theft)

N^2_{PN} = 1000/year (number of installations using post of size "2" replaced annually due to storm damage, vandalism, or theft)

N^3_{PN} = 500/year (number of installations using post of size "3" replaced annually doe to storm damage, vandalism or theft)

SV^1_N = \$1.00/installation

SV^2_N = \$2.00/installation

SV^3_N = \$3.00/installation

Thus,

$$
\begin{aligned}
AC_M = {} & (200{,}000)\left[(0.10)(5.50) + 0.25\right] \\
& + (200{,}000)\left[(0.10)(5.50) + 0.25\right] \\
& + (100{,}000)\left[(0.15)(5.50) + 0.25\right] \\
& - \left[(1{,}000)(1.00) + (1{,}000)(2.00) + (500)(3.00)\right]
\end{aligned}
$$

$$AC_M = 427{,}500 - 4500$$

$$\underline{AC_M = \$423{,}000/\text{year}}$$

9. <u>Compute present worth of annual costs (P_{AC}) ($)</u>

$$P_{AC} = (801,250 + 88,000 + 84,375 + 423,000)(K_{PU})$$

Where K_{PU} = 4.3295 (from Table III-B-1, with n = 5 and i = 0.05)

Thus,

$$\underline{\underline{P_{AC} = \$6,046,688}}$$

10. <u>Compute present worth of total costs (P_{TC}) ($)</u>

$$P_{TC} = 25,000 + 6,046,688$$

$$\underline{\underline{P_{TC} = \$6,071,688}}$$

IV. ANALYSIS OF AVAILABLE SYSTEMS

The purpose of this chapter is to present an insight into relative costs of current sign support systems and the sensitivity of costs to input variables. To the extent possible, values used in the analysis are current and reasonably representative. Data from the survey (1) were used to supplement current data when necessary and applicable. It cannot be overemphasized, however, that many of the data used in the analysis are "best estimates" that may or may not be representative. *Selection of a system should not be based solely on the contents of this chapter. It is essential that an agency determine or make a reasonable estimate of input values as they exist at the given local at the time of the analysis.*

Analysis of each system will follow the procedure presented in Section III-D. Assumptions and limitations made in the analysis are identified and discussed in the respective parts of the analysis procedure.

IV-A. Adherence to Design and Safety Standards

For purposes of this analysis it will be assumed that each system evaluated satisfies the design standards as outlined in Section II-C-1. With regard to impact behavior, each system has in fact satisfied AASHTO safety performance criteria. Reference should be made to Appendix A for data on the crashworthiness of these systems.

IV-B. Analysis Constraints

The number, types, and sizes of signposts purchased annually will obviously vary considerably from agency to agency. It is therefore impractical to select a typical or average set of constraints for analysis purposes. However, the constraints chosen enable one to at least make a gross comparison of the relative costs of various systems and at the same time illustrate the analysis procedure.

Assume that an agency makes an annual purchase of posts or post systems for 30,000 installations that support panel areas up to 7 ft^2 (0.65 m^2) and posts or post systems for 30,000 installations that support panel areas up to 12 ft^2 (1.2 m^2). Design wind speed is 70 mph (31.3 m/s). For analysis purposes, the following average values were assumed:

For panel areas up to 7 ft^2 (0.65 m^2):

A = panel area = 7 ft^2 (0.65 m^2)

e = distance from vertical centerline of panel to resultant wind force (used to compute twisting moment on single post installations) = 5.0 in. (12.7 cm)

h = distance from groundline to resultant wind force on panel = 8.0 ft (2.44 m)

C_d = drag coefficient for panel = 1.2

C_h = coefficient of height = 0.8

ℓ_p = distance from groundline to bottom of sign panel = 7.0 ft (2.14 m)

For panel areas up to 12 ft^2 (1.12 m^2):

A = 12 ft^2 (1.12 m^2)

e = 6.0 in. (15.24 cm)

h = 8.5 ft (2.59 m)

C_d = 1.2

C_h = 0.8

ℓ_p = 7.0 ft (2.14 m)

Using the guidelines in the Specifications (4), the following drag coefficients for the support posts were selected:

Post Type	C_d
Steel flanged channel or U-post	1.7
Wood (rectangular cross section)	1.7
Round pipe	1.1
Square steel tube	1.7
Aluminum type X	1.7

Yield stresses (F_Y) used in the analysis were as follows:

Post Type	F_Y (lb/in.^{2})
Steel flanged channel or U-post	60,000
Wood	1,350
Standard steel pipe	35,000
Square steel tube	40,000
Aluminum type X	35,000

Metric Conversions: 1 lb/in.^{2} = 6,895 Pa

A total of eight support systems were evaluated, as given in Table IV-B-1. Using the values previously defined and the analysis procedure in the AASHTO Specifications (4), the minimum post sizes required for each system were determined and are presented in Table IV-B-1. Design details and photographs of these systems are given in Research Reports 3254-1 (1) and 3254-3 (3) and the literature (8,9,10). Note the following:

Painted Post

TABLE IV-B-1. MINIMUM SYSTEM SIZES.

SYSTEM	MINIMUM SIZE OF SUPPORT ELEMENTS FOR PANEL AREA OF: 7 ft^2	12 ft^2
1. Full-length steel flanged channel or U-post, galvanized[a]	3 lb/ft	Two 2 lb/ft posts
2. Steel flanged channel or U-post base and signpost with bolted base assembly, galvanized (Eze-Erect System)	3 lb/ft post and 3 lb/ft base	Two 2 lb/ft posts and Two 2.75 lb/ft bases
3. Steel flanged channel or U-post base and signpost with frangible coupling, galvanized posts[a]	3 lb/ft post and 3 lb/ft base	Two 2 lb/ft posts and Two 2 lb/ft bases
4. Southern pine, grade 2, pena treated wood post	4 in. x 6 in. (nominal)	4 in. x 6 in. (nominal)
5. Standard steel pipe, schedule 40, galvanized[a]	2.0 in. I.D.	2.5 in. I.D. (with threaded pipe collar)
6. Standard steel pipe, schedule 40, with triangular slip base, galvanized	2.0 in. I.D.	2.5 in. I.D.
7. Telescoping square steel tube (Telspar System), galvanized	2.25 in. x 2.25 in. x 0.105 in. post, 2.5 in. x 2.5 in. x 0.105 in. anchor, and 3.0 in. x 3.0 in. x 0.135 in. sleeve	2.5 in. x 2.5 in. x 0.135 in. post and 3.0 in. x 3.0 in. x 0.1875 in. anchor
8. Aluminum type X (Magnode Products, Inc., System)	Two 2X posts	Two 3X posts

[a]See text for discussion of this system.

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 ft^2 = 0.093 m^2
1 lb/ft = 1.489 kg/m

1. Tests of system 1 (3) showed that adverse impact behavior may occur at high speeds (60 mph) (96.6 km/h), depending on the alloy of the post. Specific size limitations, alloy requirements, test certifications, etc., have not been clearly defined at this time for this type post. However, based on available test data, acceptable preformance of the two configurations given in Table IV-B-1 can be achieved if the post material is rail steel or has equivalent properties.

2. Note in system 3 that a frangible coupling at the base of the signpost is used as a breakaway device. At the time of this writing, the structural adequacy of the coupling for design loads had not been clearly established. It is not known with certainty that the couplings are equivalent in strength to the respective steel U-posts they are used with. It was assumed that they were equivalent in this analysis. Agencies considering this system should of course obtain certified strength capabilities prior to its adoption. Crash tests demonstrated the acceptability of the couplings considered in the analysis from a safety standpoint.

3. Note in system 4, a 2.5 in. (6.35 cm) I.D. pipe is required for the larger sign panel. However, this size pipe does not meet AASHTO safety performance specifications without a breakaway mechanism. Hence, the threaded pipe collar design, or some other acceptable weakening or breakaway device, must be used for pipe larger than 2.0 in. (5.08 cm) I.D.

It is assumed that posts used to support the smaller panel area will be 9.5 ft (2.90 m) in length above ground and those that support the larger panel will be 11 ft (3.36 m) in length above ground. Assumed embedment details are given in Table IV-B-2.

TABLE IV-B-2. ASSUMED EMBEDMENT DETAILS.

SYSTEM	ASSUMED EMBEDMENT DETAILS		
	Base Length (ft)	Embedment Depth (ft)	Method of Embedment
1. (a) 3 lb/ft full-length steel U-post	None	3.5	Driven
(b) Two 2 lb/ft full-length steel U-Posts	None	3.5	Driven
2. (a) 3 lb/ft steel U-post base and signpost with bolted base assembly	3.5	3.08	Driven
(b) Two 2.75 lb/ft steel U-post bases and two 2.0 lb/ft steel U-signposts with bolted base assemblies	3.5	3.08	Driven
3. (a) 3 lb/ft steel U-post base and signpost with frangible coupling	3.5	3.25	Driven
(b) Two 2 lb/ft steel U-post bases and signposts with frangible coupling	3.5	3.25	Driven
4. 4 in. x 6 in. wood post	None	4.0	Drill and Backfill.
5. (a) 2.0 in. I.D. steel pipe	None	3.5[a]	Drill and Backfill.
(b) 2.5 in. I.D. steel pipe with threaded pipe collar	2.0	2.5 concrete footing 2.0 base	12 in. O.D. non-reinforced concrete footing.
6. Steel pipe with triangular slip base	2.33	2.5 concrete footing 2.0 base	12 in. O.D. non-reinforced concrete footing
7. Telescoping square steel tube	3.5 base 1.5 sleeve	3.33 base 1.33 sleeve	Driven
8. (a) Two full-length aluminum type 2X posts	None	3.5	Driven
(b) Two full-length aluminum type 3X posts	None	3.5	Driven

[a] It is assumed that a 4 in. x 12 in. x 0.25 in. steel plate is welded to the base of the post to prevent twisting from wind loads.

Metric Conversions:
1 in. = 2.54 cm
1 ft = 0.305 m
1 lb/ft = 1.489 kg/m

IV-C. Application of Suggested Procedure

The following analysis follows the outline presented in Section III-D.

IV-C-1. Determine initial costs of systems

It is assumed that there are no initial costs required to incorporate any of the systems under consideration. While the validity of this assumption is, quite frankly, suspect, there appears to be no rational way to assign such costs without unfairly biasing the results. For example, suppose an agency is considering four systems, one of which it has been using for a number of years. It is entirely possible that adoption of one of the three new systems will entail capital expenditures for new equipment and/or storage facilities. Consideration of such costs can only be accomplished on an agency-to-agency basis.

IV-C-2. Select an interest rate

Let

$$i = 0.05 \text{ (5 percent)}$$

IV-C-3. Select a period of analysis

Let

$$n = 5 \text{ years}$$

IV-C-4. Determine unit values of support system component parts

Table IV-C-1 shows the number of support system components needed annually. Note that $k = 1$ will refer to components for the smaller panel area, and $k = 2$ will refer to components for the larger panel area. Also note that $m = 2$. Reference should be made to Table IV-B-1 for descriptions of the systems.

TABLE IV-C-1. REQUIRED NUMBER OF COMPONENTS.

SYSTEM	N_P^1	N_P^2	N_P
1	30,000	60,000	90,000
2	30,000	60,000	90,000
3	30,000	60,000	90,000
4	30,000	30,000	60,000
5	30,000	30,000	60,000
6	30,000	30,000	60,000
7	30,000	30,000	60,000
8	60,000	60,000	120,000

Typical lengths and best estimates of unit prices of support components are given in Tables IV-C-2. Note in system 7, the signpost is inserted 1.5 ft (0.46 m) into the base post. Also note that a 4 ft (1.22 m) length of U-post is nested into the signpost in the impact zone in System 3 (listed as a sleeve in Table IV-C-2).

IV-C-5. Compute annual cost of support system component parts (AC_P)

Using Equation 13, AC_P was computed for each system, and the results are presented in Table IV-C-3.

IV-C-6. Compute annual cost of installing new systems (AC_N)

Assume that 8,000 new sign installations are installed each year for each of the two panel sizes, i.e.,

$$N_I^1 = N_I^2 = 8{,}000$$

and that

$$C_I = \$8.00/\text{man-hr}$$

for each system.

Table IV-C-4 contains best estimates of man-hours typically required to install the various systems. These numbers were arrived at by analysis of survey data (1), by personal interviews with various transportation officials, and from observations made during installation of the systems for crash testing (3).

From Equation 14, AC_N was computed for each system, and the results are presented in Table IV-C-5.

IV-C-7. Determine annual cost of collision repairs (AC_C)

Assume

$$C_C = \$8.00/\text{man-hr}$$

for each system. Also assume that 15,000 installations of each size are impacted each year, i.e.,

$$N_C^1 = N_C^2 = 15{,}000$$

TABLE IV-C-2. ASSUMED TYPICAL LENGTHS AND UNIT PRICES.

SYSTEM	Lengths (ft) of: SIGNPOST (L_{SP})	BASE (L_{BP})	SLEEVE (L_S)	CONCRETE FOOTING (L_F)	Unit Price of: SIGNPOST (C_{SP}) ($/ft)	BASE (C_{SP}) ($/ft)	SLEEVE (C_S) ($/ft)	FOOTING (C_F) ($/ft)	HARDWARE (C_H) ($/post)
k=1									
1	13.0	-	-	-	1.10	-	-	-	-
2	9.5	3.5	-	-	1.10	1.10	-	-	1.00
3	9.5	3.5	4.0[a]	-	1.10	1.10	0.85	-	5.00
4	13.5	-	-	-	0.85	-	-	-	-
5	13.0	-	-	-	0.80	-	-	-	8.00
6	9.27	2.33	-	2.5	3.00	3.50	-	1.00	1.00
7	11.0	3.5	1.5	-	1.50	1.60	1.80	-	-
8	13.0	-	-	-	0.89	-	-	-	-
k=2									
1	14.5	-	-	-	0.75	-	-	-	-
2	11.0	3.5	-	-	0.75	1.00	-	-	1.00
3	11.0	3.5	4.0[a]	-	0.75	0.75	0.85	-	4.50
4	15.0	-	-	-	0.85	-	-	-	-
5	11.0	2.0	-	2.5	1.30	1.30	-	1.00	1.00
6	10.67	2.33	-	2.5	4.00	4.50	-	1.00	1.00
7	12.5	3.5	-	-	2.00	4.50	-	-	-
8	14.5	-	-	-	1.27	-	-	-	-

[a]See text for discussion of this item.

Metric Conversions:

1 ft = 0.305 m

TABLE IV-C-3. ASSUMED ANNUAL COSTS OF COMPONENT PARTS.

SYSTEM	AC_p ($/YEAR)
1	1,081,500
2	1,224,000
3	1,807,500
4	726,750
5	1,164,000
6	2,883,900
7	1,966,500
8	1,799,100

TABLE IV-C-4. ASSUMED LABOR TO INSTALL SYSTEMS.

SYSTEM	H_I (man-hr) k=1	H_I (man-hr) k=2
1	0.5	1.0
2	0.4	0.8
3	0.4	0.8
4	1.5	1.5
5	0.8	2.5
6	3.0	3.0
7	0.4	0.5
8	1.0	1.0

TABLE IV-C-5. ASSUMED ANNUAL COST OF INSTALLING NEW SYSTEMS.

SYSTEM	AC_N (\$/year)
1	96,000
2	76,800
3	76,800
4	192,000
5	211,120
6	384,000
7	57,600
8	128,000

Best estimates of the man-hours required to restore each system after a typical collision (H_C) and the salvage value of the material in each system after a typical collision are presented in Table IV-C-6. Assumptions made in arriving at salvage values of the support systems are given in Tables IV-C-7 and IV-C-8. Note that salvage of the sign panel is included in the estimate. It is estimated that the completed panel (with message) costs $\$3.00/ft^2$ ($\$32.25/m^2$). Hence, the 7 ft^2 (0.65 m^2) panel would cost \$21.00, and the 12 ft^2 (1.12 m^2) panel would cost \$36.00.

From Equation 15, AC_C was computed for each system, and the results are presented in Table IV-C-9.

IV-C-8. Determine annual cost of normal maintenance (AC_M)

Assume there are a total of 100,000 installations of size k=1 and 100,000 installations of size k=2, i.e.,

$$N^1 = N^2 = 100,000$$

Assume

$$C_N = \$8.00/\text{man-hr}$$

Since each system has a protective treatment to reduce corrosion and deterioration, it will be assumed that

$$C_{MN} = 0.0$$

for all systems.

Best estimates of man-hours per installation per year required to perform normal maintenance on each system is given in Table IV-C-10.

TABLE IV-C-6. ASSUMED RESTORATION AND SALVAGE VALUE OF SYSTEMS AFTER TYPICAL COLLISION.

	LABOR FOR RESTORATION (H_C)(MAN-HRS/COLLISION)		SALVAGE VALUE (SV_C) ($/INSTALLATION/COLLISION) SUPPORT SYSTEM		PANEL		TOTAL	
SYSTEM	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2
1	0.70	1.20	0.70	1.10	2.00	3.00	2.70	4.10
2	0.25	0.50	5.70	6.10	8.00	14.00	13.70	20.10
3	0.25	0.5	7.30	9.90	8.00	14.00	15.30	23.90
4	1.60	1.60	0.00	0.00	8.00	14.00	8.00	14.00
5	1.00	0.50	1.00	7.50	2.00	14.00	3.00	21.50
6	0.40	0.40	24.40	34.60	10.00	18.00	34.40	52.60
7	0.25	0.25	8.80	14.80	8.00	14.00	16.80	28.80
8	1.20	1.20	9.35	15.70	5.00	7.00	14.35	22.70

TABLE IV-C-7. ESTIMATES USED TO COMPUTE SALVAGE VALUE OF SUPPORT SYSTEMS, k=1.

SYSTEM	PERCENT OF IMPACTS WHERE BASE REUSABLE (%)	① SALVAGE VALUE OF BASE ($/COLLISION/INSTALLATION)	PERCENT OF IMPACTS WHERE SIGNPOST REUSABLE (%)	② SALVAGE VALUE OF REUSABLE SIGNPOSTS ($/COLLISION/INSTALLATION)	PERCENT OF IMPACTS WHERE DAMAGED SIGNPOST CAN BE REUSED AS BASE POST (%)	③ SALVAGE VALUE OF DAMAGED SIGNPOST ($/COLLISION/INSTALLATION)	TOTAL SALVAGE VALUE ①+②+③ ($/COLLISION/INSTALLATION)
1	-	-	0	0	-	0.70[a]	0.70
2	60	2.40[c]	10	1.00	75	2.30[b,c]	5.70
3	60	2.40[c]	30	3.10	60	1.80[b,c]	7.30
4	-	-	0	0	-	0	0
5	-	-	5	0.50	-	0.50[a]	1.00
6	95	10.10	50	13.90	40	0.40[b,c]	24.40
7	60	5.20[c]	0	0	75	3.60[b,c]	8.80
8	-	-	0	0	-	9.35[d,e]	9.35

[a]Figure based on assumption that scrap value equals 5 percent of initial cost.

[b]It is assumed that 0.15 man-hrs per post are used to salvage base post from signpost.

[c]Figure includes scrap value of damaged parts at 5 percent of initial value.

[d]It is assumed that both posts are damaged in any given collision.

[e]Scrap value provided by Magnode Products, Inc.

TABLE IV-C-8. ESTIMATES USED TO COMPUTE SALVAGE VALUE OF SUPPORT SYSTEMS, k=2.

SYSTEM	PERCENT OF IMPACTS WHERE BASE REUSABLE (%)	① SALVAGE VALUE OF BASE ($/COLLISION/INSTALLATION)	PERCENT OF IMPACTS WHERE SIGNPOST REUSABLE (%)	② SALVAGE VALUE OF REUSABLE SIGNPOSTS ($/COLLISION/INSTALLATION)	PERCENT OF IMPACTS WHERE DAMAGED SIGNPOST CAN BE REUSED AS BASE POST (%)	③ SALVAGE VALUE OF DAMAGED SIGNPOST ($/COLLISION/INSTALLATION)	TOTAL SALVAGE VALUE ①+②+③ ($/COLLISION/INSTALLATION)
1	-	-	0	0	-	1.10[a]	1.10
2	50	3.70[c]	10	1.70	0	0.70[b,c]	6.10
3	50	2.80[c]	30	5.00	60	2.10[b,c]	9.90
4	-	-	0	0	0	-	0
5	60	3.10	20	2.90	70	1.50[b,c]	7.50
6	95	12.30	50	21.30	40	1.00[b,c]	34.60
7	60	9.50[c]	0	0	75	5.30[b,c]	14.80
8	-	-	0	0	-	15.70[d,e]	15.70

[a] Figure based on assumption that scrap value equals 5 percent of initial cost.

[b] It is assumed that 0.15 man-hrs per post are used to salvage base post from signpost.

[c] Figure includes scrap value of damaged parts at 5 percent of initial value.

[d] It is assumed that both posts are damaged in any given collision.

[e] Scrap value provided by Magnode Products, Inc.

TABLE IV-C-9. ASSUMED ANNUAL COLLISION COSTS

SYSTEM	AC_C^a ($/YEAR)
1	+126,000
2	-417,000
3	-498,000
4	+ 54,000
5	-187,500
6	-1,209,000
7	-624,000
8	0267,750

[a]Reference should be made to Section III-D, item 7, for a discussion of the significance of negative AC_C values.

TABLE IV-C-10. ASSUMED LABOR FOR NORMAL MAINTENANCE.

SYSTEM	H_I(man-hr/installation/year)	
	k=1	k=2
1	0.1	0.15
2	0.1	0.15
3	0.1	0.15
4	0.1	0.1
5	0.1	0.05
6	0.05	0.05
7	0.1	0.1
8	0.15	0.15

Assume 3,500 installations of each post size are replaced annually due to normal wear. Assume there is no salvage value for such posts. Table IV-C-11 contains assumed man-hours to replace worn-out supports.

Assume 3,500 installations of each post size are replaced annually due to storm damage. Assume the labor to restore such installations and the salvage value of the support system are equal to that after a typical collision, as given in Table IV-C-6. Assume there is no measurable difference in the salvage value of the panel for each system after storm damage.

Using the assumed values and Equation 16, the annual normal maintenance costs were computed and are given in Table IV-C-12.

IV-C-9. Compute present worth of annual cost (P_{AC})

From Table III-B-1,

$$K_{PU} = 4.3295$$

Using Equation 17, the present worth of annual cost for each system for a five-year period was computed, and the results are presented in Table IV-C-13.

IV-C-10. Compute present worth of total cost (P_{TC})

Since it was assumed that there were no initial costs associated with any of the eight systems analyzed, the present worth of total cost, P_{TC}, equals the present worth of annual costs computed in Section IV-C-9 . Note that if there are no initial costs, the relative costs of each system can be determined from annual costs.

Based on this analysis and the assumed values, the relative costs of the eight systems are shown in Figure IV-C-1.

TABLE IV-C-11. LABOR TO REPLACE WORN-OUT SUPPORT SYSTEMS.

SYSTEM	H_I(man-hr/installation) k=1	k=2
1	0.70	1.20
2	0.50	1.00
3	0.50	1.00
4	1.60	1.60
5	1.00	3.00
6	3.75	3.75
7	0.50	0.70
8	1.20	1.20

TABLE IV-C-12. ASSUMED ANNUAL NORMAL MAINTENANCE COSTS.

SYSTEM	AC_M ($/YEAR)
1	300,100
2	221,700
3	202.800
4	339,200
5	244,250
6	105,900
7	133,400
8	286,730

TABLE IV-C-13. ASSUMED PRESENT WORTH OF ANNUAL COSTS.

SYSTEM	P_{AC} ($)
1	6,942,780
2	4,786,260
3	6,880,010
4	5,680,090
5	6,199,280
6	9,372,500
7	6,639,280
8	8,425,550

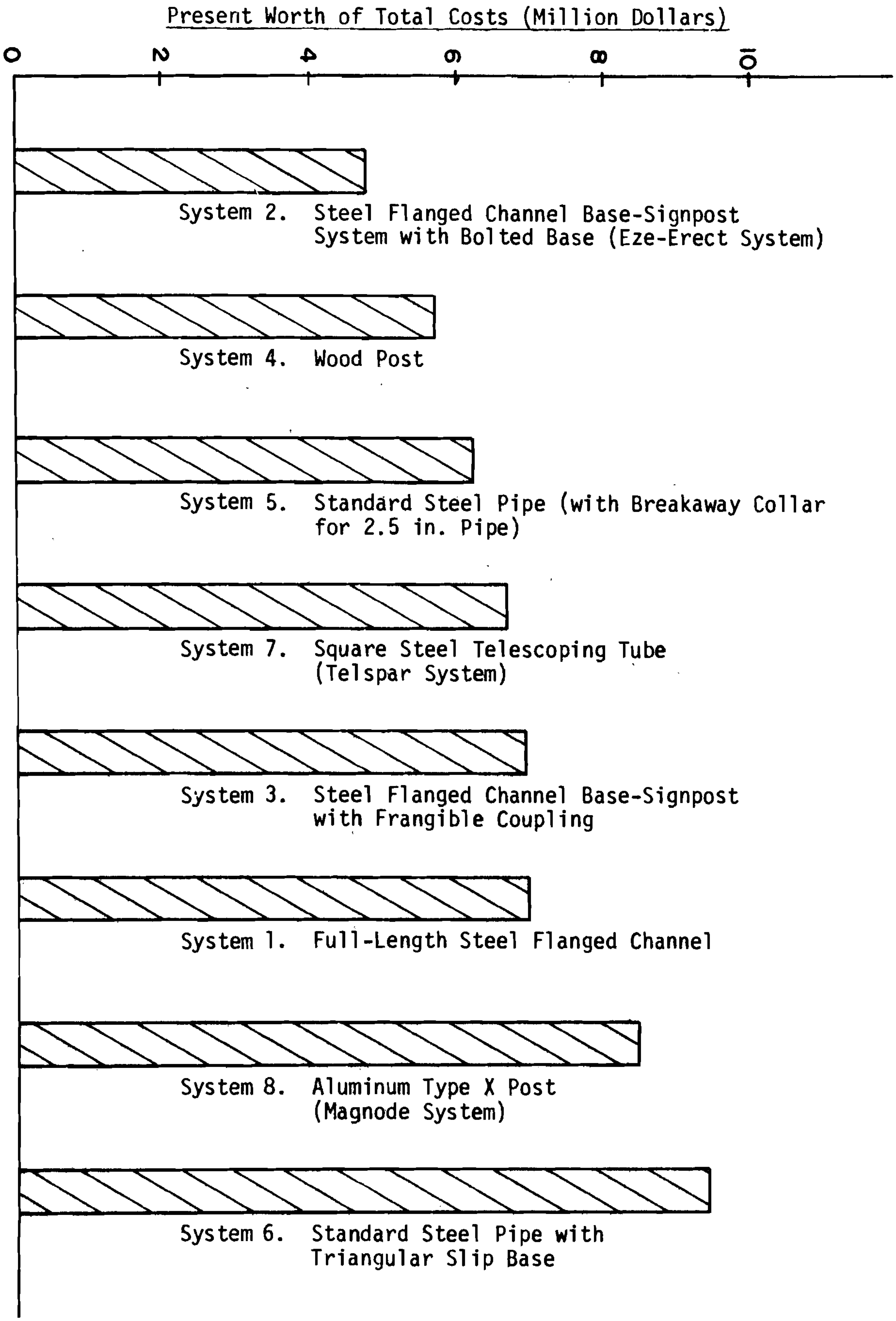

FIGURE IV-C-1. COSTS OF SUPPORT SYSTEMS CONSIDERED IN EXAMPLE.

IV-D. Sensitivity Analysis

A knowledge of the sensitivity of costs to the input variables is important in evaluating various candidate systems. Figure IV-D-1 shows how costs of the systems analyzed in the previous section vary as the ratio of the number of installations knocked down to new installations changes. All other input values were as given in Section IV-C. As shown, costs of each system decrease as the ratio increases. However, it is important to note the rate of decrease of each system. Systems with relatively low collision repair costs and high salvage values (such as systems 2, 3, 5, 6, and 7) decrease at a considerably higher rate than do the other systems. In particular, note that system 6 (pipe with slip base) is much more costly than all other systems for a low ratio but is more cost-effective than two of the systems at the higher ratio.

Figure IV-D-2 shows how costs vary as the ratio of installations knocked down to total installations purchased annually changes. All other input variables were as given in Section IV-C. Again, the rate of change of costs varies from system to system, with those that have lower collision repair costs and higher salvage values having the lower rate of increase.

Figure IV-D-3 shows the influence of labor cost on the total cost of each system. All other input variables were as given in Section IV-C. Systems which require relatively little labor to install, repair, and maintain such as systems 2, 5, and 7 have a lower rate of increase with increasing labor costs than do the other systems.

It should be noted that the most cost-effective sign support system may actually be a combination of two systems. For example, it may be

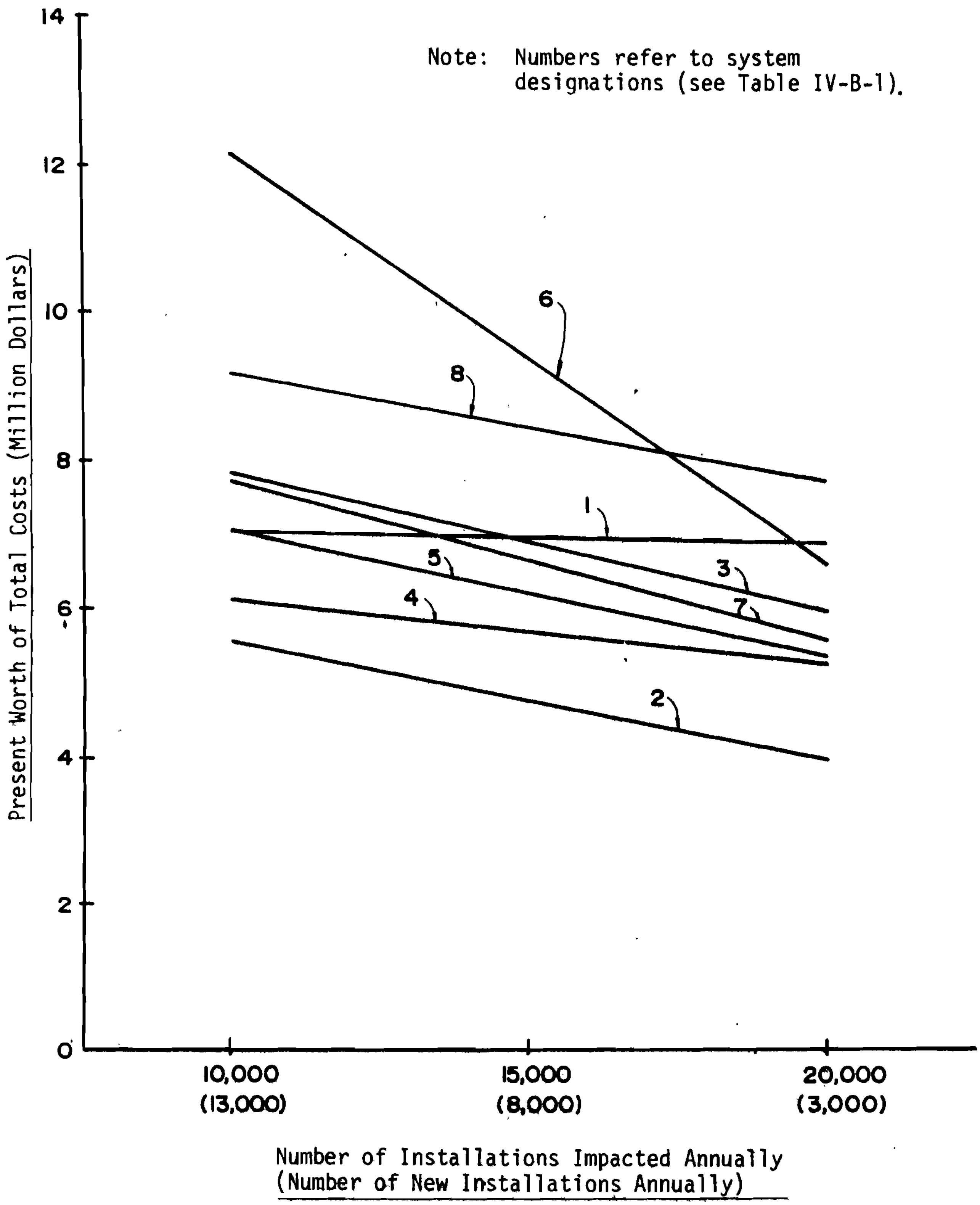

FIGURE IV-D-1. COSTS AS FUNCTION OF RATIO OF IMPACTED INSTALLATIONS TO NEW INSTALLATIONS.

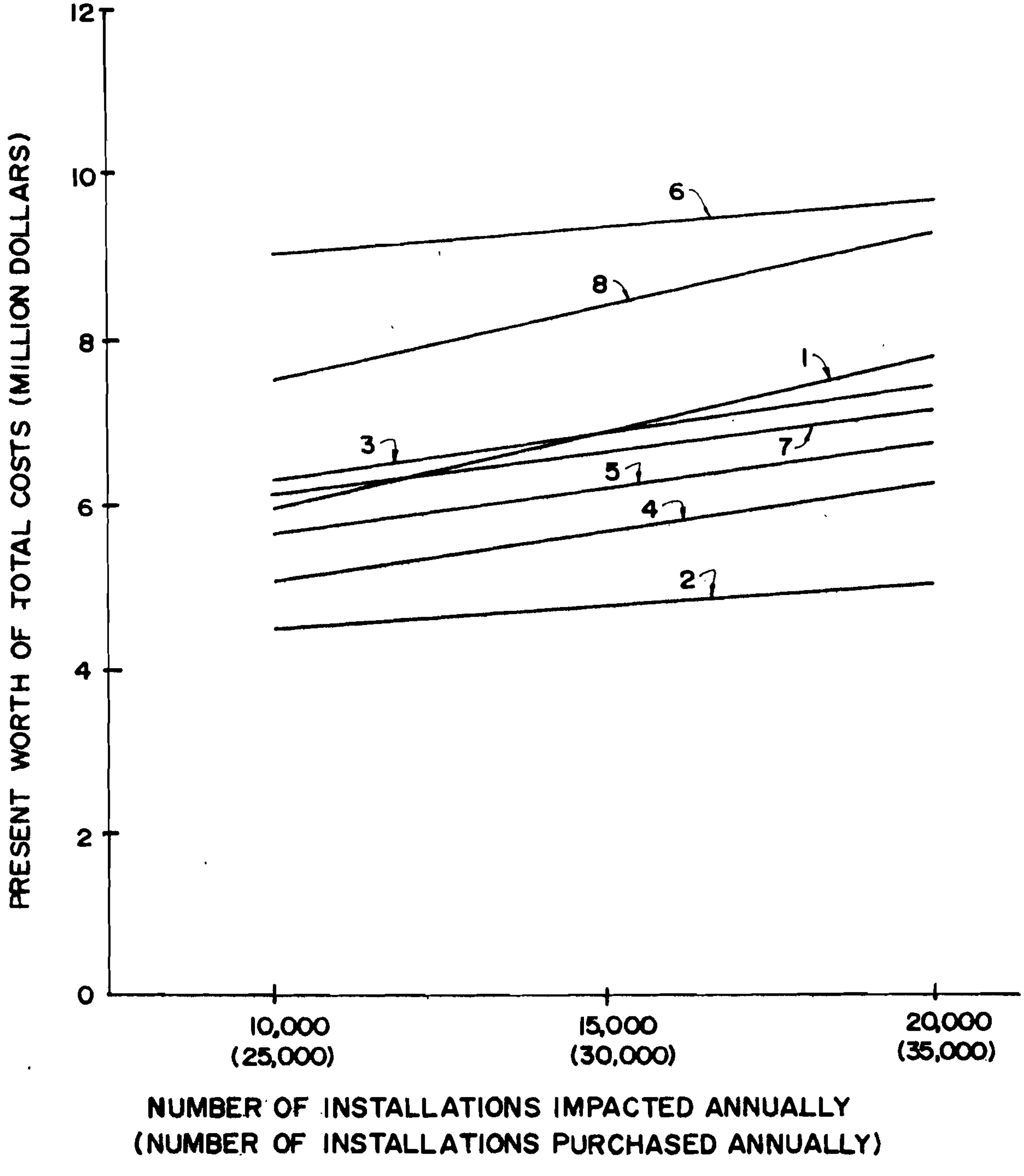

FIGURE IV-D-2. COSTS AS FUNCTION OF RATIO OF IMPACTED INSTALLATIONS TO NUMBER OF INSTALLATIONS PURCHASED.

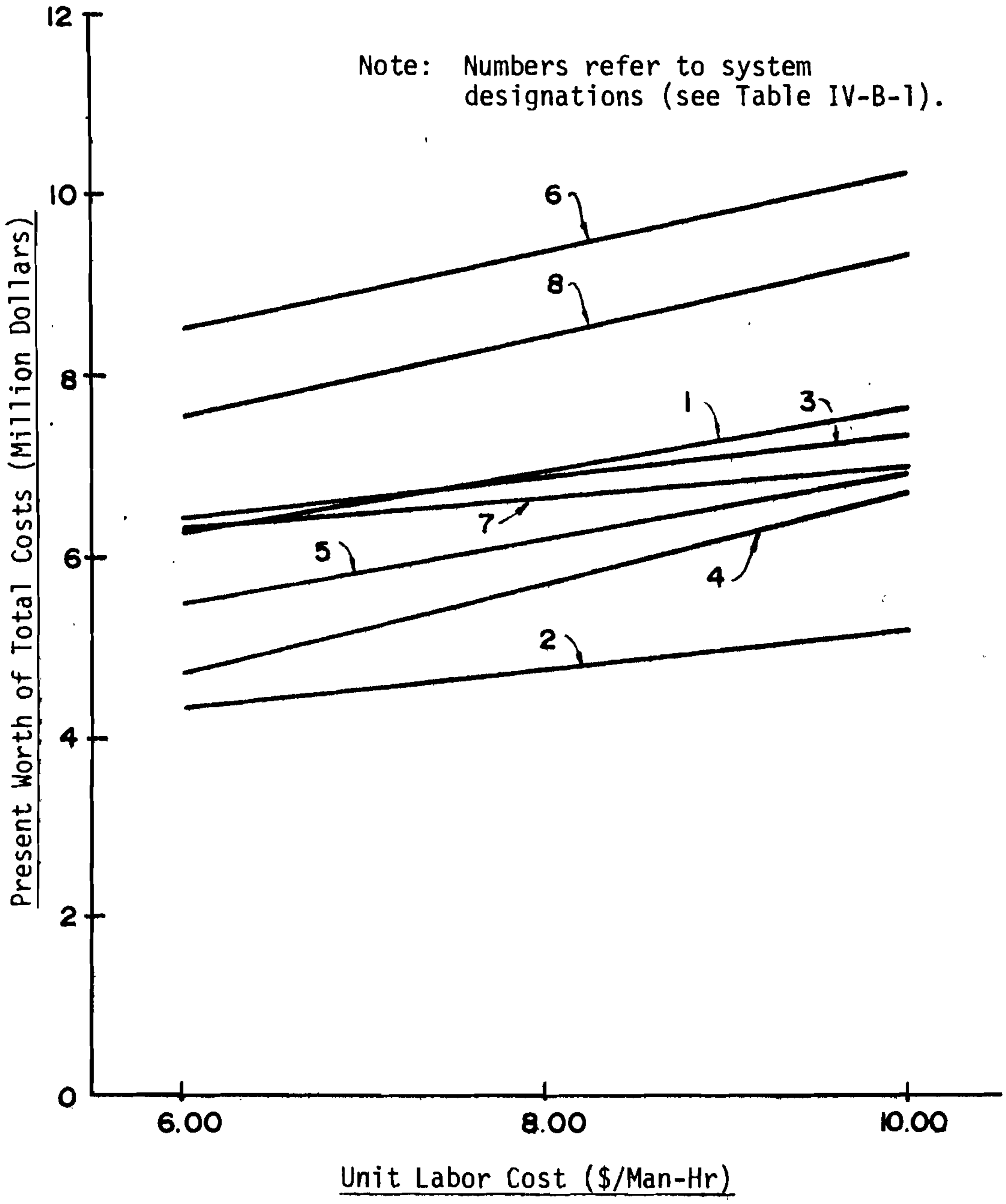

FIGURE IV-D-3. COSTS AS FUNCTION OF LABOR COSTS.

V. SUMMARY AND CONCLUSIONS

Most, if not all, transportation agencies are experiencing increasing demands for services without accompanying increases in revenues. Consequently, more and more emphasis is being placed on the selection of cost-effective or cost-beneficial systems and programs.

Annual costs associated with the installation and maintenance of small highway sign supports are usually a significant portion of an agency's annual expenditures. It is therefore incumbent upon responsible officials to evaluate the cost-effectiveness of available support systems before a selection is made. Guidelines and analysis procedures are presented to aid in the evaluation and selection process.

Three basic factors must be evaluated for a given candidate system:

(1) Safety - The system should not pose an undue hazard to the traveling public. Impact behavior of widely used systems and promising new systems is provided in the report. Behavior is defined in terms of current AASHTO (4) performance specifications. Although these specifications are aimed at highway conditions, it should be a goal of county and municipal agencies to achieve a level of safety comparable to that of state agencies. This can be accomplished without compromising costs in most cases.

(2) Design - The system should meet an agency's design specifications in terms of strength, durability, aesthetics, service life, etc. Most state transportation agencies require that the candidate system meet the AASHTO design specifications(4). Design characteristics not addressed in

the Specifications (4) which may be important are (a) method of post embedment, (b) storage and handling requirements, (c) versatility, (d) design complexity, (e) flutter, and (f) availability of system for short- and long-term needs.

(3) Economics - Candidate systems satisfying items 1 and 2 should be evaluated to determine the most cost-effective or economical system. Chapter III of this report contains a procedure for this purpose, considering five basic costs which are associated with a given system: (1) initial costs, (2) annual cost of components, (3) annual cost associated with new sign installations (4) annual cost associated with restoration of knocked down installations, and (5) annual cost associated with other maintenance activities such as replacement of worn-out systems. The procedure is used to compute the present worth of all such costs for a given system for a given period of analysis.

An analysis was conducted using the procedure of Chapter III to make a gross comparison of costs of various support systems. The analysis was based on a given set of constraints which are not necessarily typical. Also, it was necessary that estimates be made regarding certain input values. Discretion is therefore advised in interpretation of the results. It is highly advisable that an agency make its own analysis using conditions and input values appropriate for the given locale and time. With these cautions in mind, the analysis indicated that a steel flanged channel signpost-basepost system with a bolted base connection and wood posts are two of the more cost-effective sign support systems currently available.

A sensitivity analysis was also conducted to evaluate the effects of variables such as the number of installations impacted annually and labor costs. It was found that systems with breakaway devices such as a slip base, while having high initial costs, become more cost-effective as the number of installations impacted increase relative to the number of installations purchased annually. It was also found that a combination of two systems may be cost-effective, one for vulnerable areas where installations are frequently hit and another for the less vulnerable areas. A system that is easily repaired and has salvageable parts would be used for the vulnerable areas while a system with low initial costs would be used for other areas.

It is recognized that implementation of the guidelines and procedures proposed herein may entail a considerable effort, and in some cases estimates of input values will likely be required. In reality the problem is complex and there are a number of intangibles which must be addressed. The proposed guidelines and procedures should be considered as a tool to aid in the selection process. However, they must be used in conjunction with sound judgment and experience. The procedures also point out the need for comprehensive records of expenditures, labor, accident data, and maintenance activities relative to sign support systems.

APPENDIX A. CRASHWORTHINESS
OF SMALL SIGN SUPPORT SYSTEMS

APPENDIX A. CRASHWORTHINESS OF SMALL SIGN SUPPORT SYSTEMS

Systems given in Table A-1 have been evaluated in terms of current safety performance criteria (4) and found to be satisfactory for single post installations. References 1, 3, and 13 should be consulted for general design and installation details, photographs, and test results of these systems. Also presented in references 1 and 13 is a summary of current safety performance specifications and an evaluation of each system in terms of the specifications. Note that a "desirable" and a "maximum" limiting size is given for the signpost of each system. Sizes up to the desirable limit produced a change in momentum less than 750 lb-sec (341 kg/m). Sizes listed in the maximum column produced a change in momentum in excess of 750 lb-sec (341 kg/m) but less than 100 lb-sec (499 kg/m). Size breakdowns according to limiting changes in momentum are in keeping with AASHTO Specifications (4).

Also, as noted in Table A-1, absolute desirable and/or maximum limits of some systems have not been established, at least through crash testing. Limits given in Table A-1 are based on results from tests conducted in accordance with recommended guidelines (4,12).

As regards limits on multiple post installations, only limited test data are available. As noted in Table A-1, multiple post tests have been conducted on System A-a. Other multiple post tests are summarized in Appendix B of Reference 1.

Limits on the number and size of posts for single and multiple post installations have been established by FHWA (15). However, recent tests (3)

TABLE A-1. CRASHWORTHY SINGLE POST SIGN SUPPORT SYSTEMS.

SYSTEM DESCRIPTION	DESIRABLE	MAXIMUM
A. Steel U-post or flanged channel		
a. Rail steel U-post with bolted base assembly (Eze-Erect System)	4 lb/ft[b]	-
b. U-post with frangible cast iron coupling	3 lb/ft[f]	(e)
c. Full-length rail steel U-post	3 lb/ft[c]	6 lb/ft[d]
d. Full-length experimental billet steel U-post	6 lb/ft[d]	(e)
e. Vertical U-post with U-post back brace	-	2 lb/ft
f Full-length billet steel U-post	-	3 lb/ft
B. a. Wood post (with no breakaway or weakening devices) (No. 2 pena-treated southern pine or equivalent)	4 in. 6 in.[f] (Nominal Size)	(e)
b. Wood post (pena-treated southern pine or equivalent) with drilled holes to affect breakaway during impact - post embedded in concrete footing[h]	6 in. 8 in.[f] (Nominal Size)	(e)
C. Steel pipe (Schedule 40)		
a. Full-length pipe with no breakaway or weakening devices	2.0 in.ϕ	2.0 in.ϕ
b. Pipe with breakaway collar		2.5 in.ϕ
c. Pipe with breakaway slip base	4.0 in.ϕ	(e)
D. Square steel tube (perforated) with breakaway base (Telspar System)	2½ in. x 2½ in. 10 gauge	(e)
E. Aluminum Type X post (Magnode System)	3X[g]	6X[g]
F. Steel "W" or "S" shapes with breakaway slip base	(i)	W12x45

[a] See text for discussion.

[b] System not available for post larger than 4 lb/ft. However, tests of a multiple post installation in which three 4 lb/ft posts were impacted simultaneously proved satisfactory, i.e., change in momentum was less than desirable limit.

[c] Tests of post sizes between 3 lb/ft and 6 lb/ft have not been conducted, hence the desirable size limit is not known.

[d] Two 3 lb/ft posts bolted together back-to-back.

[e] Maximum size limit unknown.

[f] Tests of larger sizes not available, hence desirable limit is unknown.

[g] Size designations are Magnode Products, Inc., designations. Post sizes between 3X and 6X have not been tested, hence the actual desirable limit is unknown.

[h] See Reference 14 for details.

[i] Desirable limit unknown.

Metric Conversions:
1 in. = 2.54 cm
1 lb/ft = 1.489 kg/m

have shown that some of the recommended limits in Reference 15 are not appropriate, and at the time of this writing changes to the recommendations were being contemplated.

Three multiple post installations were used in the example analyzed in Chapter IV of this report. With reference to the designations in Table IV-B-1, System 2 used two 2 lb/ft (3.0 kg/m) steel U-posts for the larger sign installation. System 8 used two type 2X posts for the smaller installation and two type 3X posts for the larger installation. Satisfactory impact performance of both systems is inferred from crash test results (3,9,10,16) and from Reference 15.

APPENDIX B. REFERENCES

REFERENCES

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