ARIZONA DEPARTMENT OF TRANSPORTATION

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SMALL SIGN SUPPORT ANALYSIS

Phase III
Benefit/Cost Analysis

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16. Abstract

Guidelines were developed to assist ADOT in (1) determining if an existing sign installation, not in compliance with current safety standards, should be replaced by a system that does meet the safety standards, and (2) selecting a cost effective sign support for new installations. A benefit/cost (B/C) program, developed at TTI was used to develop the guidelines.

Existing systems that were analyzed included single and multiple post installations for both square steel tubes (ADOT P2 systems) and 3 lb/ft high carbon steel U-posts. Systems that were considered as candidates for new installations and for upgrading existing systems include installations with up to three 3 lb/ft high carbon steel U-posts with an improved short ground splice, standard steel pipe with a uni-directional slip base, and hollow rectangular sections of laminated veneer lumber.

This report is one of three reports prepared in the subject project. The other two are:

Small Sign Support Analysis:
Phase I - Crash Test Program
Phase II - Development of a New Small Sign Support (two volumes)

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PREFACE

Arizona Department of Transportation (ADOT) Project HPR-PL-1(31), Item 202, "Small Sign Support Analysis," was initiated by the Texas Transportation Institute (TTI) October 1, 1984. Originally, the project consisted of 18 full-scale vehicular crash tests to evaluate ADOT small sign supports. Upon completion of one-half of the tests it became evident that additional tests would be needed. The project was modified May 31, 1985 to increase the number of tests to 23. Also, the modification included a benefit/cost (B/C) study to develop guidelines for upgrading existing ADOT small sign supports and for selection of new small sign supports. The project was again modified in August, 1986 to develop an improved small sign support system. The B/C study was also modified to include results of the improved support system.

A description of the 23 crash tests and results therefrom are presented in a report entitled "Small Sign Support Analysis: Phase I - Crash Test Program."

A description of the study in which an improved sign support system was developed is presented in a report entitled "Small Sign Support Analysis: Phase II - Development of New Small Sign Support," (two volumes).

A description of the B/C study and results therefrom are presented herein.

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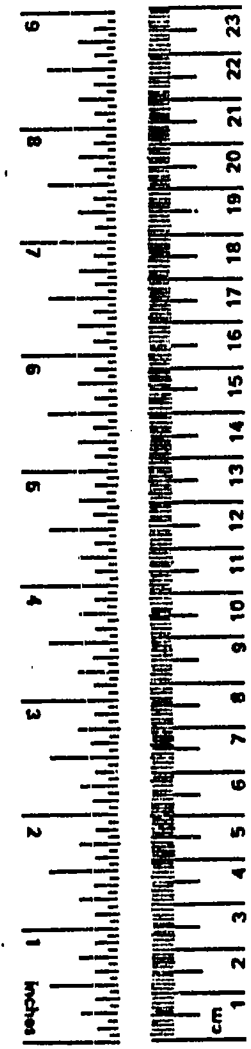
METRIC CONVERSION FACTORS

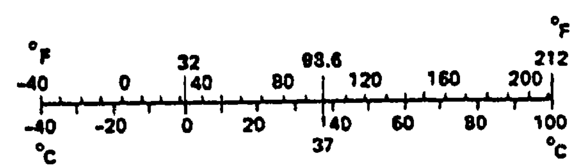
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

I. INTRODUCTION AND OBJECTIVES

This report is the culmination of a three part study on small sign supports. In phase I (1), widely used small sign installations by the Arizona Department of Transportation (ADOT), were crash tested and evaluated according to nationally recognized safety standards (2,3). Phase II (4) of the study focused on developing and testing improved sign support designs.

The third and final phase of this study, described herein, addressed the economics of small sign supports. The objectives were as follows:

(1) Develop guidelines that identify conditions for which an existing sign installation should be replaced with an improved (i.e. safer) system.

(2) Evaluate candidate systems for new installations in terms of their cost effectiveness.

II. STUDY APPROACH

A benefit/cost (B/C) program, developed at TTI, was used to accomplish the study objectives. Details of the program are documented in the literature (5,6) and will not be given here. Basically, the program estimates the benefits and costs of one safety alternative with respect to another. The B/C ratio is computed as follows:

$$B/C = \frac{\text{Difference in Accident Costs of Alternatives}}{\text{Difference in Direct Costs of Alternatives}} \quad \text{...........(1)}$$

Benefits are measured in terms of reductions in accident costs. A key element of the program is an encroachment-probability model used to estimate the frequency a given roadside feature will be struck by errant vehicles. Factors such as traffic volume (ADT), vehicle mix, operating speeds, the size and location of the roadside feature, and roadway alignment can be included in the analysis.

For each accident predicted to occur with a given roadside feature (e.g., a roadside sign) the program computes an accident's cost. Accident costs are related to impact severity through a "severity index" (SI). Table 1 shows the relationship between SI, the implied severity probability, and net accident costs that would result. The scale is given in the AASHTO Barrier Guide (7). Accident costs have been updated to reflect current estimates (8). Interpretation of the values in Table 1 are illustrated as follows. For an accident having an SI of 5.0, there is a 30 percent probability it will be a "property damage only" accident, a 65 percent probability it will be an accident with injuries, and a 5 percent probability it will be an accident with fatalities.

In general, the SI depends on the impact speed, impact angle, vehicle size, and the type of feature struck. The methodologies and assumptions used to estimate the SI for impacts with existing and candidate ADOT sign support systems are given in Appendix A.

The following are basic assumptions made in the application of the B/C model. Limitations relate primarily to input data.

1. Average Daily Traffic (ADT) for a highway design increases at an annual rate of 3% for a design life of 20 years.
2. The speed limit is 55 miles per hour.

TABLE 1. SEVERITY INDEX SCALE

Severity Index	% Property Damage Only Accidents	%Injury Accidents	Percent Fatal Accidents	Societal Cost Per Accident
0	100	0	0	$ 1,960
1	85	15	0	$ 4,230
2	70	30	0	$ 6,750
3	55	45	0	$ 9,200
4	40	59	1	$ 19,400
5	30	65	5	$ 52,000
6	20	68	12	$107,800
7	10	60	30	$203,000
8	0	40	60	$482,000
9	0	21	79	$629,000
10	0	5	95	$753,000

3. Service life for all alternatives is 20 years with an annual interest rate of 4%.
4. The relationship between severity indices and accident costs are as given in Table 1. Severity indices associated with the various sign support systems evaluated are discussed in Appendix A.
5. No adjustment is made for roadway alignment (roadway assumed to be straight).
6. Traffic delay cost associated with sign accidents is negligible.
7. Maintenance costs of all sign support systems considered are similar and therefore can be neglected.
8. Impact repair costs of all sign support systems considered are similar and therefore can be neglected.
9. Salvage value of all sign support systems considered is negligible.

It should be noted from item 2 that the assumed speed limit for the benefit/cost analysis was 55 mph. Many states, including Arizona, have recently adopted a higher limit of 65 mph for rural Interstate highways. The researchers do not anticipate a change in the guidelines developed herein due to this increased speed limit. Although there my conceivably be a slight increase in encroachment frequency due to higher speeds, there is not enough data currently available to quantify this change or to determine whether or not it is even significant. Furthermore, as discussed in Appendix A, crash tests have indicated that the severity associated with impacting small sign supports is independent of impact speed.

III. GUIDELINES FOR UPGRADING

A. Existing Systems Not in Compliance With Safety Standards

A review of Table A5, Appendix A, and data in reference 1 shows that all single post systems now used by ADOT are in compliance with current safety performance standards (2,3). From Table A7, Appendix A, and data in reference 1, it can be seen that the following systems are not in compliance:

(A) Installations with two or more square steel tubes (ADOT P2 Systems) within a 7 ft spacing, and

(B) All installations with three or more 3 lb/ft high carbon steel U-posts within a 7 ft spacing.

From Table A7, Appendix A, it can be seen that the two post, 3 lb/ft U-post system with the "short lap splice" is "marginally acceptable" since the estimated occupant impact velocity (15.5 ft/sec) is slightly greater than the recommended limit (15 ft/sec). However, preliminary B/C analysis of this system clearly showed that it would not be cost beneficial to replace existing installations.

B. Upgrading Alternatives

In the second phase of this contract, an alternate steel U-post support system was developed (4). It employs a short ground splice with the high carbon steel U-posts. Based on impact performance standards, up to three 3 lb/ft posts and two 4 lb/ft posts can be used within a 7 ft spacing for a given installation. Also developed in Phase II was a candidate for upgrading existing ADOT P2 systems (4). It consists of standard square steel tubes mounted on multi-directional slip bases. Up to four of these posts may be used within a 7 ft spacing for a given P2 system. Performance data for these systems are given in Tables A6 and A8, Appendix A.

Other systems were also considered as candidates to upgrade existing systems. These included standard steel pipe with a uni-directional slip base, aluminum tube, solid wood posts, and hollow rectangular sections of laminated veneer lumber.

Cross-sectional properties of the candidate systems are given in Table 2. Parameters given in the table are second moment of area, I, section modulus, S, tensile yield stress, Fy, and yield moment, My. The yield moment is a direct measure of the load carrying capacity of the post.

TABLE 2. PROPERTIES OF POSTS

Post Type	Size	I (in^4)	S (in^3)	Fy (ksi)	My (k-in)
Steel U-Post	3 Lb/Ft	0.415	0.419	80	33.5
	4 Lb/Ft	0.500	0.560	80	44.8
Steel Pipe	3" Diam.	3.02	1.72	36	61.9
	4" Diam.	7.23	3.21	36	115.6
	5" Diam.	15.2	5.45	36	196.2
Solid Wood	4" x 4"	21.3	10.7	1.4	14.9
	4" x 6"	72.0	24.0	1.4	33.6
Aluminum Tube	4" x 0.188"	4.08	2.04	35	71.4
Hollow Rectangular Laminated Veneer Lumber	7.875" x 7.875" x 1.25"	251.0	63.7	2.5	159.3
	7.875" x 14.875" x 1.25" [a]	1110.3 [b]	149.3 [b]	2.5	373.3 [b]

[a] Post weakened at base by saw cuts (13)

[b] Properties through weakened section

After discussions with ADOT engineers, the list of alternate systems was narrowed down to the following systems:

- 3 lb/ft High Carbon Steel U-Post with Ground Splice
- Square Steel Tube (ADOT P2 Post) with Slip Base
- Steel Pipe Post with Uni-Directional Slip Base
- Laminated Veneer Wood Post

The U-post and square tube were included because of their relatively low costs for upgrading and the improved safety performance of the ground splice and slip-base designs over existing installations. Also, ADOT has used the U-Post and square tube as sign supports for many years. Their sign crews are obviously familiar with these designs and little, if any, additional installation equipment would be required. The other two candidate systems were selected because of their excellent impact performance as demonstrated through crash tests and their load carrying capacity. Appendix A contains information and references on tests of these systems.

The selection of a steel pipe post with uni-directional slip base was meant to be representative of a wide variety of slip base designs. It was assumed that the performance of any slip base installation with features similar to the ones tested would be essentially the same and, therefore, would have a similar impact severity. In instances where a slip base design is judged to be cost-effective, it is intended for ADOT to use their slip-base design or some other slip-base installation which complies with current AASHTO specifications.

It is noted that at the present time only two post sizes are known to be available for the laminated wood posts as shown in Table 2. Currently, approval of these designs is limited to one support within a 7 ft spacing. The California Department of Transportation uses this system to support relatively large signs in lieu of steel shapes with slip bases. As will be shown later in this report, even the smaller of the two posts does not appear to be cost effective for most small sign installations. However, it is clear that if smaller sizes can be produced, the system has the potential to be a very cost effective small sign support alternative.

The 4 lb/ft U-posts were not considered because of ADOT's concern relative to the handling and installation of the heavier post by sign crews and problems that could arise if both the 3 lb/ft and the 4 lb/ft posts were used. Further, only two 4 lb/ft posts are permitted within a 7 ft spacing while three 3 lb/ft posts are permitted. The three post, 3 lb/ft system will carry approximately 12 percent more load than the two, 4 lb/ft system.

Aluminum pipe was ruled out because of strength and cost factors. Most existing ADOT installations that are candidates for upgrading (i.e., those that do not meet current safety standards) involve those with three or more U-posts within an 8 ft spacing. As such, one 4" x 0.188" aluminum pipe is not equivalent in load carrying capacity to three 3 lb/ft U-posts. Hence, a multiple-post aluminum system would be required. Based on crash test results (9), it is apparent that two 4" x 3/16" aluminum pipe supports within a 7 ft spacing would not meet safety standards. Two smaller aluminum pipes (say two 3 1/2" x 3/16") would satisfy the strength requirements, but the impact performance of such a system is not presently known.

The solid wood post was not considered because of its relatively low load carrying capacity and its impact performance. Based on previous tests (10), it was concluded that at most, only two 4" x 4" posts could be used within a 7 ft spacing and only one 4" x 6" could be used for compliance with current AASHTO safety standards (2).

C. B/C Analysis

As discussed in Section III-A, existing installations with two or more posts in the P2 system and existing installations with three or more 3 lb/ft U-posts are candidates for upgrading. The three systems considered as upgrading alternatives were described in Section III-B.

The need to upgrade a given installation depends in part on its offset or lateral distance from the travelway and the number and spacing of the support posts. The frequency of vehicular impacts will increase as the offset decreases. The severity of impacts will increase as the post spacing decreases. The offset distance and post spacing parameters are given in Figure 1. ADOT engineers indicated that most of their small signs have offsets between 12 ft and 20 ft. The guidelines were therefore developed for three offsets, namely 12 ft, 16 ft, and 20 ft. Post spacing of most ADOT signs is greater than 2 ft. A post spacing of 2 ft was used in the B/C analysis. As such, the analysis will generally overstate the severity of multiple-post installations.

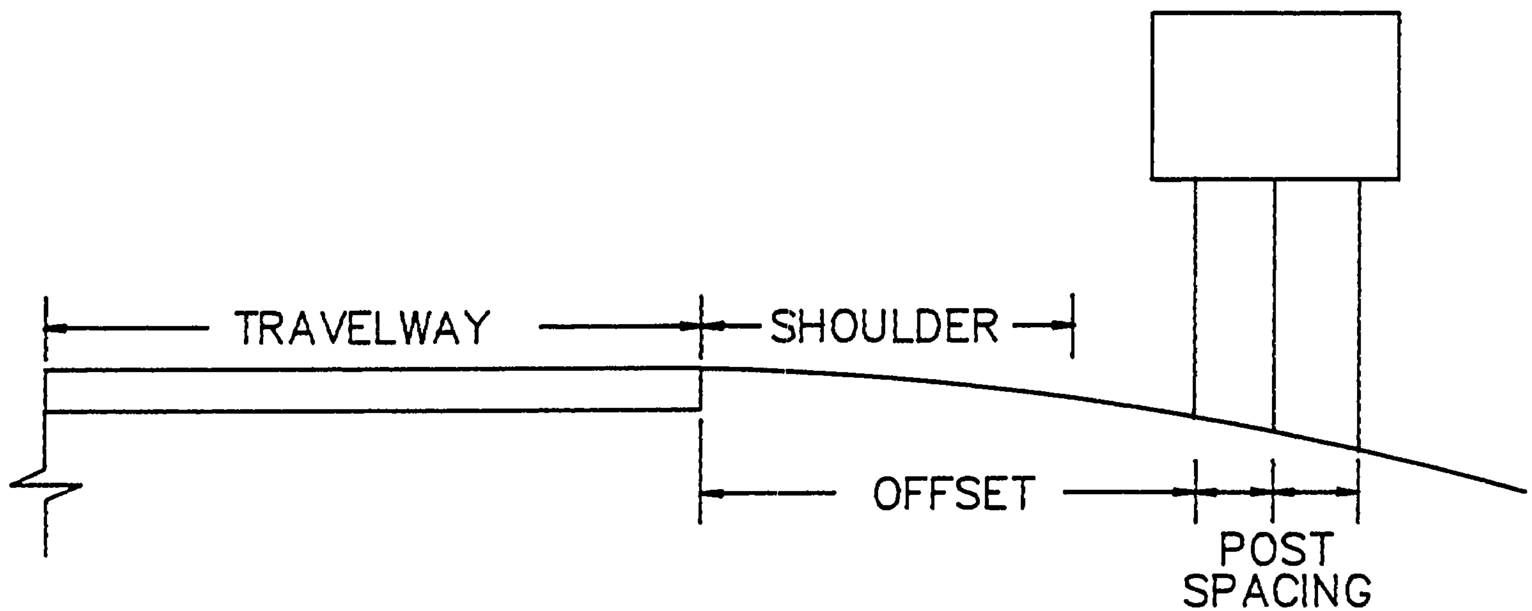


FIGURE 1. SIGN PARAMETER DEFINITIONS

1. U-Posts

Shown in Figure 2 is a typical set of guidelines developed using the B/C program previously discussed. The shape of the B/C curve shown in Figure 2 is directly related to the encroachment data used in the B/C model. The encroachment data used for the study was collected by Cooper (11) and is the best and most extensive data base currently available. The transition at the lower end of the graph is due to a change in driver attention when going from a very low volume traffic condition to a condition of more steady or moderate traffic flow. On very low volume roadways driver attention is low, thus resulting in a relative increase in the number of run-off-road incidents. As the traffic flow increases to a more steady level, driver attention and awareness is increased due to the surrounding traffic, and the encroachment per vehicle mile of travel declines significantly. As the ADT continues to increase, howver, the effects of driver attention are negated by the sheer number of vehicles on the roadway, and the number of encroachments again begin to rise. Similar behavior is evident in other encroachment studies as well (12).

Specifically, the guidelines shown in Figure 2 are for upgrading an existing three-post, 3 lb/ft U-post "long lap splice" system with a three-post, 3 lb/ft U-post "ground splice" system (system 1). The guidelines are for a 12 ft offset. The B/C program was used to construct these curves as follows:

(1) The severity indices for impacts with the existing and retrofit systems were obtained as described in Appendix A. It will be noted that ADOT uses one of three types of splices in the U-post system. From data developed in Appendix A, it can be seen that there are no major differences in the severity indices of the three systems. Values for the "long lap splice" system are nominal for the three systems and were therefore used to represent all existing ADOT U-post systems.

(2) An initial cost for the retrofit system and an ADT were input to the B/C program. For these conditions together with the other impact parameters previously described, a B/C ratio was determined.

(3) Step 2 was repeated as the initial cost was incremented until a value of initial cost was obtained that produced a B/C of one.

(4) Steps 2 and 3 were repeated as the ADT was incremented until enough values were obtained to plot a curve whose coordinates represent initial

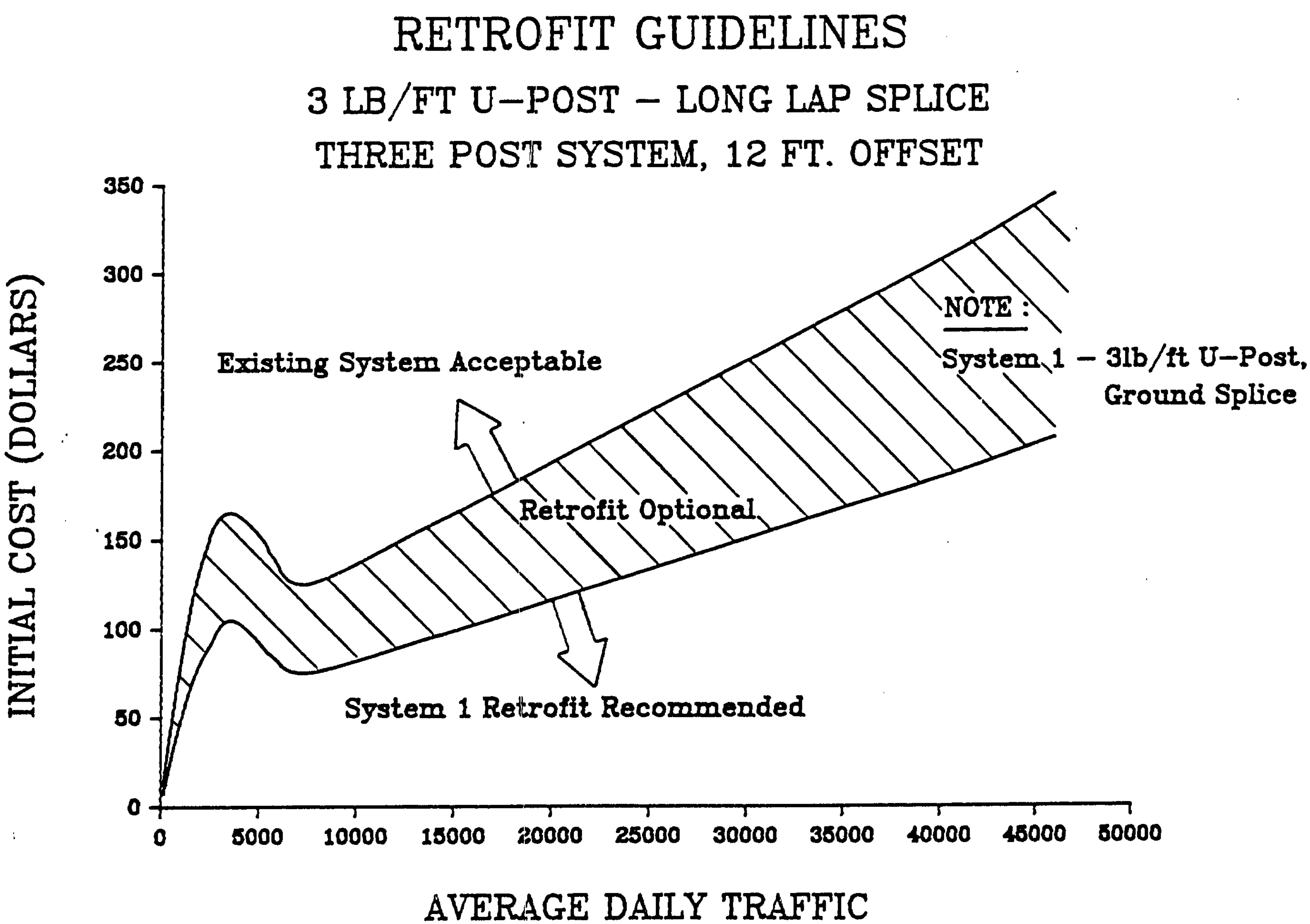


FIGURE 2. RETROFIT GUIDELINES

cost and ADT values for which the B/C is one.

(5) Due to the probabilistic nature of the B/C program and the assumptions inherent therein, a certain degree of judgment should be used in the use of the guidelines. As shown in Figure 2, there is an optional range (indicated by the hashed area) in which judgment should be used. The upper and lower limits of this area were obtained, arbitrarily, by a $\pm$25 percent variation in the B/C = 1 curve.

Use of the guidelines is made by first determining the initial cost to retrofit. This initial cost is defined as the actual cost to remove the existing installation plus the cost to replace it with the alternate system. In addition to materials and labor, replacement costs should include the purchase of any new equipment required to install the alternate system. Using the initial cost of the equipment and the anticipated number of posts to be installed within its life expectancy, a cost per post can be determined. The cost/post is then multiplied by the number of posts in the system and added to the initial cost. The B/C guidelines were developed in this way so that changing cost data may be reflected in the analysis without outdating the curves.

With the initial cost determined, a point is defined whose coordinates are the ADT of the roadway and the initial cost. If the point lies below the hashed area, the retrofit system is cost beneficial and should be installed if funds permit. If the point is above the hashed area, it is not cost beneficial to replace the installation. If the point lies in the hashed area, replacement is optional. Factors that should be considered in this case include the accident history of this or similar installations and the likelihood of the sign being hit. If there is a record of injury-producing accidents with the installation or if the sign is located in an area where higher than average run-off-the-road accidents occur (such as gore areas or on the outside of sharp curves), retrofitting should be strongly considered. In fact, *retrofitting should be strongly considered for any installation for which injury-producing accidents are occurring, regardless of the guidelines.*

The complete set of upgrading guidelines for existing three and four support, U-post installations is given in Figures B-1 through B-15, Appendix B. The following should be noted:

(1) System 1 in Figures B1-B3 is three, 3 lb/ft high strength U-posts with the ground splice (system developed in Phase 2 of study (4)). It is

noted that no more than three posts are permitted within a 7 ft spacing for system 1 to comply with AASHTO safety criteria (2).

(2) System 2 in Figures B4-B6 and Figures B10-B12 is a single, standard steel pipe with a uni-directional slip base. Note in Figures B4-B6 that a 4 inch pipe is used to replace the three-post system while a 5-inch diameter is needed to replace the four-post system in Figures B10-B12. In the absence of impact data for the 4 inch pipe, its severity index was assumed to equal that of the 5 inch pipe.

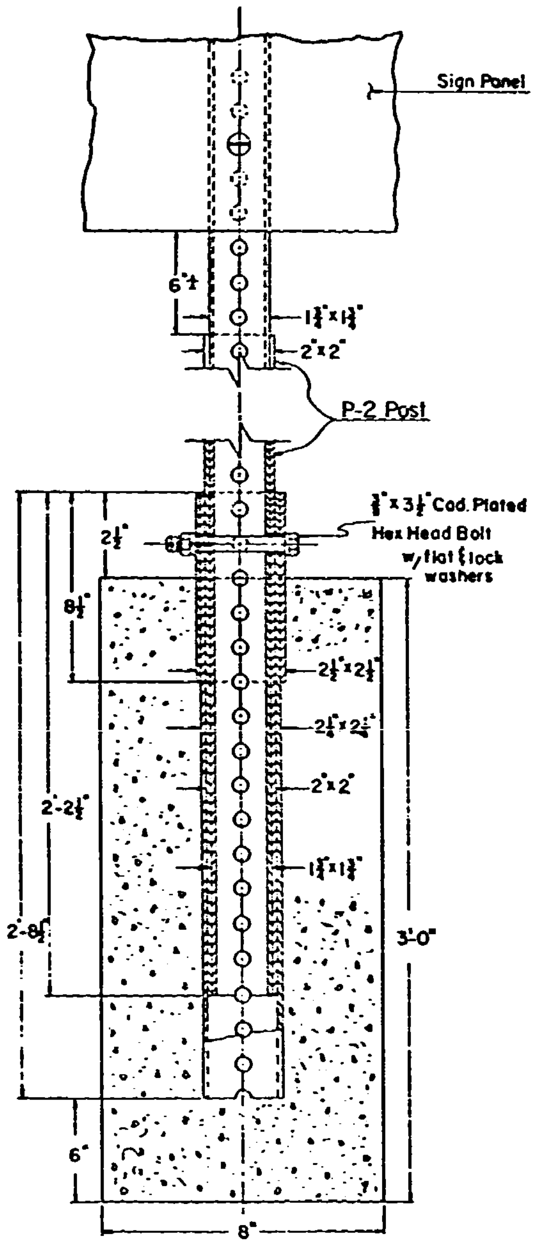
(3) System 3 in Figures B7-B9 and Figures B13-B15 is a single, 7.875-inch by 7.875-inch by 1.25-inch "Micro-Lam" laminated wood post. Severity indices for this system were not directly available. As given in Table A8, Appendix A, test data for this system are available only for a much larger post (a 7.875 inch x 14.875 inch x 1.25 inch section) weakened by saw cuts at its base to facilitate fracture at impact. *It was assumed that the severity index for impacting one unweakened 7.875 inch x 7.875 inch x 1.25 inch post equaled that for impacting one of two weakened 7.875 inch by 14.875 inch by 1.25 inch posts.*

(4) Systems 2 and 3 are single post systems. Since many of the signs that these systems would support would have relatively large horizontal dimensions, special provisions such as wind beams and connection details would be needed. The degree to which these structural details could be cost effectively accommodated would obviously have to be determined. At some point, the added costs and design complexities of a single-post support would dictate that a two-post system be used. In that case, the guidelines would not be applicable unless the post spacing was 7 ft or greater.

(5) The system composed of square steel tubes with slip bases was not a cost-effective alternative for upgrading the U-post installations. Although the U-post with ground splice and the square steel tube with slip base have similar B/C ratios, the lower replacement cost of the ground splice system made it the more cost-effective alternative.

2. P2 Posts

Upgrading guidelines for the ADOT P2 sign support systems were developed in the same manner as were those for the U-post system. Details of the P2 system are given in Figure 3. Note that a 1.75 inch by 1.75 inch by 0.105



FOUNDATION DETAIL
P-2 POST

FIGURE 3. P2 POST DETAILS

inch post is nested in a 2 inch by 2 inch by 0.105 inch post. The "effective" section properties of the nested configuration are as follows:

$$I = 0.64 \text{ in}^4$$
$$S = 0.68 \text{ in}^3$$

The minimum tensile yield stress for these posts is 40 ksi. Hence, the effective moment capacity, My, is 27.2 k-in.

Figures C1 through C24 contain the retrofit guidelines for two, three, and four post P2 systems. Note the following:

(1) System 1, the 3 lb/ft U-post with ground splice, was not a cost-effective alternative for upgrading the ADOT P2 sign support systems. Use of the U-post installation requires removal and replacement of the existing system, whereas use of the square steel tube (ADOT P2 post) with slip base is simply a retrofit operation. Therefore, since these systems have similar B/C ratios, the lower initial cost of the retrofit system made it the more cost-effective alternative.

(2) System 2 in Figures C4-C6, C13-C15, and C22-C24 is a single, standard steel pipe with a uni-directional slip base.

(3) System 3 in Figures C7-C9, C16-C18, and C25-C27 is a single, 7.875 inch by 7.875 inch by 1.25 inch laminated wood post.

(4) System 4 in Figures C1-C3, C10-C12, and C19-C21 is composed of square steel tubes (ADOT P2 posts) mounted on multi-directional slip bases. This system was developed in Phase 2 of this study (4), and details of the retrofit are shown in Figure 4. Retrofitting an existing ADOT P2 sign support system simply involves cutting the existing post and bolting both ends to the pre-fabricated slip base mechanism. Based on test results (4) and analysis in Appendix A, it is noted that up to four posts are permitted with a 7 ft spacing for this system to comply with AASHTO safety criteria (2). It is further noted that the stub height of this system is below the recommended value set forth in the AASHTO specification (2).

    Guidelines for two-post systems are found in Figures C1-C3, three-post systems are shown in Figures C10-C12, and four-post systems are presented in Figures C19-C21.

(5) See note 4 in previous section regarding systems 2 and 3.

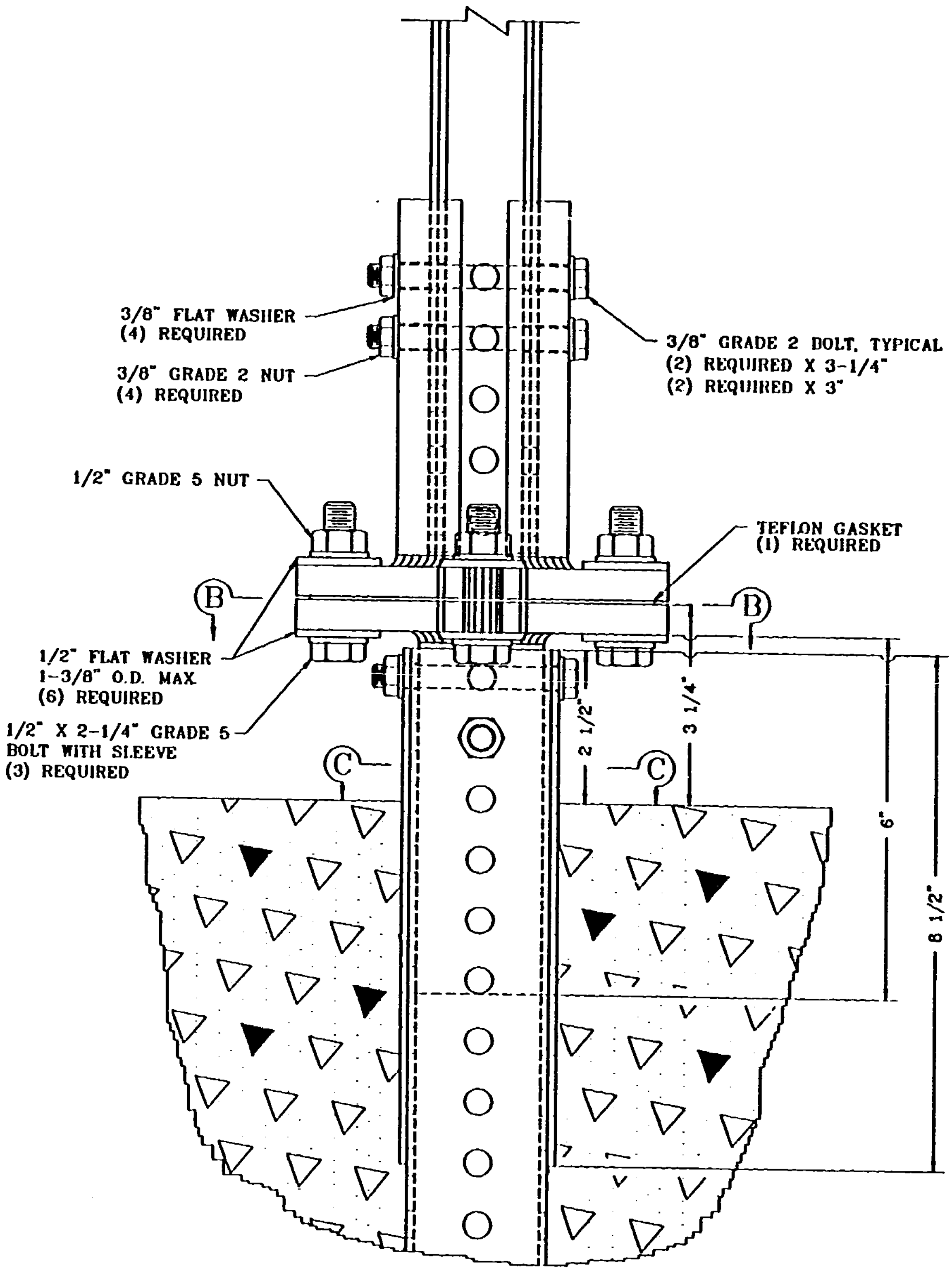


FIGURE 4. SLIP-BASE RETROFIT FOR P2 POST

D. Examples

The following examples are included to illustrate use of the upgrading guidelines. Although costs used in the examples are estimates, they are believed to be "in the ballpark." As such, tentative conclusions can be drawn from results of these examples.

Example 1

<u>Given</u>: - An existing three-post, 3 lb/ft U-post installation
- Offset = 12 ft
- ADT = 10,000
- Replacement costs (initial costs) for following systems:
  (1) three-post, 3 lb/ft U-post with ground splice - $200
  (2) one 4" diameter pipe with slip base - $400
  (3) one 7.875" x 7.875" x 1.25" laminated wood post - $300

<u>Required</u>: Determine if the existing installation should be replaced by any of the above systems.

<u>Solution</u>: (1) From Figure 5 it can be seen that replacement by system 1 is not warranted since the point representing the combination of ADT and cost lies above the hashed area. Further, replacement by system 1 is not warranted for ADT's up to 21,200. For ADT's between 21,200 and 44,300, the replacement is optional and for ADT's above 44,300, replacement is recommended.

(2) From Figure 6 it can be seen that replacement by system 2 is not warranted since the point representing the combination of ADT and cost lies above the hashed area. Further, replacement by system 2 is not warranted for ADT's up to 21,300. For ADT's between 21,300 and 44,500, replacement is optional and for ADT's above 44,500, replacement is recommended.

(3) From Figure 7 it can be seen that replacement by system 3 is not warranted since the point representing the combination of ADT and cost lies above the hashed area. Further, replacement by system 3 is warranted for ADT's up to 20,000. For ADT's between 20,000 and 42,600, replacement is optional and for ADT's above 42,600, replacement is recommended.

A review of the guidelines for larger offsets shows that *if replacement is not warranted for a 12 ft offset, replacement will not be warranted for larger offsets.*

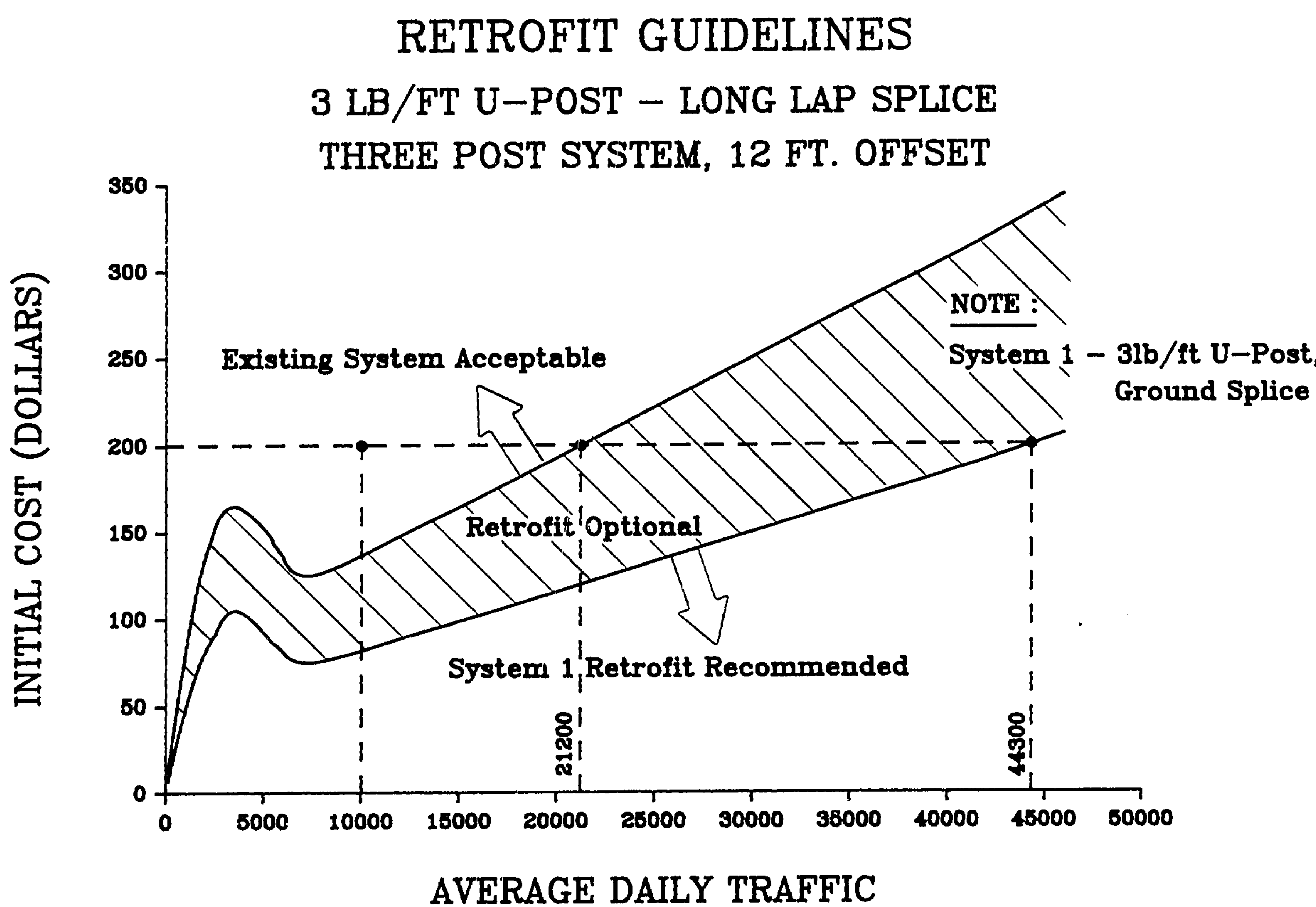


FIGURE 5. U-POST RETROFIT GUIDELINES, EXAMPLE 1-1

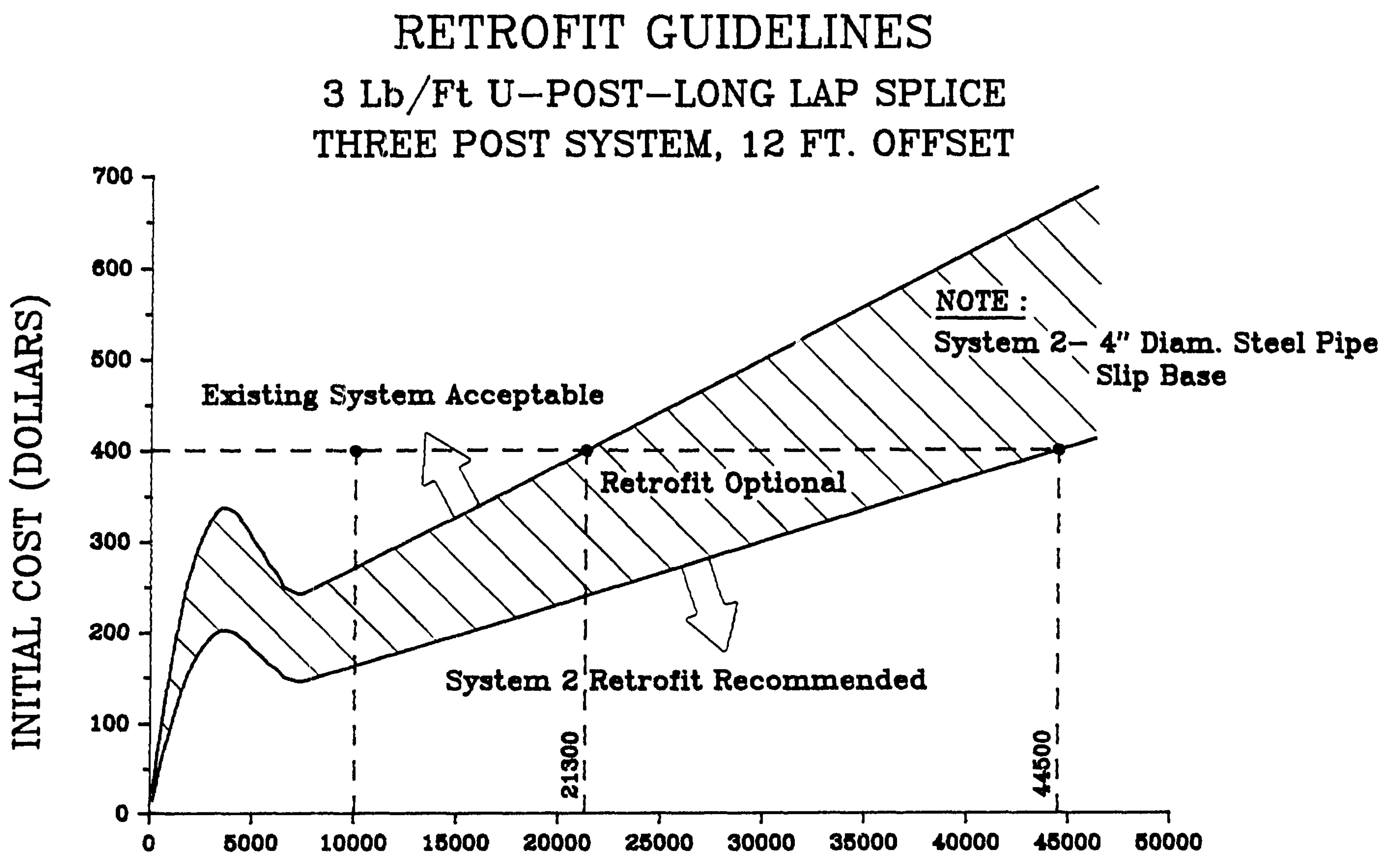


FIGURE 6. U-POST RETROFIT GUIDELINES, EXAMPLE 1-2

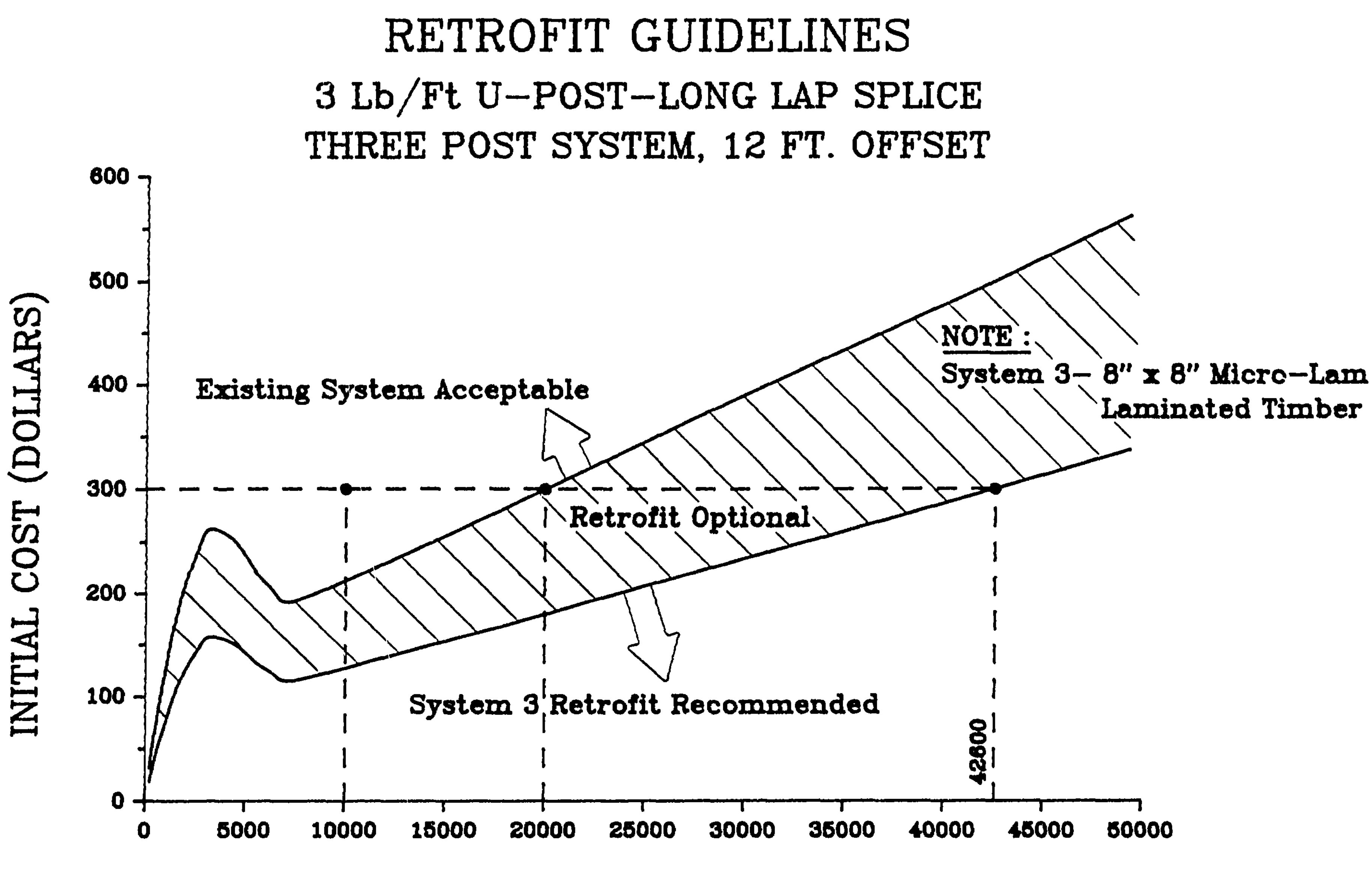


FIGURE 7. U-POST RETROFIT GUIDELINES, EXAMPLE 1-3

Example 2

Given: - An existing three-post P2 installation
- Offset = 12 ft
- ADT = 10,000
- Initial costs for following systems
  (1) System 4: three-post, square tube with slip base - $150
  (2) System 2: one 4" diameter pipe with slip base - $400
  (3) System 3: one 7.875" x 7.875" x 1.25" laminated post -$300

Required: Same as Example 1.

Solution: (1) From Figure 8 it can be seen that replacement by system 4 is optional for the given conditions. Except for relatively low ADT's, system 4 is optional for ADT's up to 14,900. It is recommended that the existing system be replaced for ADT's above 14,900.

(2) From Figure 9 it can be seen that replacement by system 2 is probably not warranted for the given condition. However, replacement by system 2 appears to be optional for most ADT's up to 26,800. Beyond this point, system 2 is recommended.

(3) From Figure 10 it can be seen that replacement by system 3 is optional. Except for relatively low ADT's, system 3 is optional for ADT's up to 21,900. It is recommended that the existing system be replaced for ADT's above 21,900.

E. Discussion of Results

Shown in Table 3 is a set of tentative guidelines for retrofitting existing ADOT small sign installations. They are based on the criteria in Appendices B and C, the aforementioned assumptions, and estimated costs to replace or retrofit the existing systems. Estimated replacement costs for the three retrofit systems are listed in Table 4. *These findings must be viewed as preliminary in nature, subject to change as more definitive data are developed by ADOT on costs and design alternatives.*

From the criteria of Table 3, certain findings are noted as follows:

U-Posts - Retrofit of three-post installations is not necessary for ADT's approximately 20,000 or less. Retrofit of four-post installations with offsets of 12 ft or less is optional for ADT's up to 25,000. It is important to note that the guidelines are based on an assumed post spacing of 2 ft. If the spacing of a four-post installation exceeds approximately 2.5 ft, the three-post guidelines apply. It should also be noted that only systems 2 and

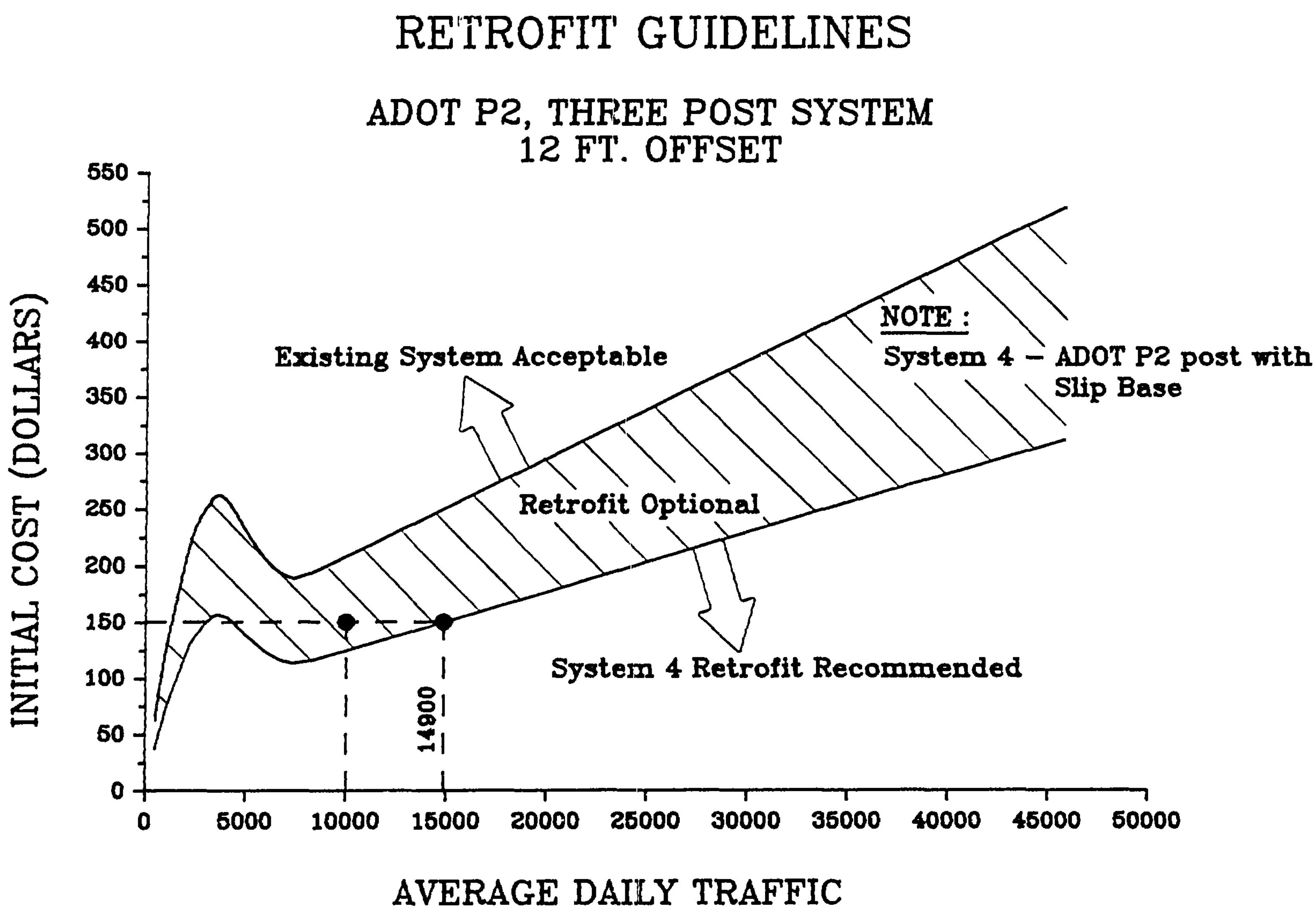


FIGURE 8. P2 POST RETROFIT GUIDELINES, EXAMPLE 2-1

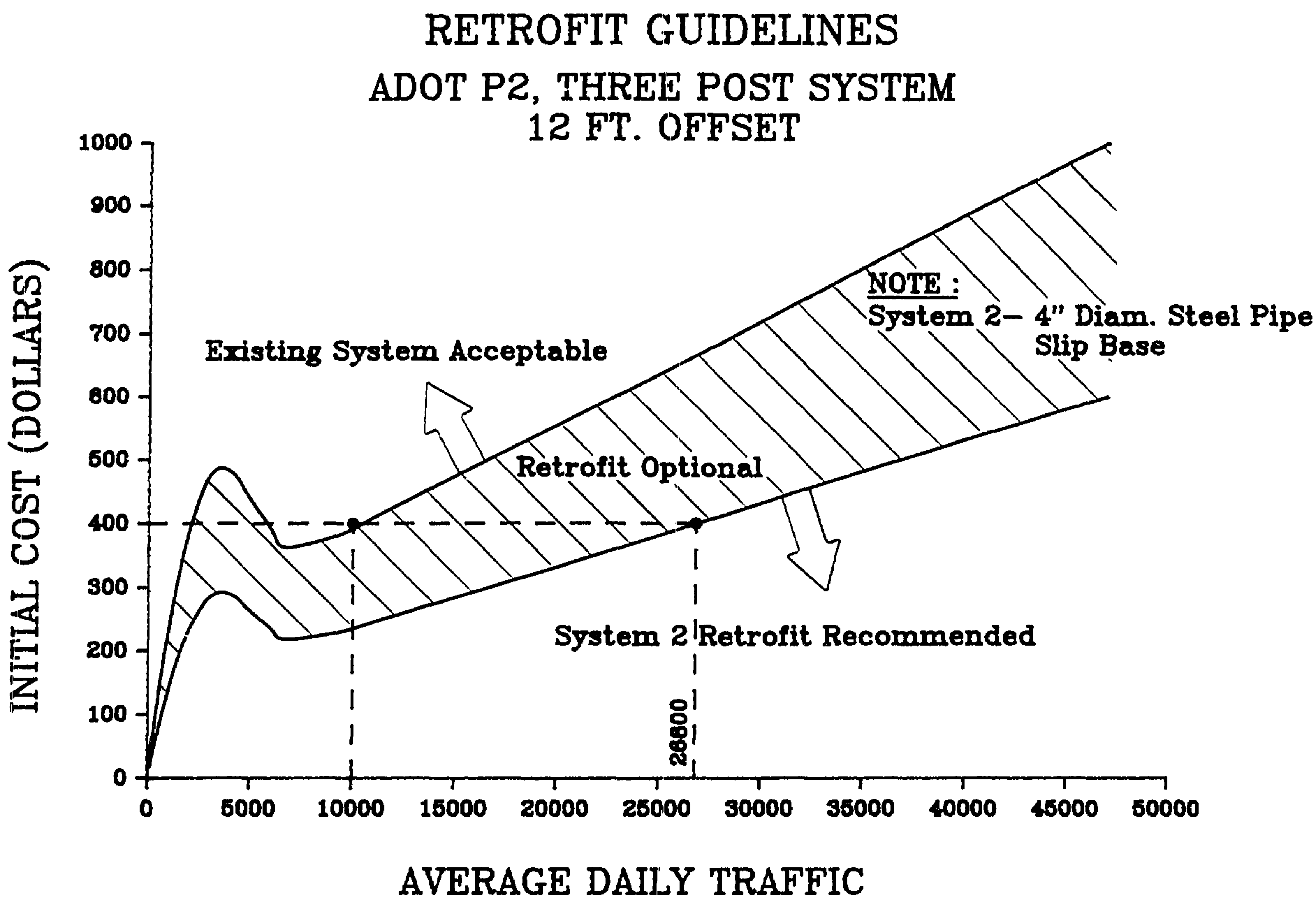


FIGURE 9. P2 POST RETROFIT GUIDELINES, EXAMPLE 2-2

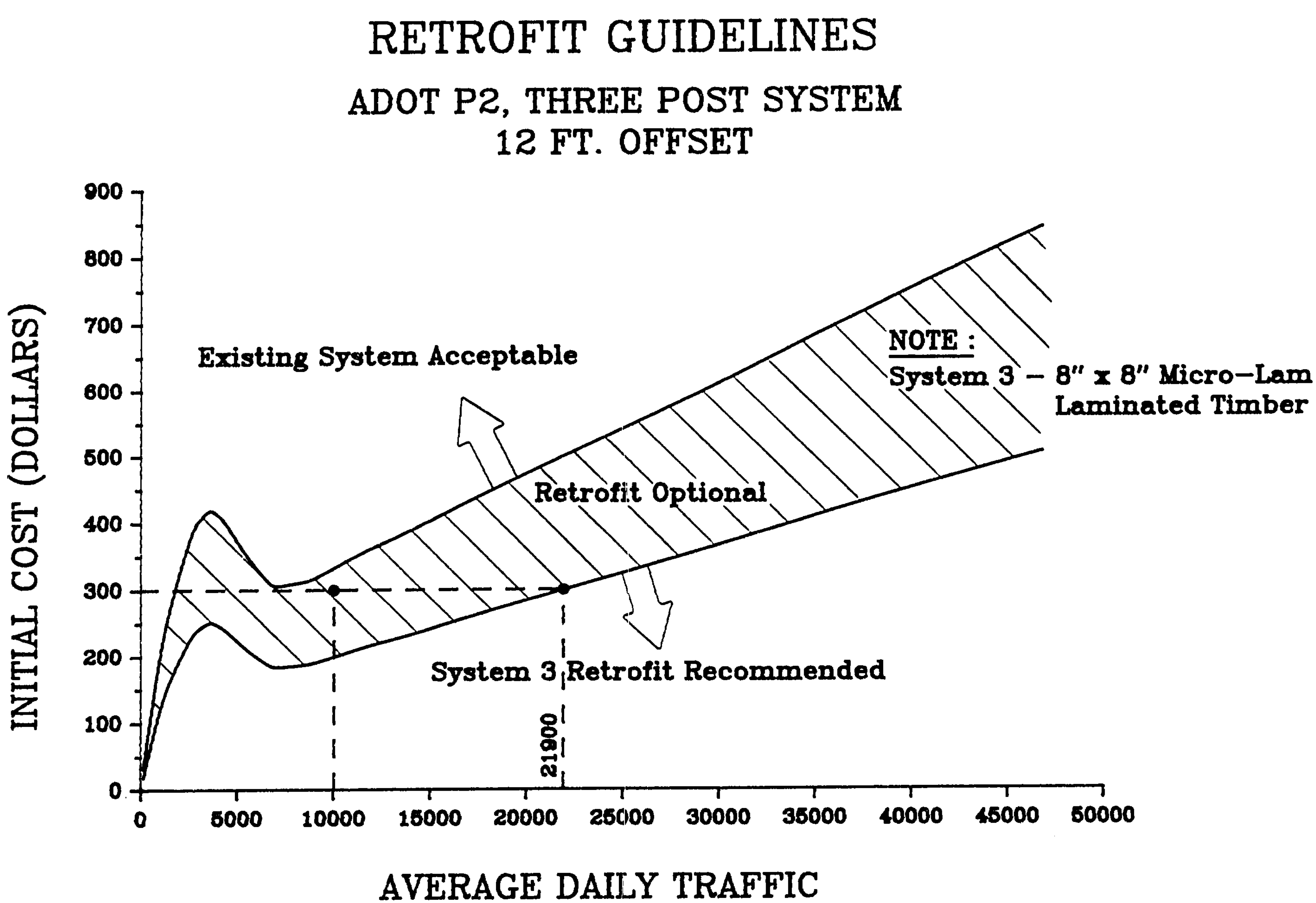


FIGURE 10. P2 POST RETROFIT GUIDELINES, EXAMPLE 2-3

TABLE 3. TENTATIVE RETROFIT GUIDELINES

EXISTING POST TYPE	NO. OF POSTS	OFFSET (FT)	ADT RANGE FOR FOLLOWING: RETROFIT NOT NECESSARY	ADT RANGE FOR FOLLOWING: RETROFIT OPTIONAL	ADT RANGE FOR FOLLOWING: RETROFIT RECOMMENDED	SUGGESTED RETROFIT SYSTEM
U-Post	3	12	0-20,000	10,000-45,000	>45,000	Three 3 lb/ft U-Post with Ground Splice
		16	0-30,000	>30,000	---	Three 3 lb/ft U-Post with Ground Splice
		20	0-43,000	>43,000	---	Three 3 lb/ft U-Post with Ground Splice
	4	12	---	0-25,000	>25,000	Steel Pipe with Slip Base or Laminated Wood Post
		16	0-12,000	12,000-30,000	>30,000	Steel Pipe with Slip Base or Laminated Wood Post
		20	0-20,000	20,000-40,000	>40,000	Steel Pipe with Slip Base or Laminated Wood Post
P2 Post	2	12	0- 1,700	1,700-21,000	>21,000	Two Square Steel Tubes (ADOT P2) with Slip Base
		16	0- 2,300	2,300-30,000	>30,000	Two Square Steel Tubes (ADOT P2) with Slip Base
		20	0-19,000	19,000-41,000	>41,000	Two Square Steel Tubes (ADOT P2) with Slip Base
	3	12	0- 1,300	1,300-14,500	>14,500	Three Square Steel Tubes (ADOT P2) with Slip Base
		16	0- 1,800	1,800-22,300	>22,300	Three Square Steel Tubes (ADOT P2) with Slip Base
		20	0-13,000	13,000-31,000	>31,000	Three Square Steel Tubes (ADOT P2) with Slip Base
	4	12	---	0-1,000	> 1,000	Four Square Steel Tubes (ADOT P2) with Slip Base
		16	---	0-1,300	> 1,300	Four Square Steel Tubes (ADOT P2) with Slip Base
		20	---	0-1,500	> 1,500	Four Square Steel Tubes (ADOT P2) with Slip Base
	4	12	---	0-1,000	> 1,000	Steel Pipe with Slip Base or Laminated Wood Post
		16	---	0-1,500	> 1,500	Steel Pipe with Slip Base or Laminated Wood Post
		20	---	0-2,000	> 2,000	Steel Pipe with Slip Base or Laminated Wood Post

TABLE 4. ESTIMATED REPLACEMENT COSTS

RETROFIT SYSTEM	POST SIZE	NO. OF POSTS	ESTIMATED REPLACEMENT COST ($)
1. Steel U-Post with Ground Splice	3 lb/ft	2	150
	3 lb/ft	3	200
2. Square Steel Tube with Slip Base	ADOT P2	2	115
	ADOT P2	3	150
	ADOT P2	4	190
3. Standard Steel Pipe with Slip Base	3 in. dia.	1	350
	4 in. dia.	1	400
	5 in. dia.	1	450
4. Hollow, Square Laminated Lumber Post	7.875 in x 7.875 in x 1.25 in.	1	300

3 are retrofit designs for four-post installations. Reference should be made to note 4 at the end of Section III-C-1 for potential limitations of these systems.

P2 Posts - Retrofit of two and three-post systems is not necessary for low volume roads (i.e. ADT's of approx. 2000 or less). Retrofit of two-post installations with offsets of 12 ft or less is optional for ADT's of 14,850 or less. Retrofit of three-post installation (for all posts within a 7 ft spacing) is recommended for all but low volume roads, i.e., ADT's of 2000 or less.

IV. GUIDELINES FOR NEW INSTALLATIONS

The purpose of this phase of the study was to evaluate candidate designs for new installations and to develop tentative selection guidelines. With minor exceptions, the same B/C procedure used in the development of retrofit guidelines (Chapter III) was used to develop guidelines for new installations. The main difference is that the retrofit guidelines were developed in terms of the cost to replace an existing system while the new installation guidelines were developed in terms of the incremental cost between the candidate designs.

The candidate systems for the new installations are the same systems considered as retrofit alternatives in the previous chapter (see Section III-B). For use with the new installation guidelines, the systems were classified as follows:

(1) System 1 is three, 3 lb/ft high strength U-posts with ground splice
(2) System 2 is three, square steel tubes with slip bases
(3) System 3 is either a single, standard steel pipe with slip base, or a single, 7.875-inch by 7.875-inch by 1.25-inch laminated wood post.

Note that system 3 is either the steel pipe with slip base or the laminated wood post. These installations were grouped together because of their similarities to each other. Both systems are single-support installations with high load carrying capacities and similar B/C ratios. Either system would, therefore, be acceptable for larger signs. The more cost-effective system would be the system with the lower maintenance cost. However, as has been previously discussed, there are inherent design limitations associated with these single post systems (see note 4 at the end of Section III-C-1).

Figure 11 shows the criteria comparing the candidate systems for an offset of 12 ft. These guidelines involve a relative comparison of three acceptable sign support systems. The selection of one system over the others is, therefore, not as critical as for the upgrade guidelines discussed in the previous section. For this reason, the optional range was eliminated and the B/C =1 curves were plotted directly. Use of the guidelines is accomplished as follows:

(1) Determine material, fabrication, and installation cost of the candidate systems.

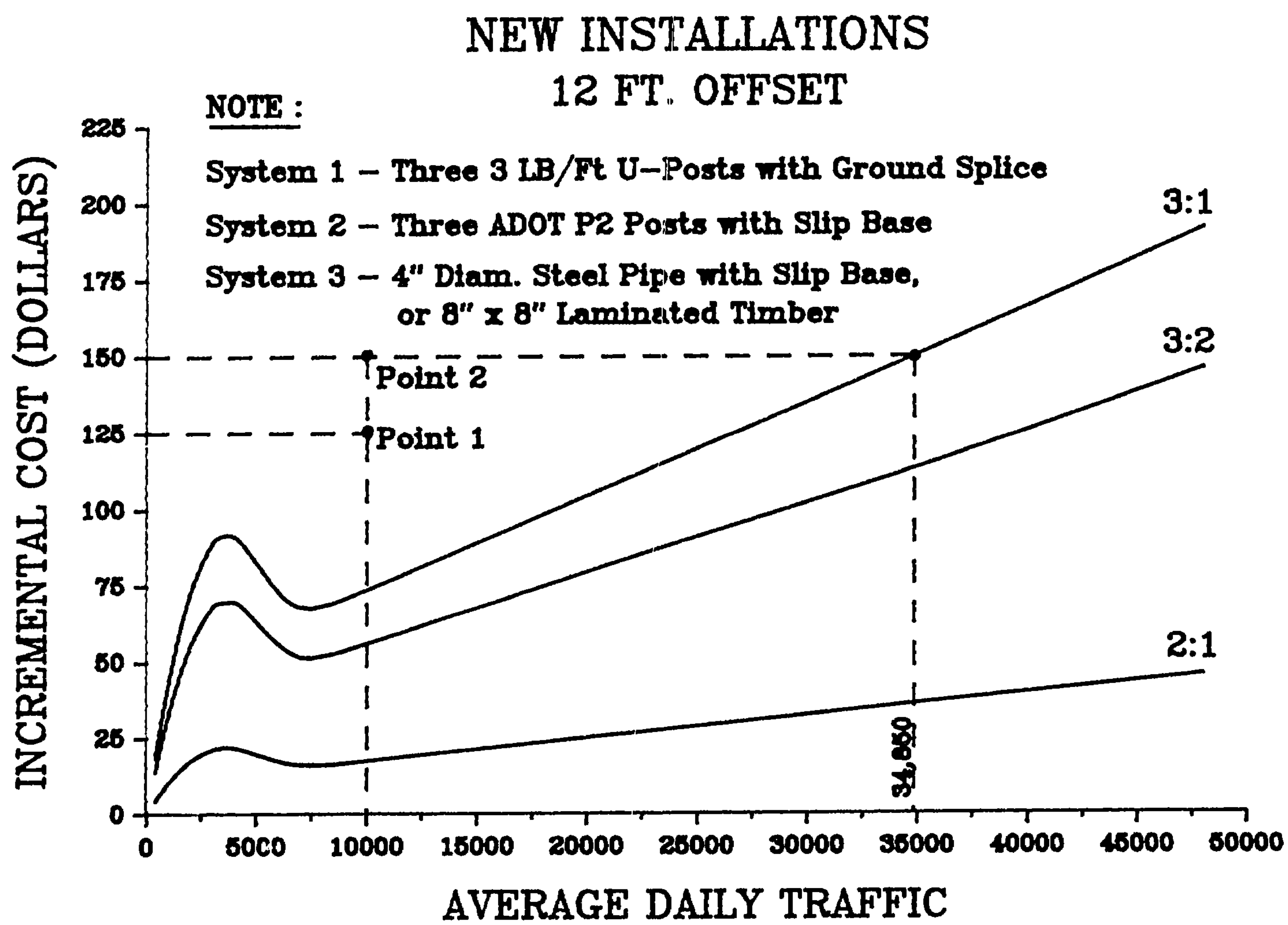


FIGURE 11. NEW INSTALLATION GUIDELINES

(2) Determine the cost difference between the alternatives (i.e. incremental cost). Denote IC31 as the incremental cost of alternative 3 with respect to 1.

(3) Determine ADT.

(4) Plot point 1 whose coordinates are the ADT and IC21.

(5) Plot point 2 whose coordinates are the ADT and IC31.

(6) If point 2 lies above the 3:1 curve and point 1 lies above the 2:1 curve, system 1 is cost beneficial.

(7) If point 2 lies on or below the 3:1 curve and point 1 lies above the 2:1 curve, system 3 is the preferred option.

(8) If point 2 lies on or below the 3:1 curve and point 1 lies on or below the 2:1 curve, do the following:

  (a) Determine IC32, the incremental cost of alternative 3 with respect to 2.

  (b) Plot point 3 whose coordinates are ADT and IC32.

  (c) If point 3 lies above the 3:2 curve, alternative 2 is the preferred option.

  (d) If point 3 lies on or below the 3:2 curve, alternative 3 is the preferred option.

The following example is included to illustrate the use of new installation guidelines. Although costs used in the examples are estimates, they are believed to be "in the ballpark." As such, tentative conclusions can be drawn from the results of this example.

Example

Given: - Offset = 12 ft
- ADT = 10,000
- Installation costs for following systems:
  (1) three-post, 3 lb/ft U-post with ground splice - $125
  (2) three-post, square steel tube with slip base - $250
  (3) single 7.875" x 7.875" x 1.25" laminated wood post - $275

Required: Determine which of the above systems should be installed.

Solution: (1) Determine incremental costs. I21= 250-125 = 125
I31= 275-125 = 150

(2) From Figure 11 it can be seen that system 1 is cost beneficial since points 1 and 2 lie above the 2:1 and 3:1 curves respectively. Further, system 1 is the preferred option for ADT's up to 34,850.

(3) From Figure 11 it can be seen that installation of system 2 for new construction is not warranted since point 1 lies above the 2:1 curve for all ADT's below 50,000.

(4) From figure 11 it can be seen that system 3 is cost beneficial for ADT's above 34,850.

The complete set of criteria is given in Figures D1-D3, Appendix D. Shown in Table 5 is a set of tentative guidelines for new installations based on criteria in Appendix D, the aforementioned assumptions made in the B/C analysis, and estimated incremental costs between candidate systems. Estimated incremental costs between candidate systems are given in Table 6. It should be noted that system 1 is three 3 lb/ft U-posts with the ground splice. If more than three U-posts are needed to support a sign and if all the posts are within a 7 ft spacing, systems 2 and 3 are the only options that meet AASHTO safety criteria.

From Table 5 it appears that system 1 is preferred for all but high volume roadways. For signs near the travelway and for high volume, the breakaway supports of system 3 become warranted. *These findings must be viewed as preliminary, subject to change as more definitive data are developed by ADOT on costs and design alternatives.*

TABLE 5. NEW INSTALLATION GUIDELINES

	ADT RANGE FOR FOLLOWING:		
OFFSET (FT)	SYSTEM 1	SYSTEM 2	SYSTEM 3
12	0-34,850	---	>34,850
16	0-47,000	---	>47,000
20	0-62,000	---	>62,000

TABLE 6. ESTIMATED INCREMENTAL COST

SYSTEM	INSTALLATION COST ($)	INCREMENTAL COST ($)
1	125	
2	250	100 (2 to 1)
3	275	150 (3 to 1)

V. CONCLUSIONS

Guidelines were developed to assist ADOT in (1) determining if an existing sign installation, not in compliance with current safety standards, should be replaced by a system that does meet the safety standards (see Table 3), and (2) selecting a cost effective sign support for new installations (see Table 5). A benefit/cost analysis procedure was used to develop the guidelines. Results of the study provide the following general conclusions.

A. Retrofit Guidelines for Existing ADOT Sign Supports

1. Three 3 lb/ft U-post installations with ADOT splice - Most installations do not need to be replaced. For high traffic volumes and for installations in close proximity to the travelway, replacement is optional.
2. Four 3 lb/ft U-post installations with ADOT splice - Replacement is optional for most installations. Replacement is recommended for high traffic volumes.
3. Two and three P2 post installations - Replacement is optional for most installations. Replacement is recommended for high traffic volumes.
4. Four P2 post installations - Replacement of most installations is recommended.

B. New Installation Guidelines

The 3 lb/ft high strength U-post with ground splice system appears to be the most cost effective small sign support currently available. Up to three of these posts can be used within a 7 ft spacing. For signs requiring more than three of these posts within a 7 ft spacing, and for larger signs near the travelway of a roadway with high traffic volumes, a slip base system or the laminated wood post system is recommended.

These findings must be viewed as tentative, subject to change as more definitive data are developed by ADOT on costs and design alternatives. Users of the guidelines should also be cognizant of the assumptions and limitations inherent in the analysis procedures used.

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APPENDIX A. ESTIMATING THE SEVERITY INDEX OF SMALL SIGN SUPPPORTS

The primary measure of severity of vehicular impacts with sign supports is the velocity at which an occupant will impact the interior of the vehicle (3). According to current standards (2, 3), the occupant impact velocity should not exceed 15 ft/sec.

Estimating Vehicular Velocity Change

The vehicle population is composed of a wide variety of sizes and types, and the B/C program approximates the distribution of vehicle mix. Since impact data on the ADOT small sign supports were determined by tests of small cars only, it was necessary to estimate the impact performance of the sign supports for larger vehicles.

Since the mass of most small sign installations is relatively small in comparison to the impacting vehicle, the velocity change that an impacting vehicle experiences is due in large part to an energy loss (distortions in sign posts, soil displacements and damping, and vehicular crush) as opposed to a momentum transfer. For purposes of estimating velocity change, it was assumed that the energy loss is independent of vehicle size. It is recognized that this assumption will generally result in an overestimation of energy loss in larger vehicles since vehicular crush, and hence the energy loss due to crush, will generally decrease as the size of the impacting vehicle increases. Based on this assumption, the velocity change in larger vehicles is estimated from that measured in the tests of the small vehicles as follows:

$$(\Delta KE)_T = 1/2\ M_T(V_{IT}^2 - V_{FT}^2) \quad \text{..................(A1)}$$

where

$(\Delta KE)_T$ = change in kinetic energy of test vehicle

M_T = mass of test vehicle

V_{IT} = impact velocity of test vehicle

V_{FT} = final velocity of test vehicle (after post fracture)

Then, for a different size vehicle with mass M_V impacting at V_{IT}:

$$1/2 \quad M_V(V_{IT}^2 - V_{FV}^2) = (\Delta KE)_T \ldots\ldots\ldots\ldots\ldots\ldots (A2)$$

and

$$V_{FV} = \sqrt{V_{IT}^2 - 2(\Delta KE)_T / M_V} \ldots\ldots\ldots\ldots\ldots\ldots (A3)$$

where

V_{FV} = final velocity of vehicle

The change in velocity is then computed as follows:

$$\Delta V_V = V_{IT} - V_F \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (A4)$$

In the B/C program the vehicle population is assumed to be composed of four different vehicle sizes, the first three being automobiles and small trucks, and the remaining one being heavy vehicles. Each functional class of roadway has associated with it a pre-established vehicle mix. The first three sizes were assumed to collectively represent approximately 76 percent of the population. These three sizes are an 1800 lb vehicle, a 3000 lb vehicle, and a 4500 lb vehicle. Using crash test results (1) and formulas A1 through A4, data in Table A1 were developed for these three vehicle sizes for existing ADOT sign supports. Similar data are presented in Table A2 for the alternative systems evaluated in the Phase II study (4). Impacts by heavy vehicles with the small sign supports were assumed to be inconsequential in terms of velocity change with a negligible probability of injury.

For sign impacts, the occupant impact velocity will, in most cases, approximately equal the velocity change of the vehicle during impact. This is borne out by the results given in Tables A1 and A2. The predicted change in vehicular velocity for the 3000 lb and the 4500 lb vehicles can therefore be assumed to equal the occupant impact velocity for those vehicles.

Relationship Between Occupant Impact Velocity and Severity Index

According to NCHRP Report 230 (3), it is a life threatening event if an unrestrained occupant impacts the vehicle's interior compartment, in the fore-aft direction, at a velocity in excess of 40 ft/sec. It is the collective judgement of TTI researchers that the onset of a "life

TABLE A1. VEHICULAR VELOCITY CHANGE FOR IMPACTS WITH EXISTING ADOT SYSTEMS

SUPPORT TYPE	CRASH TEST DATA - 1800 LB TEST CAR (1): IMPACT SPEED Vi, (ft/sec)	FINAL SPEED Vf, (ft/sec)	ΔV (FT/SEC)	ΔKE (FT-LB)	OCCUPANT IMPACT VELOCITY (FT/SEC)	PREDICTED CHANGE IN VEHICULAR VELOCITY (FT/SEC) FOR: 3000 lb vehicle	4500 lb vehicle
A. One Square Steel Tube ADOT P1 Post Design (Tests 3 & 4)	29.3	25.8	3.5	5,839	3.5[b]	2.2	1.5
	83.3	74.8	8.5	40,691	8.5[b]	5.4	3.6
B. Two Square Steel Tubes ADOT P2 Design (Tests 19 & 20)	27.7	13.0	14.7	18,116	14.1	8.2	5.2
	84.3	66.4	17.9	81,681	17.4	11.1	7.2
C. Three Suare Steel Tubes ADOT P2 Design (Tests 5[a] & 6)	28.9[a]	8.2	20.7	23,254	21.0	10.6	6.4
	87.0	60.7	26.3	117,623	24.9	16.0	10.3
D. Two 3 lb/ft High Carbon Billet Steel U-Posts (80 ksi) (Two Foot Lap Splice) (Tests 22 & 23)	29.3	19.9	9.4	14,004	10.1	5.7	3.6
	92.1	80.4	11.7	61,113	11.8	7.4	4.9
E. Three 3 lb/ft High Carbon Billet Steel U-Posts (80 ksi) (Long Lap Splice)	29.3	1.4	27.9	25,936	22.4	11.9	7.2
	90.9	72.0	18.9	93,226	12.8	11.8	7.7
F. Three 3 lb/ft High Carbon Billet Steel U-Posts (80 ksi) (Short Lap Splice) (Tests 18 & 21)	28.6	3.7	24.9	24,353	22.5	11.4	6.9
	90.2	67.8	22.4	107,167	19.0	13.8	8.9

a Two of Three Posts Hit in Test 5.
b Based on Vehicle ΔV.

TABLE A2. VEHICULAR VELOCITY CHANGE FOR IMPACTS WITH ALTERNATE SYSTEMS DEVELOPED BY ADOT

SUPPORT TYPE	CRASH TEST DATA - 1800 LB TEST CAR (4)					PREDICTED CHANGE IN VEHICULAR VELOCITY (FT/SEC) FOR	
	IMPACT SPEED Vi, (ft/sec)	FINAL SPEED Vf, (ft/sec)	ΔV (FT/SEC)	ΔKE (FT-LB)	OCCUPANT IMPACT VELOCITY (FT/SEC)	3000 lb vehicle	4500 lb vehicle
A. Three 3 lb/ft High Carbon Billet Steel U-Posts (80 ksi) (Ground Splice) (Tests 26 & 27)	31.8	19.2	12.6	19,458	12.5	7.4	4.7
	90.3	81.2	9.1	47,256	-0-(9.1)[a]	5.8	3.8
B. Three 4 lb/ft High Carbon Billet Steel U-Posts (80 ksi) (Ground Splice) (Tests 24 & 25)	30.2	2.2	28.0	27,470	21.9	12.2	7.4
	91.8	78.6	13.2	68,108	13.2	8.3	5.5
C. Three Square Steel Tubes (ADOT P2 Design) with Unistrut Slip Base (Tests 7024-29, 30)	27.4	17.4	10.4	14,060	8.9	6.2	4.0
	90.2	84.1	6.1	32,152	-0-(6.1)[a]	3.9	2.6

[a] Based on Vehicle ΔV.

threatening" event implies a severity index (SI) of 5. The SI scale is given in Table 1 of the main text. Furthermore, it is assumed that the SI varies linearly with occupant impact velocity as shown in Figure A1. It is noted that this assumption does not mean that the severity of an impact is directly proportional to the impact velocity. As can be seen in Figure VII-C-6 of the AASHTO Barrier Guide (7), accident costs (a measure of accident severity) vary exponentially with the SI, and hence with occupant impact speed.

Data in Tables A1 and A2 and the relationship given in Figure A1 were used to develop the SI values given in Tables A3 and A4. With reference to Tables A1 and A2, it can be seen that for most of the support systems the velocity change of the test vehicle (ΔV) did not vary significantly between the low and high speed impacts. *It was therefore assumed that ΔV (and hence the occupant impact velocity and hence the SI) was constant within the impact speed range of interest (approximately 20 mph to 60 mph).* However, in the interest of insuring that the severity of impact was not understated, the values of SI in Tables A3 and A4 were based on the higher value of ΔV from the high and low speed tests.

Estimating SI per Number of Posts Hit

Small signs are supported by one or more posts and the degree of hazard they present to an errant motorist depends on the number of posts that can be struck. Furthermore, the severity of striking one post of a given size and type in a multiple-post installation is generally greater than striking the same post in a single-post installation. In using the B/C procedure, it is necessary that an estimate be made of the SI for (a) impacts with single-post installations, and (b) impacts with one, two, three, etc., posts in a multiple-post installation. This was done as follows:

Single-Post Installation - When available, test data were used to determine the SI. System A of Table A3 was the only single post system tested in the present study. For single-post systems not tested, it was assumed that the energy loss equaled that of the multiple-post impact divided by the number of posts hit, that is:

$$E_1 = E_N / N \qquad \text{(A5)}$$

where

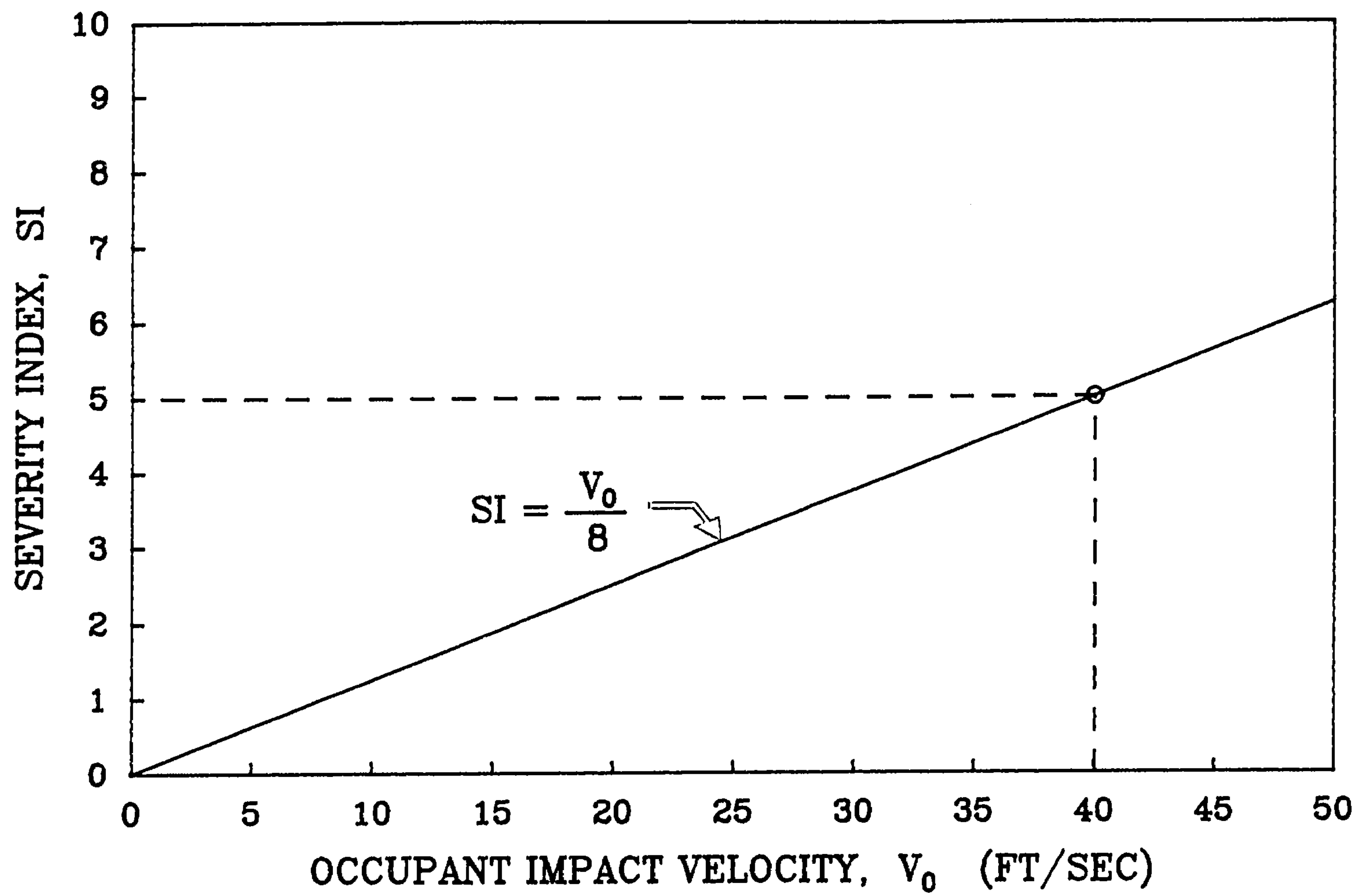

FIGURE A1. SEVERITY INDEX VERSUS OCCUPANT IMPACT VELOCITY

TABLE A3. SEVERITY INDICES FOR EXISTING ADOT SYSTEMS BASED ON CRASH TESTS

SUPPORT TYPE	S.I. FOR VEHICLE WEIGHING 1800 LB	3000 LB	4500 LB
A. One Square Steel Tube ADOT P1 Design	1.1	0.7	0.5
B. Two Square Steel Tubes ADOT P2 Design	2.2	1.4	0.9
C. Three Square Steel Tubes ADOT P2 Design	3.1	2.0	1.3
D. Two 3 lb/ft High Carbon Billet Steel U-Posts (Two Foot Lap Splice)	1.5	0.9	0.6
E. Three 3 lb/ft High Carbon Billet Steel U-Posts (Long Lap Splice)	2.8	1.5	1.0
F. Three 3 lb/ft High Carbon Billet Steel U-Posts (Short Lap Splice)	2.8	1.7	1.1

TABLE A4. SEVERITY INDICES OF ALTERNATE SYSTEMS DEVELOPED BY ADOT

SUPPORT TYPE	S.I. FOR VEHICLE WEIGHING 1800 LB	3000 LB	4500 LB
A. Three 3 lb/ft High Carbon Billet Steel U-Posts (Ground Splice)	1.6	0.9	0.6
B. Three 4 lb/ft High Carbon Billet Steel U-Posts (Ground Splice)	2.7	1.5	0.9
C. Three Square Steel Tubes (ADOT P2 Design) with Unistrut Slip Base	1.1	0.8	0.5

E_1 = energy loss in single post installation

E_N = energy loss for impact with N posts

Tables A5 and A6 give energy loss values obtained in the described manner, the implied vehicular velocity change, and the associated SI value for existing ADOT systems and candidate (alternate) systems, respectively.

It should be noted that "alternate" systems C and D in Table A6 were not tested in the present study. Test data for these slip-base systems were obtained from the literature (13,14). They were included due to their demonstrated ability to easily meet impact performance standards. As a result, they are candidate systems for upgrading existing substandard systems or as new support systems. The SI values for systems C and D were also determined by use of Equations A1 through A4.

Multiple-Post Installations - When available, test data were used to determine the SI. For combinations not tested, the energy loss was estimated as follows:

$$E_n = (n / N)\ E_N \qquad \text{.......................(A6)}$$

where

E_n = energy loss for impact with "n" posts

E_N = energy loss for impact with "N" posts (from crash test data)

Tables A7 and A8 give energy loss, change in vehicular velocity, and the associated SI values for two, three, and four post systems for existing ADOT systems and candidate (alternate) systems, respectively. Equations A1 through A4 and A6 were used to compute values given in the tables.

It should be noted that "alternate" system C in Table A8 was not tested in the present study. Test data for this laminated wood system were obtained from the literature (15). It was included due to its demonstrated ability to easily meet impact performance standards.

Adjustments to SI for B/C Program

The B/C program used in the analysis does not allow input of SI as a function of vehicle size (or weight). Thus, to account for size effects it was necessary to compute a weighted average of the SI.

TABLE A5. SEVERITY INDICES FOR EXISTING ADOT SINGLE POST INSTALLATIONS

SUPPORT TYPE	ENERGY LOSS ΔKE (FT-LB)	CHANGE IN VEHICULAR VELOCITY (FT/SEC) FOR VEHICLE WEIGHING			S.I. FOR VEHICLE WEIGHING		
		1800 LB	3000 LB	4500 LB	1800 LB	3000 LB	4500 LB
A. Square Steel Tube	5,839[a] / 40,691[b]	3.5[c] / 8.5[c]	2.2 / 5.4	1.5 / 3.6	1.1	0.7	0.5
B. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Two Foot Lap Splice)	7,002[a] / 30,557[b]	4.3 / 5.7	3.0 / 3.6	1.8 / 2.4	0.7	0.5	0.3
C. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Long Lap Splice)	8,645[a] / 31,075[b]	5.9 / 6.3	3.4 / 3.8	2.2 / 2.5	0.8	0.5	0.3
D. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Short Lap Splice)	8,118[a] / 35,722[b]	5.6 / 7.4	3.2 / 4.4	2.1 / 2.9	0.9	0.6	0.4

[a] Low speed impact (approximately 20 mph)
[b] High speed impact (approximately 60 mph)
[c] Occupant impact velocity measured in crash test

TABLE A6. SEVERITY INDICES FOR ALTERNATE SINGLE POST INSTALLATIONS

SUPPORT TYPE	ENERGY LOSS ΔKE (FT-LB)	CHANGE IN VEHICULAR VELOCITY (FT/SEC) FOR VEHICLE WEIGHING			S.I. FOR VEHICLE WEIGHING		
		1800 LB	3000 LB	4500 LB	1800 LB	3000 LB	4500 LB
A. 3 lb/ft High Carbon Steel U-Post (Ground Splice)	6,486[a] 15,752[b]	3.9 3.2	2.3 1.9	1.5 1.3	0.5	0.3	0.2
B. 4 lb/ft High Carbon Steel U-Post (Ground Splice)	9,157[a] 22,703[b]	6.0 4.5	3.5 2.7	2.3 1.8	0.8	0.4	0.3
C. Square Steel Tube with Unistrut Slip Base	4,687[a] 10,717[b]	3.0 2.0	1.9 1.3	1.3 0.9	0.4	0.2	0.15
D. 3 in. Diam. Steel Pipe on Multi-Directional Slip Base Test 4 (11) Tests S-8 & S-18 (12)	13,647[c] 9,080[d] 7,618[e]	3.8 2.5 3.1	2.2 1.5 1.8	1.5 1.0 1.2	0.4	0.2	0.1
F. 5 in. Diam. Steel Pipe on Multi-Directional Slip Base Tests S-11 & S-17 (12)	16,635[f] 21,190[g]	4.7 5.9	2.8 3.5	1.8 2.3	0.7	0.4	0.3

[a] Low speed impact (approximately 20 mph)
[b] High speed impact (approximately 60 mph)
[c] Impact speed was 45.4 mph
[d] Impact speed was 46.0 mph
[e] Impact speed was 31.3 mph
[f] Impact speed was 44.5 mph
[g] Impact speed was 45.5 mph

TABLE A7. SEVERITY INDICES FOR EXISTING ADOT MULTIPLE POST INSTALLATIONS

SUPPORT TYPE	NO. OF POSTS	ENERGY LOSS ΔKE (FT-LB)	CHANGE IN VEHICULAR VELOCITY (FT/SEC) FOR VEHICLE WEIGHING			S.I. FOR VEHICLE WEIGHING		
			1800 LB	3000 LB	4500 LB	1800 LB	3000 LB	4500 LB
A. Square Steel Tube	2	18,116[a]	14.1[c]	8.2	5.2			
		81,681[b]	17.4[c]	11.1	7.2	2.2	1.4	0.9
	3	34,881[a]	29.3	19.6	10.6			
		117,623[b]	24.9[c]	16.0	10.3	3.7	2.5	1.3
	4	46,508[a]	29.3	29.3	15.9			
		156,831[b]	42.8	22.2	14.0	5.4	3.7	2.0
B. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Two Foot Lap Splice)	2	14,004[a]	10.1[c]	5.7	3.6			
		61,113[b]	11.8[c]	7.4	4.9	1.5	0.9	0.6
	3	21,006[a]	19.0	9.1	5.7			
		91,670[b]	20.0	11.4	7.4	2.5	1.4	0.9
	4	28,008[a]	29.3	13.3	7.9			
		122,226[b]	28.0	15.6	10.0	3.7	2.0	1.3
C. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Long Lap Splice)	2	17,291[a]	13.8	7.2	4.6			
		62,151[b]	13.2	7.7	5.0	1.7	1.0	0.6
	3	25,936[a]	22.4[c]	11.9	7.2			
		93,226[b]	12.8[c]	11.8	7.7	2.8	1.5	1.0
	4	34,581[a]	29.3	18.5	10.2			
		124,301[b]	29.1	16.1	10.4	3.7	2.3	1.3
D. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Short Lap Splice)	2	16,235[a]	13.2	6.9	4.4			
		71,445[b]	15.5	8.9	5.9	1.9	1.1	0.7
	3	24,353[a]	22.5[c]	11.4	6.9			
		107,167[b]	19.0[c]	13.8	8.9	2.8	1.7	1.1
	4	32,471[a]	29.3	17.6	9.8			
		142,889[b]	35.2	19.0	12.2	4.4	2.4	1.5

[a] Low speed impact (approximately 20 mph)
[b] High speed impact (approximately 60 mph)
[c] Occupant impact velocity measured in crash test

TABLE A8. SEVERITY INDICES FOR ALTERNATE MULTIPLE POST INSTALLATIONS

SUPPORT TYPE	NO. OF POSTS	ENERGY LOSS ΔKE (FT-LB)	CHANGE IN VEHICULAR VELOCITY (FT/SEC) FOR VEHICLE WEIGHING 1800 LB	3000 LB	4500 LB	S.I. FOR VEHICLE WEIGHING 1800 LB	3000 LB	4500 LB
A. 3 lb/ft High Carbon Steel U-Post (80 ksi) (Ground Splice)	2	12,972[a]	8.4	4.7	3.1			
		31,504[b]	6.5	3.8	2.5	1.1	0.6	0.4
	3	19,458[a]	12.5[c]	7.4	4.7			
		47,256[b]	9.1	5.8	3.8	1.6	0.9	0.6
	4	25,944[a]	22.7	10.5	6.5			
		63,008[b]	13.5	7.8	5.1	2.8	1.3	0.8
B. 4 lb/ft High Carbon Steel U-Post (80 ksi) (Ground Splice)	2	18,314[a]	14.2	7.4	4.7			
		45,406[b]	9.3	5.5	3.6	1.8	0.9	0.6
	3	27,470[a]	21.9[c]	12.2	7.4			
		68,108[b]	13.2[c]	8.3	5.5	2.7	1.5	0.9
	4	36,628[a]	29.3	19.0	10.5			
		90,812[b]	19.8	11.3	7.4	3.7	2.4	1.3
C. Square Steel Tube with Unistrut Slip Base	2	9,373[a]	6.3	4.0	2.6			
		21,435[b]	4.0	2.6	1.7	0.8	0.5	0.3
	3	14,060[a]	8.9[c]	6.2	4.0			
		32,152[b]	6.1	4.0	2.6	1.1	0.8	0.5
	4	18,747[a]	15.7	8.8	5.5			
		42,869[b]	8.1	5.3	3.5	2.0	1.1	0.7
D. "Micro-Lam" Laminated Veneer (Saw Cut) 8"x15"x1 1/4" (13)	2[d]	11,705[a]	7.8[c]	4.5	2.9			
		41,083[b]	8.8[c]	5.3	3.5	1.1	0.7	0.44

[a] Low speed impact (approximately 20 mph)
[b] High speed impact (approximately 60 mph)
[c] Occupant impact velocity measured in crash test
[d] Installation had two posts but only one hit in test

Four vehicle sizes are assumed to represent the vehicle population in the B/C program. In the present analysis, the distribution is assumed as follows:

Vehicle	Vehicle Weight W, (lb)	Percent of Population, P(%)
1	1800	12
2	3000	43
3	4500	21
4	>4500	24

The first step in the adjustment process is to compute a weighted average of the accident costs, AC, associated with the SI for each of the four vehicle sizes.

$$\overline{AC} = \frac{AC\ (P_1) + AC_2(P_2) + AC_3(P_3) + AC_4(P_4)}{1.0} \quad \text{....................(A7)}$$

where

AC_i = Accident cost for vehicle "i" for given SI_i, i=1,4

P_i = Fractional portion of population of vehicle "i", i=1,4

The weighted $\overline{SI}$ is then the SI corresponding to the value of $\overline{AC}$. It should be noted that in the present analysis, it was assumed that AC_4 was zero.

As an example of the use of Equation A7, consider a 3 lb/ft high carbon steel U-post system. It is desired to compute an SI for a two-post impact. From Table A8,

$$SI_1 = 1.1$$
$$SI_2 = 0.6$$
$$SI_3 = 0.4$$

Then, using Table 1 (in main text) the following values are obtained (using linear interpolation).

$$AC_1 = \$4480$$
$$AC_2 = \$3320$$
$$AC_3 = \$2870$$

Next, from Equation A7,

$$\overline{AC} = (4480)\ (0.12) + (3320)\ (0.43) + (2870)\ (0.21)$$

$$\overline{AC} = \$2570$$

Finally, using Table 1 the value of $\overline{SI}$ is obtained by linear interpolation.

$$\overline{SI} = 0.3$$

A P P E N D I X B

RETROFIT GUIDELINES FOR U-POSTS

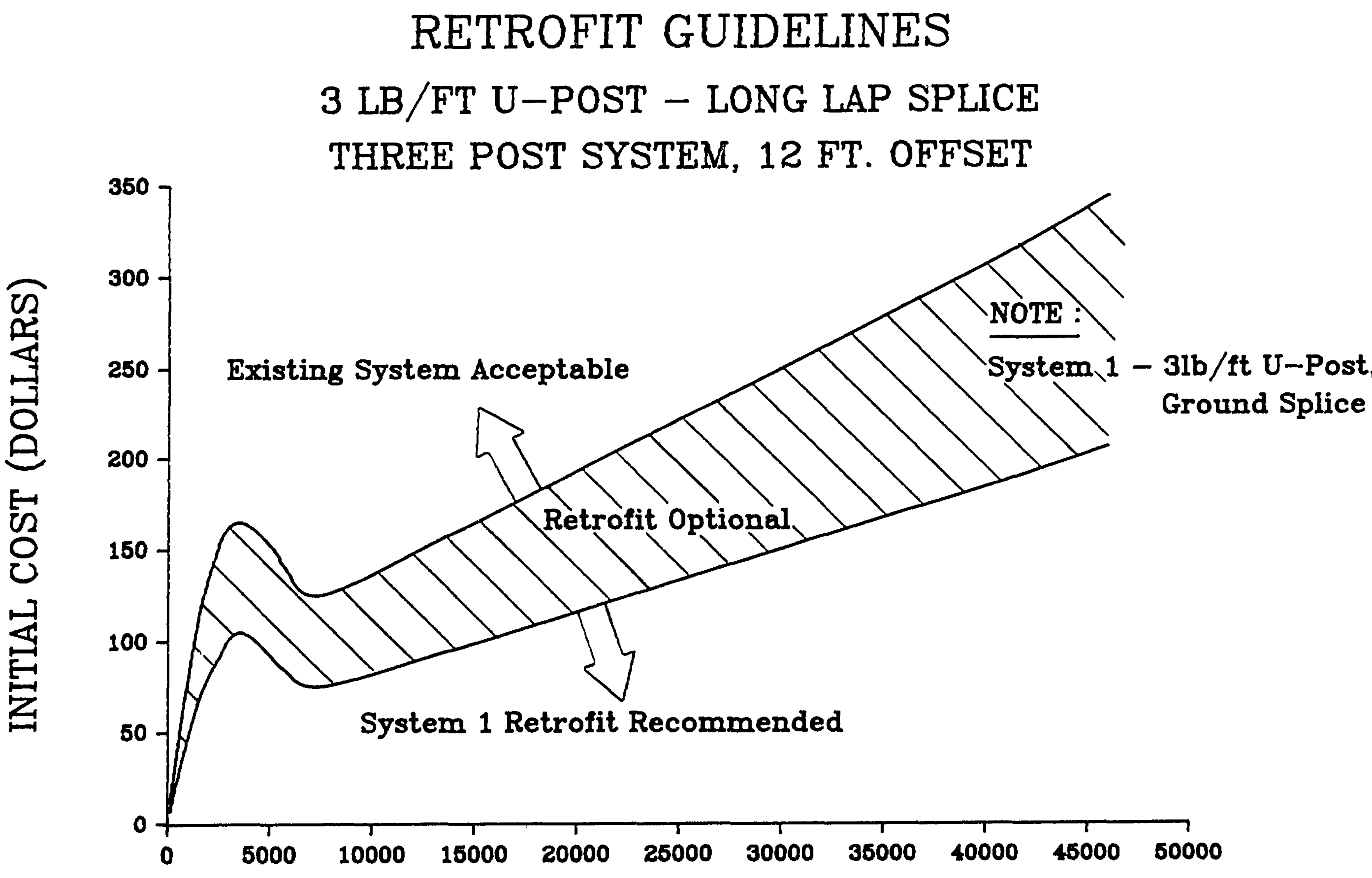

FIGURE B1. U-POST RETROFIT GUIDELINES, PART A

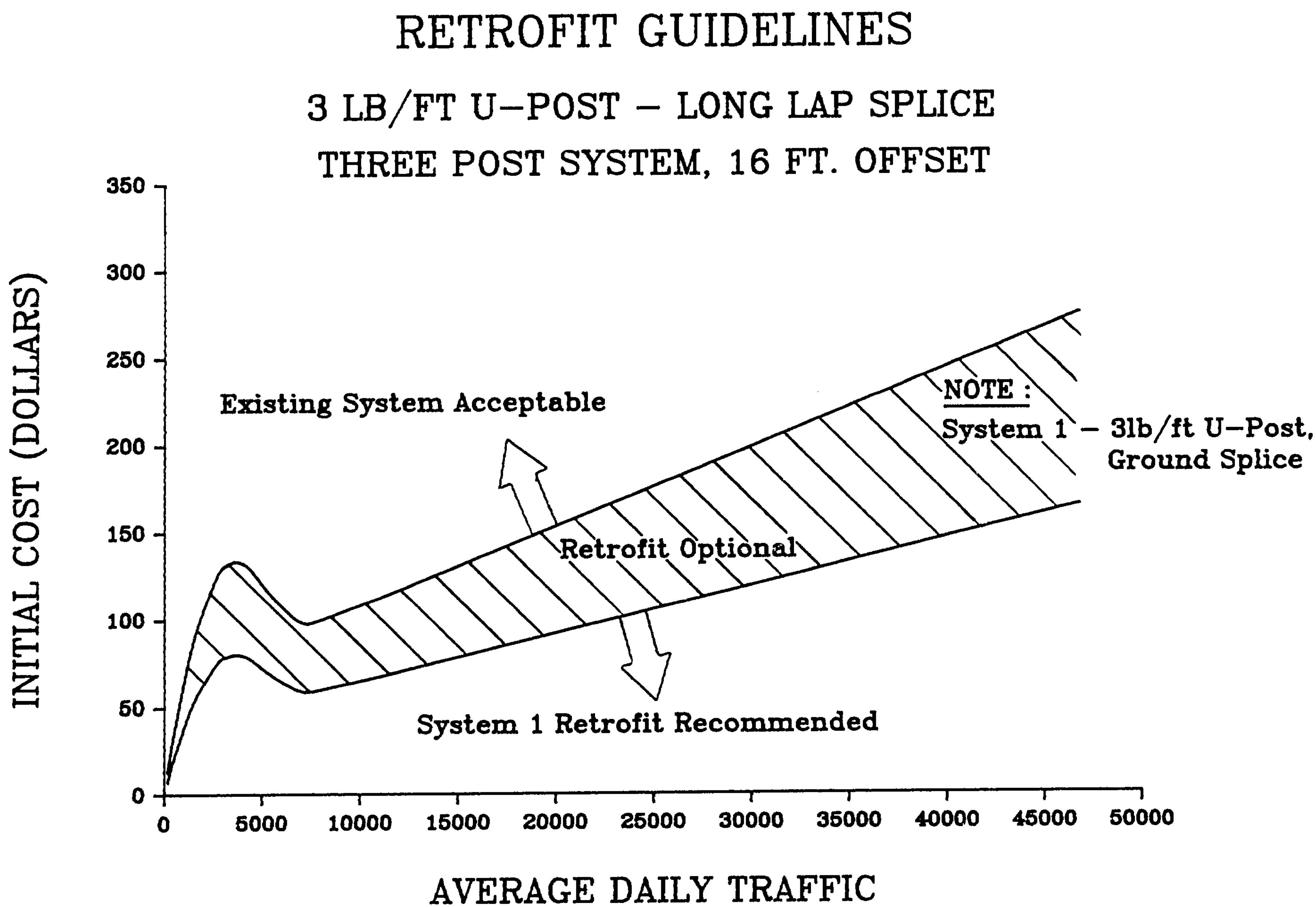

FIGURE B2. U-POST RETROFIT GUIDELINES, PART B

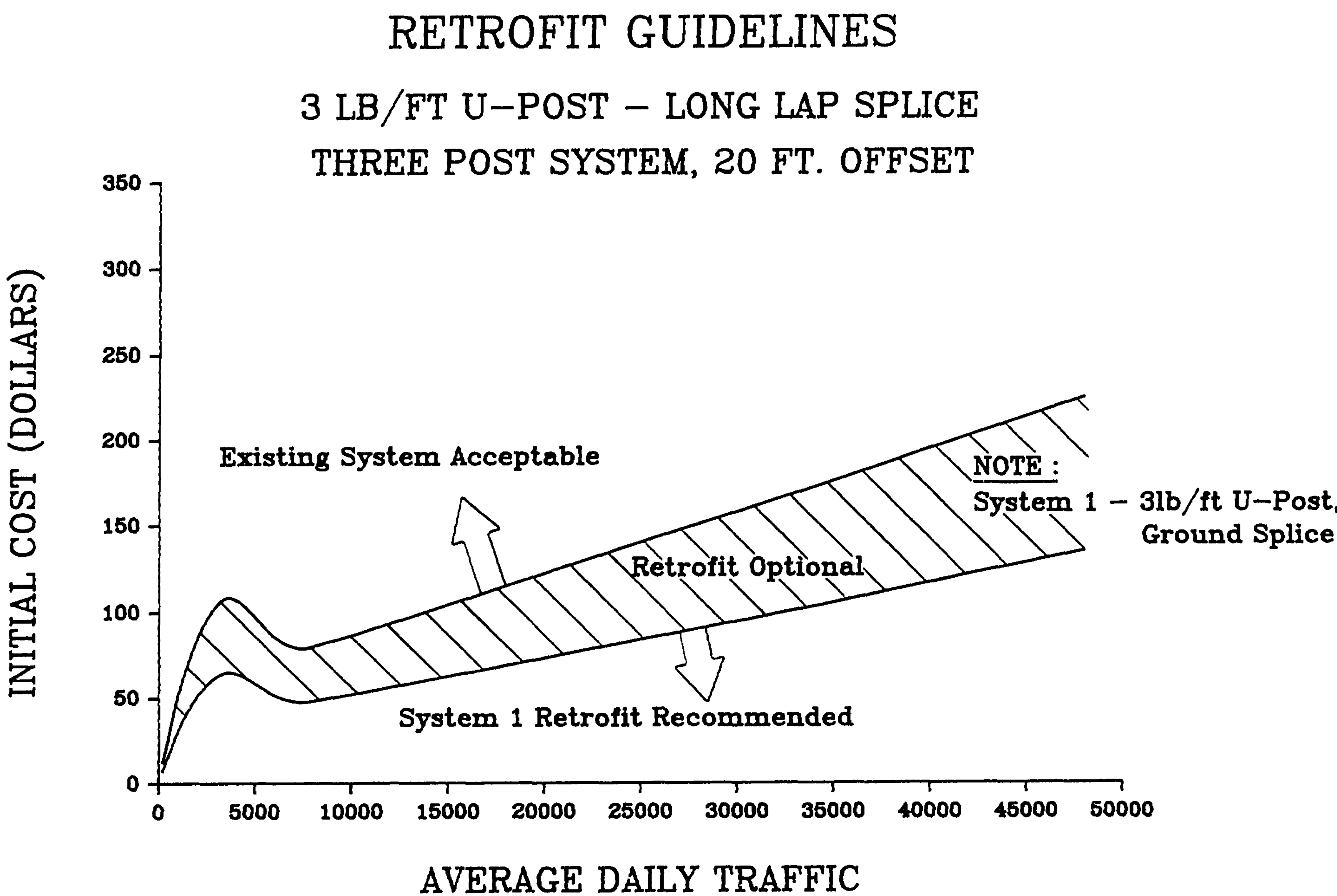

FIGURE B3. U-POST RETROFIT GUIDELINES, PART C

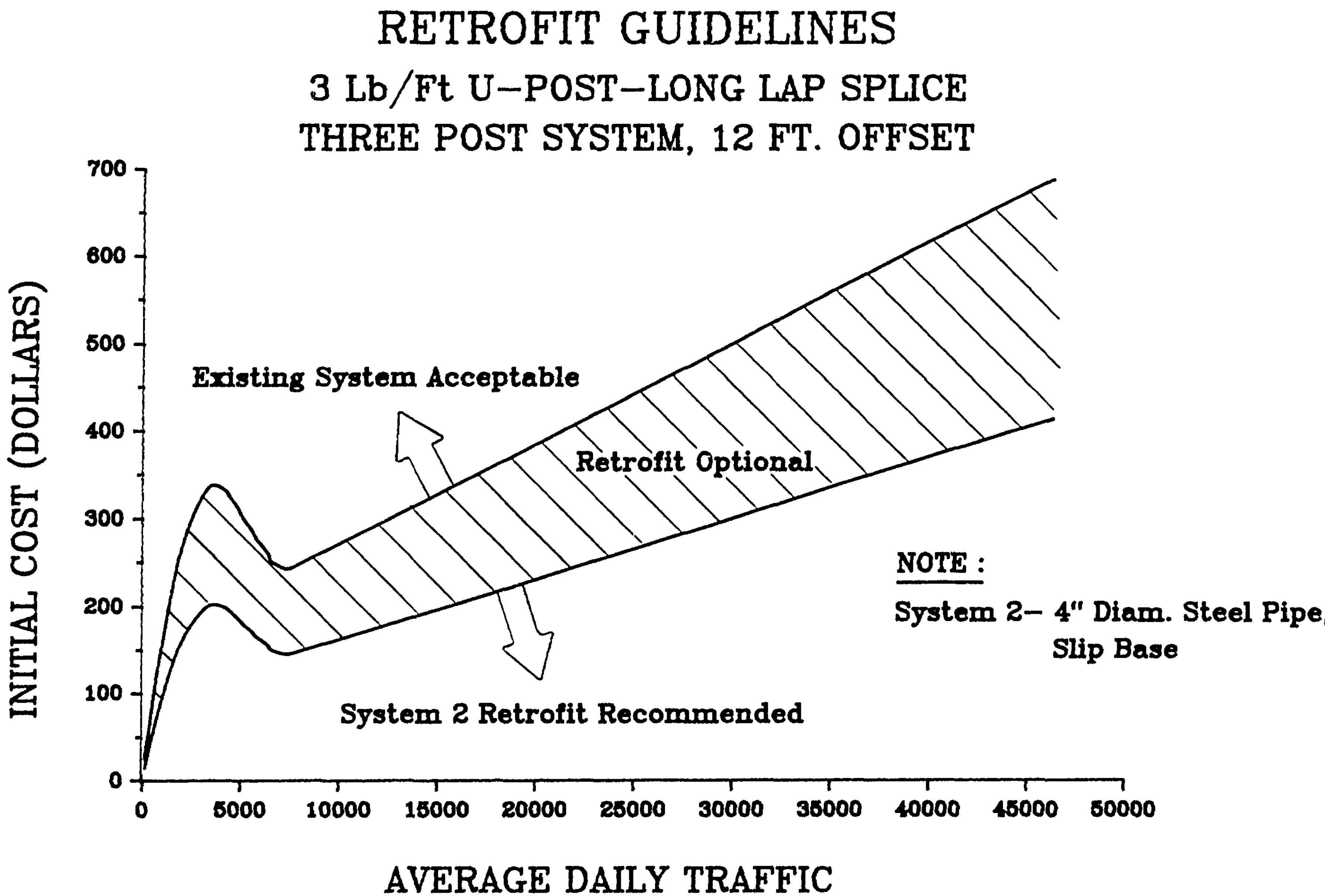

FIGURE B4. U-POST RETROFIT GUIDELINES, PART D

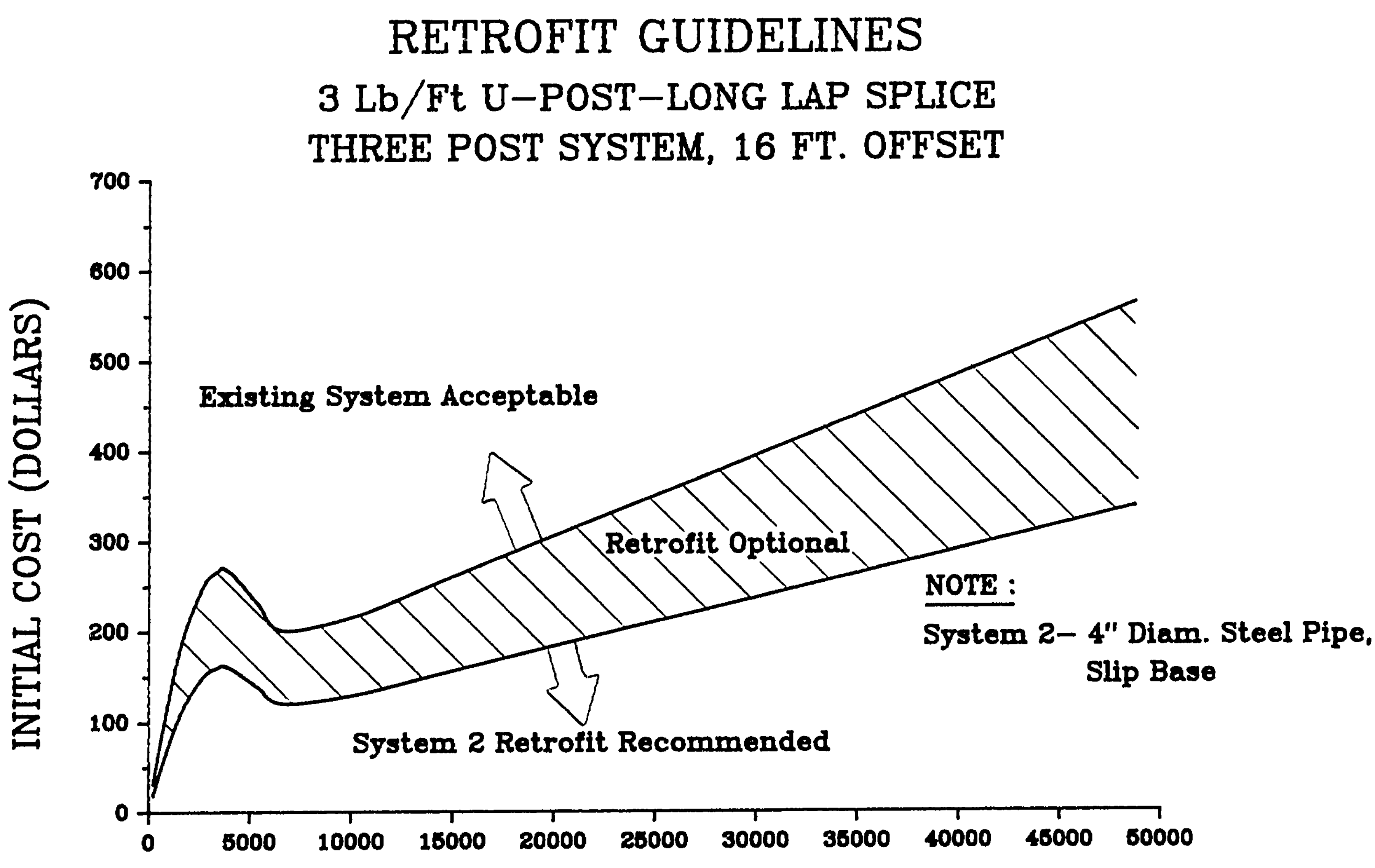

FIGURE B5. U-POST RETROFIT GUIDELINES, PART E

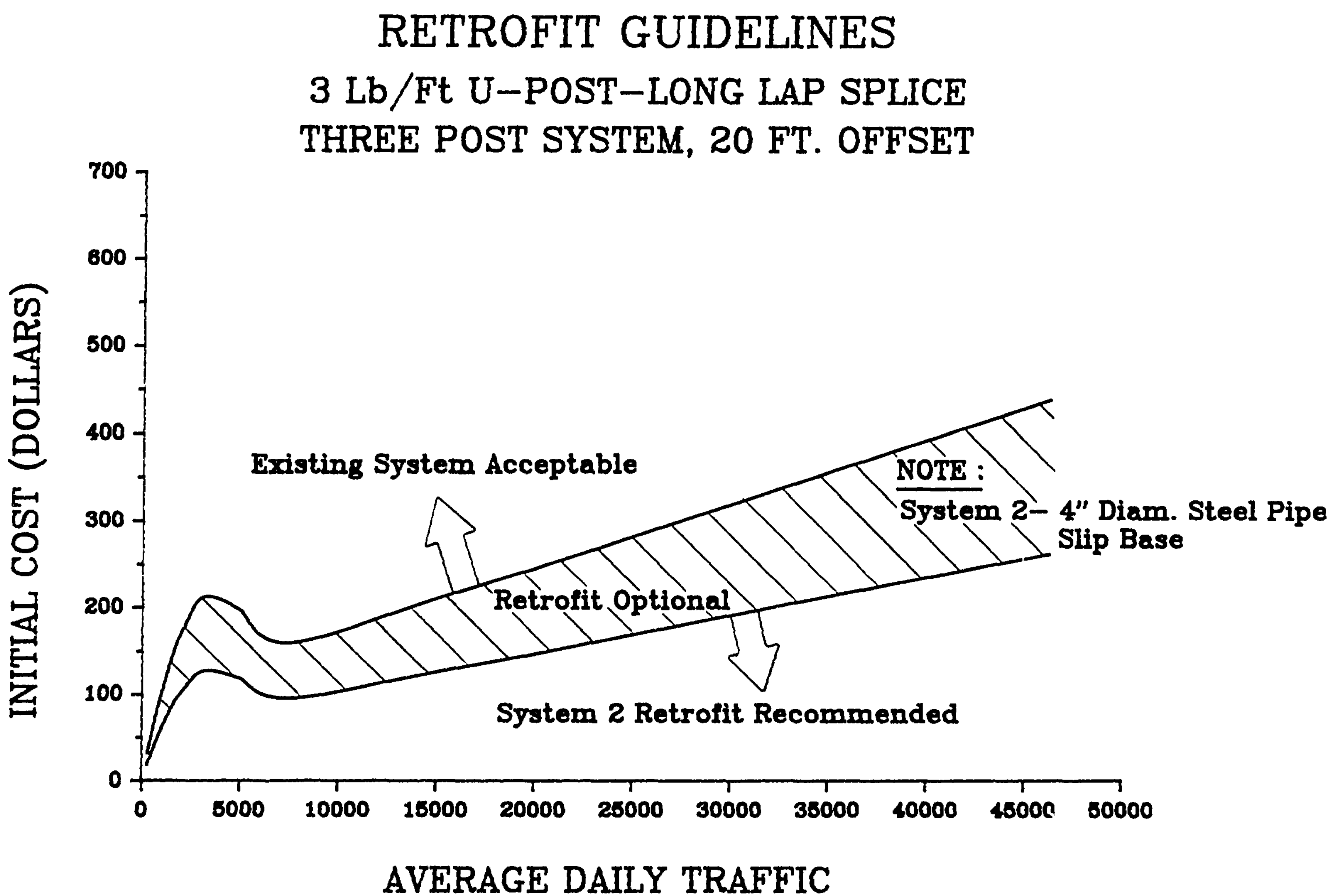

FIGURE B6. U-POST RETROFIT GUIDELINES, PART F

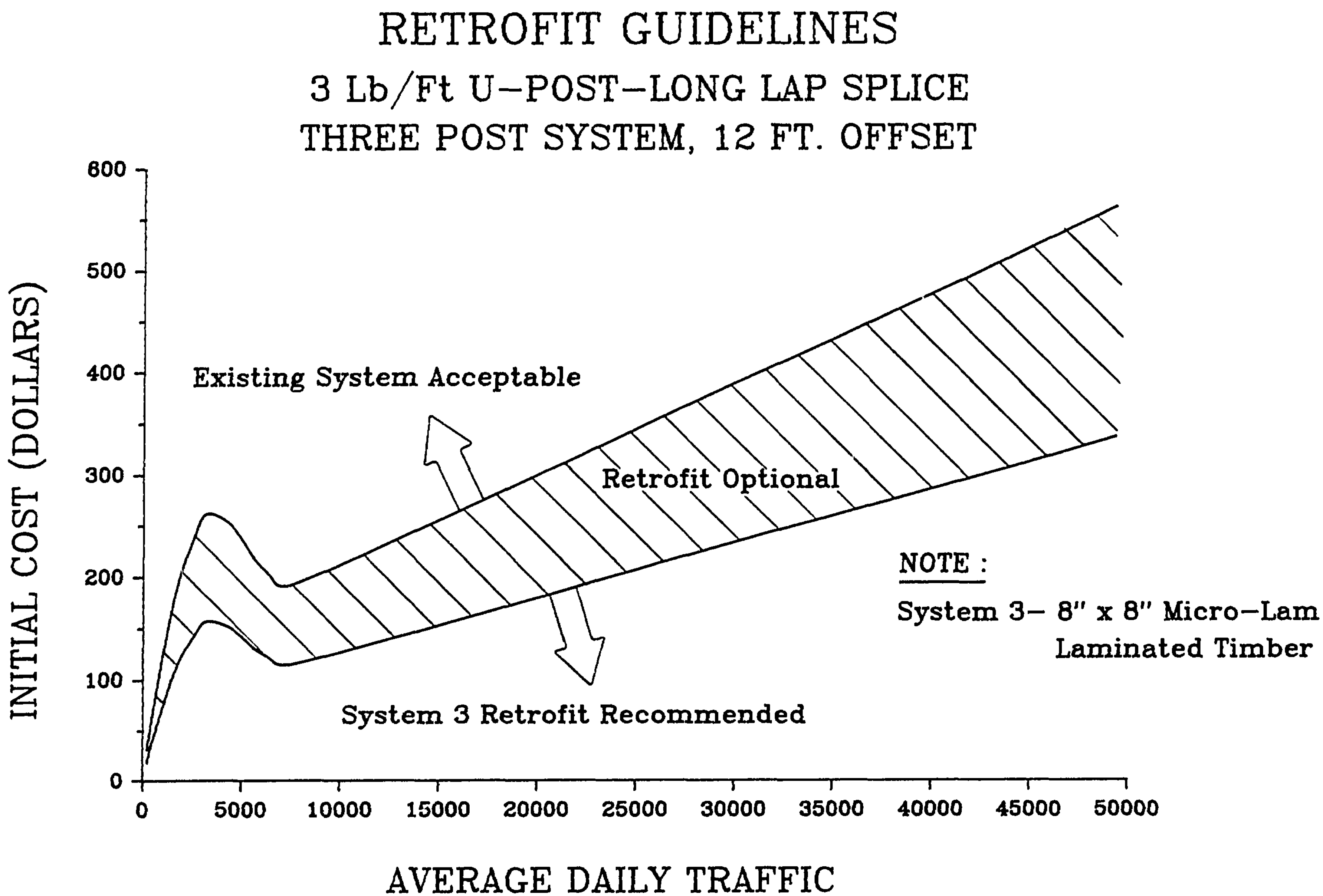

FIGURE B7. U-POST RETROFIT GUIDELINES, PART G

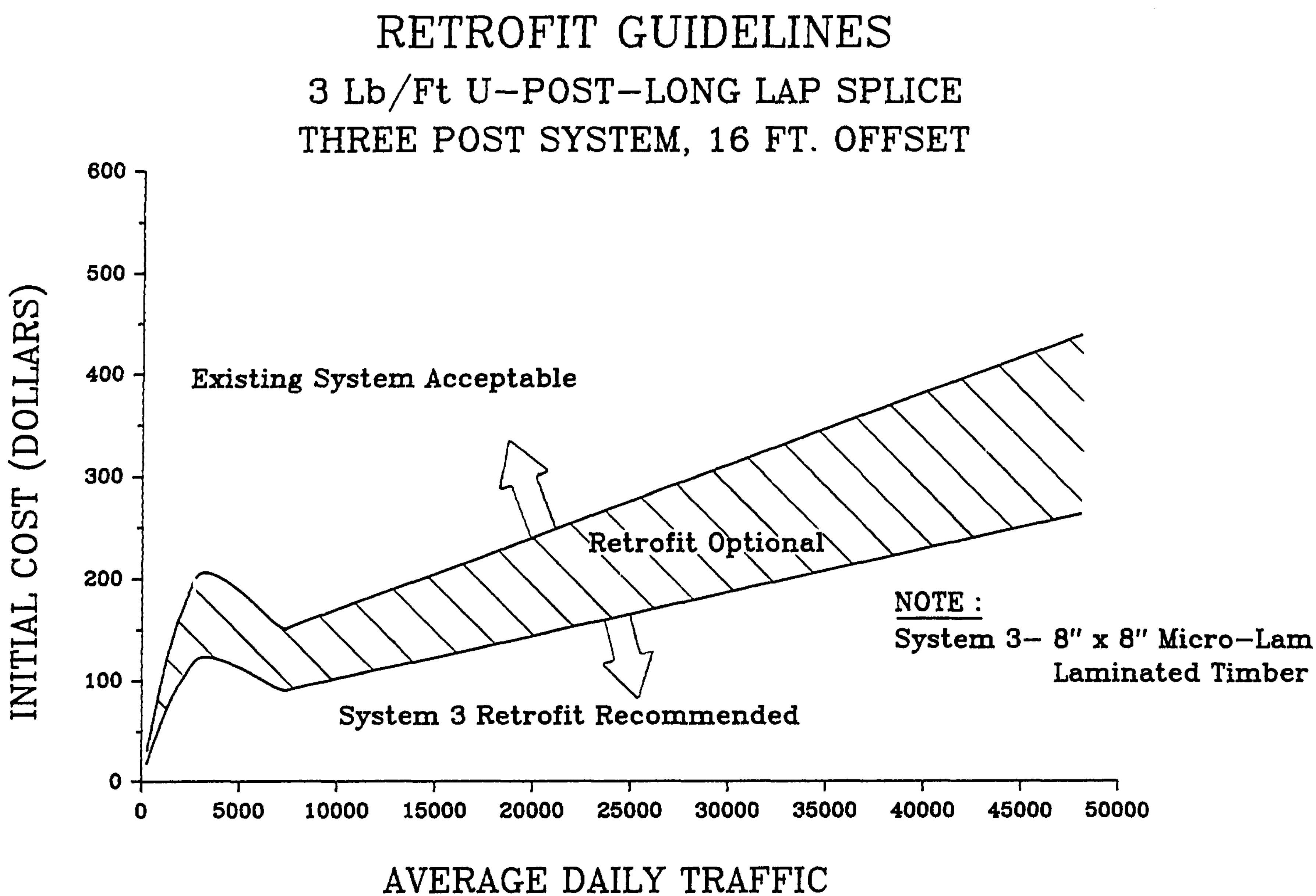

FIGURE B8. U-POST RETROFIT GUIDELINES, PART H

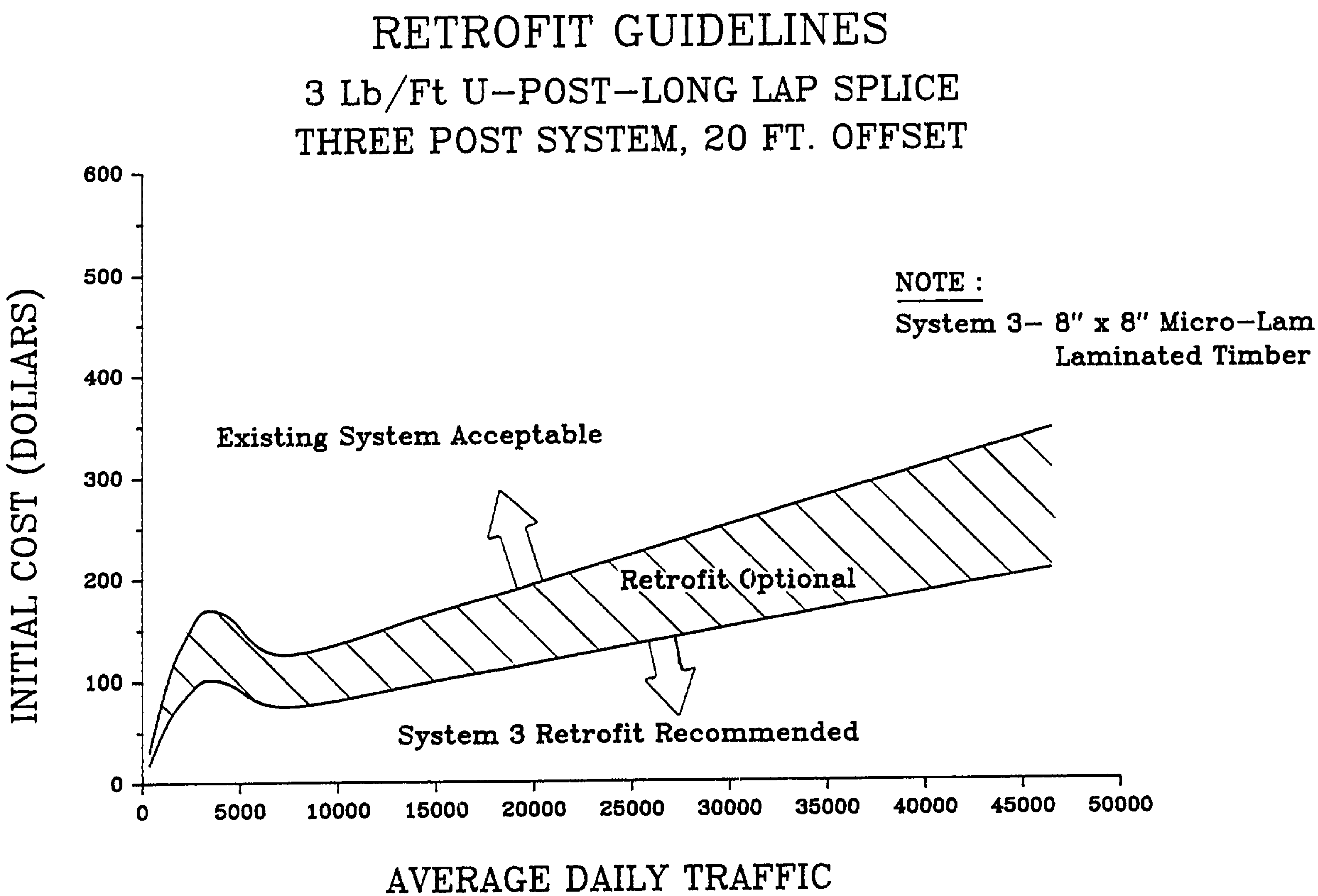

FIGURE B9. U-POST RETROFIT GUIDELINES, PART I

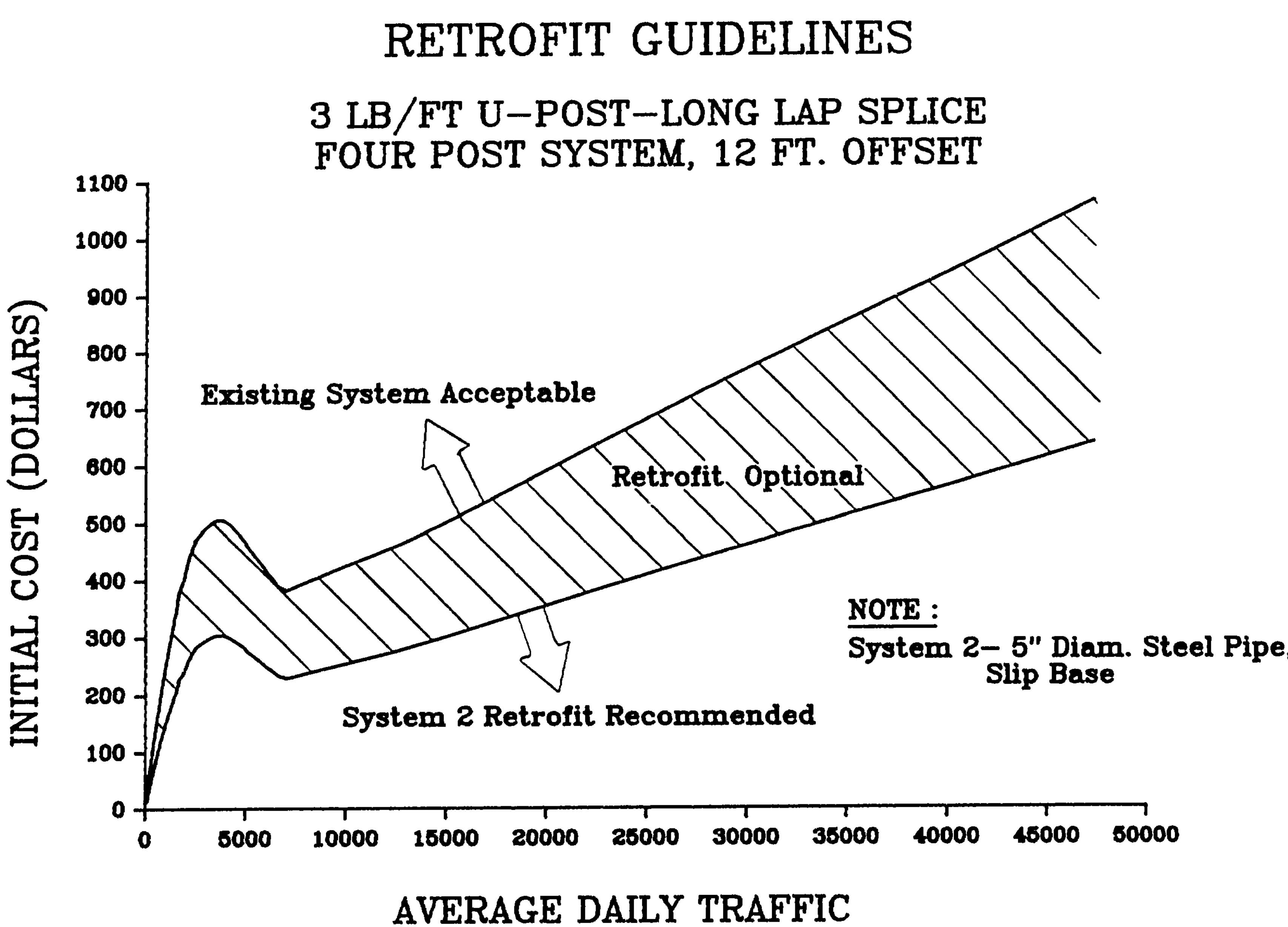

FIGURE B10. U-POST RETROFIT GUIDELINES, PART J

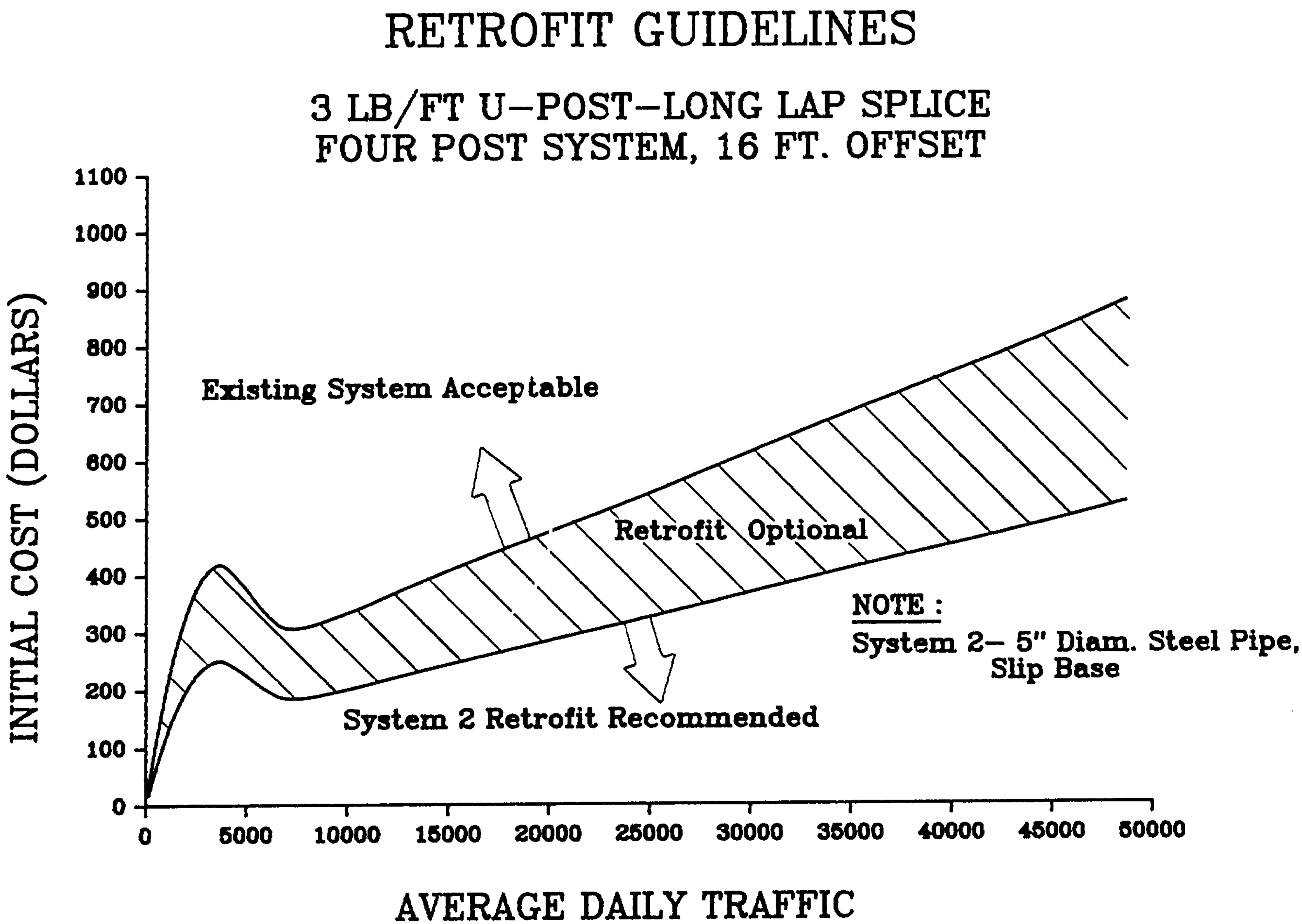

FIGURE B11. U-POST RETROFIT GUIDELINES, PART K

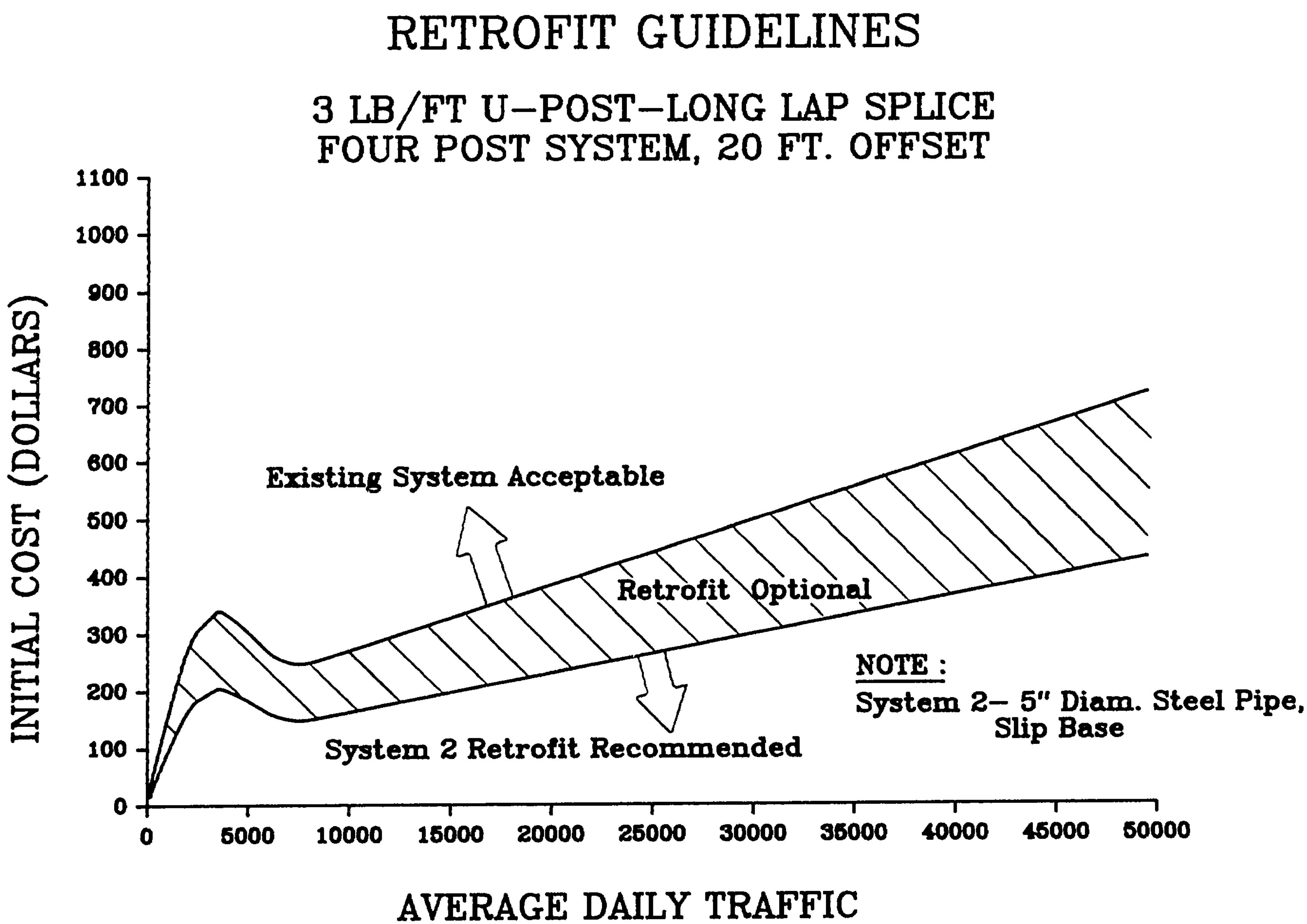

FIGURE B12. U-POST RETROFIT GUIDELINES, PART L

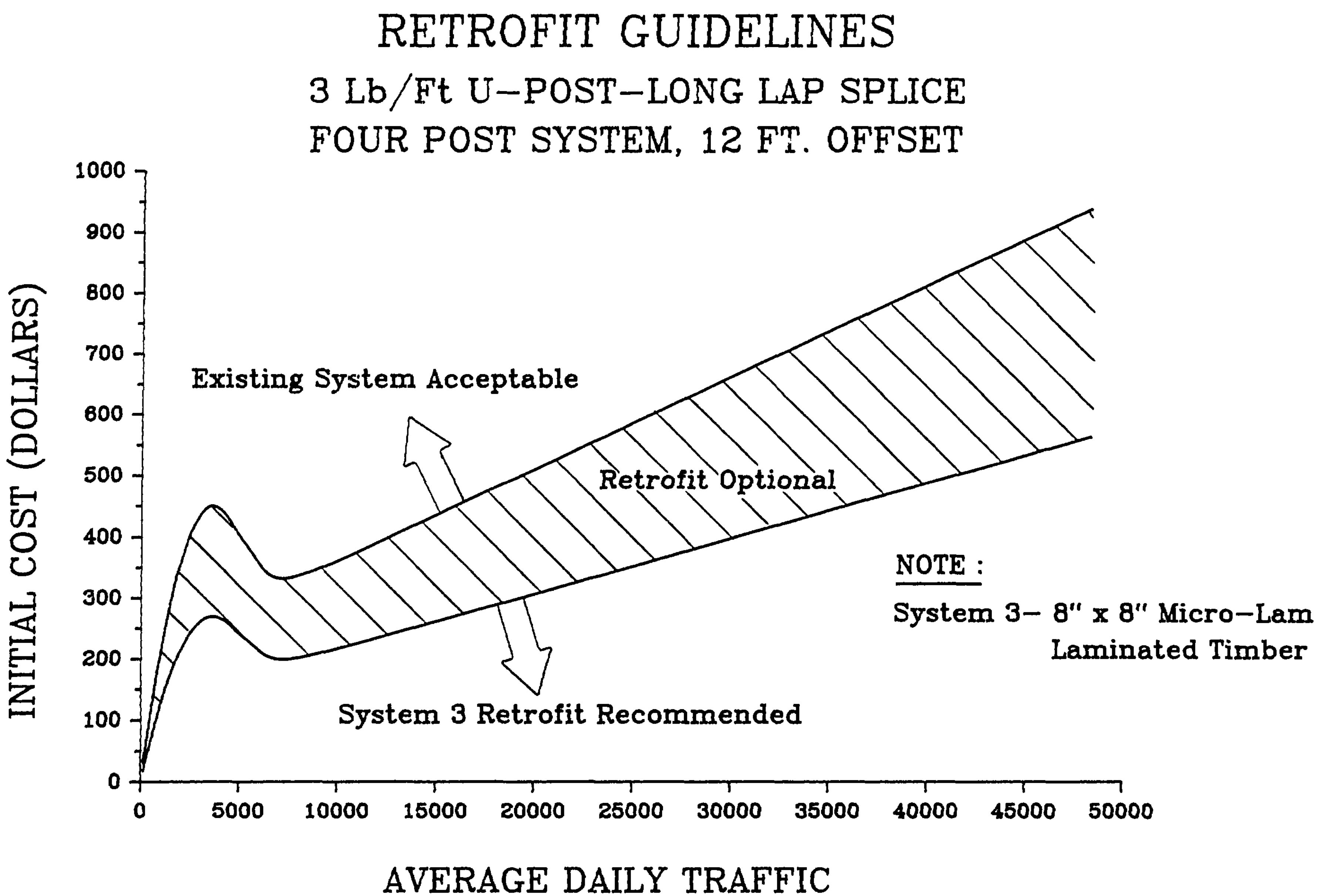

FIGURE B13. U-POST RETROFIT GUIDELINES, PART M

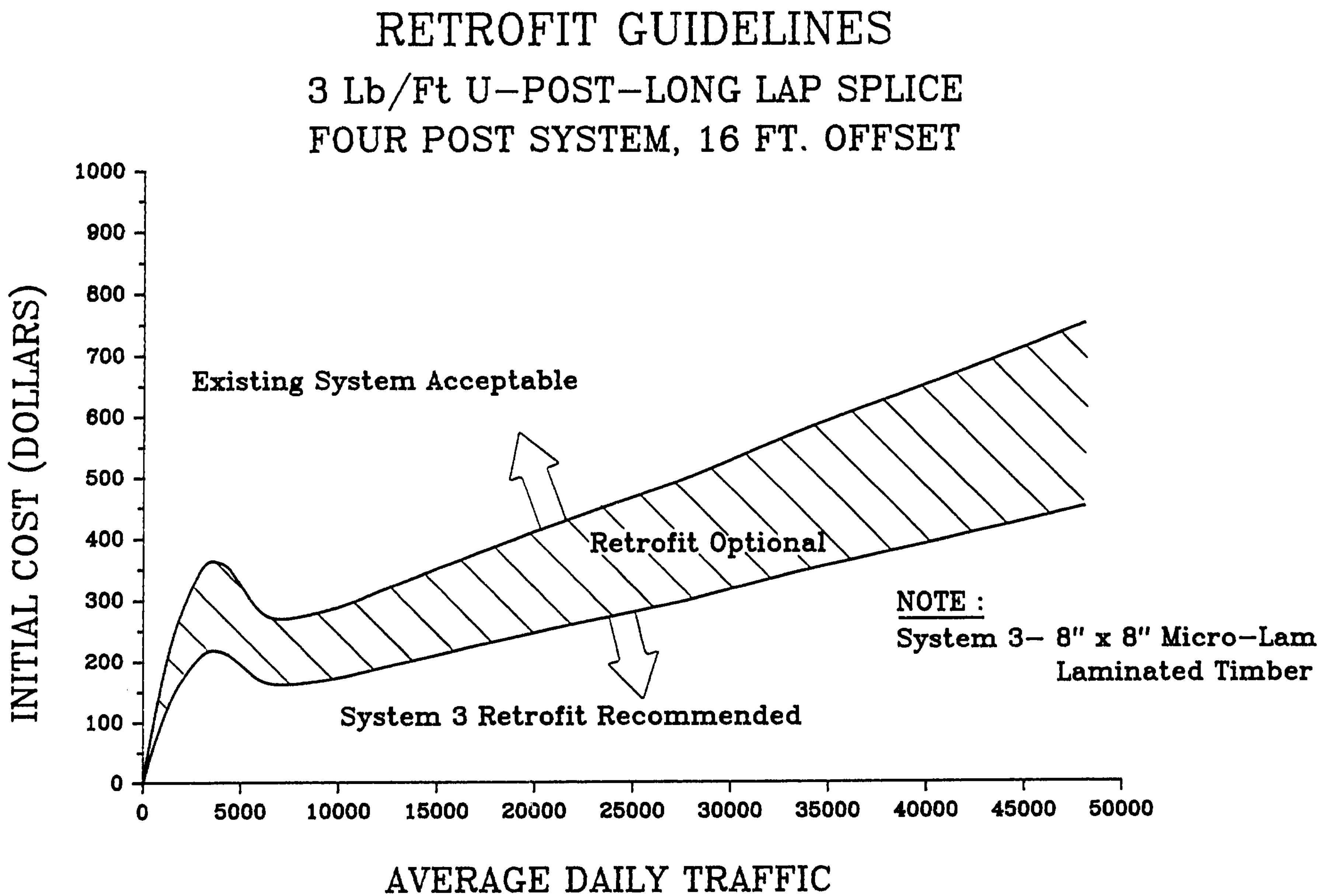

FIGURE B14. U-POST RETROFIT GUIDELINES, PART N

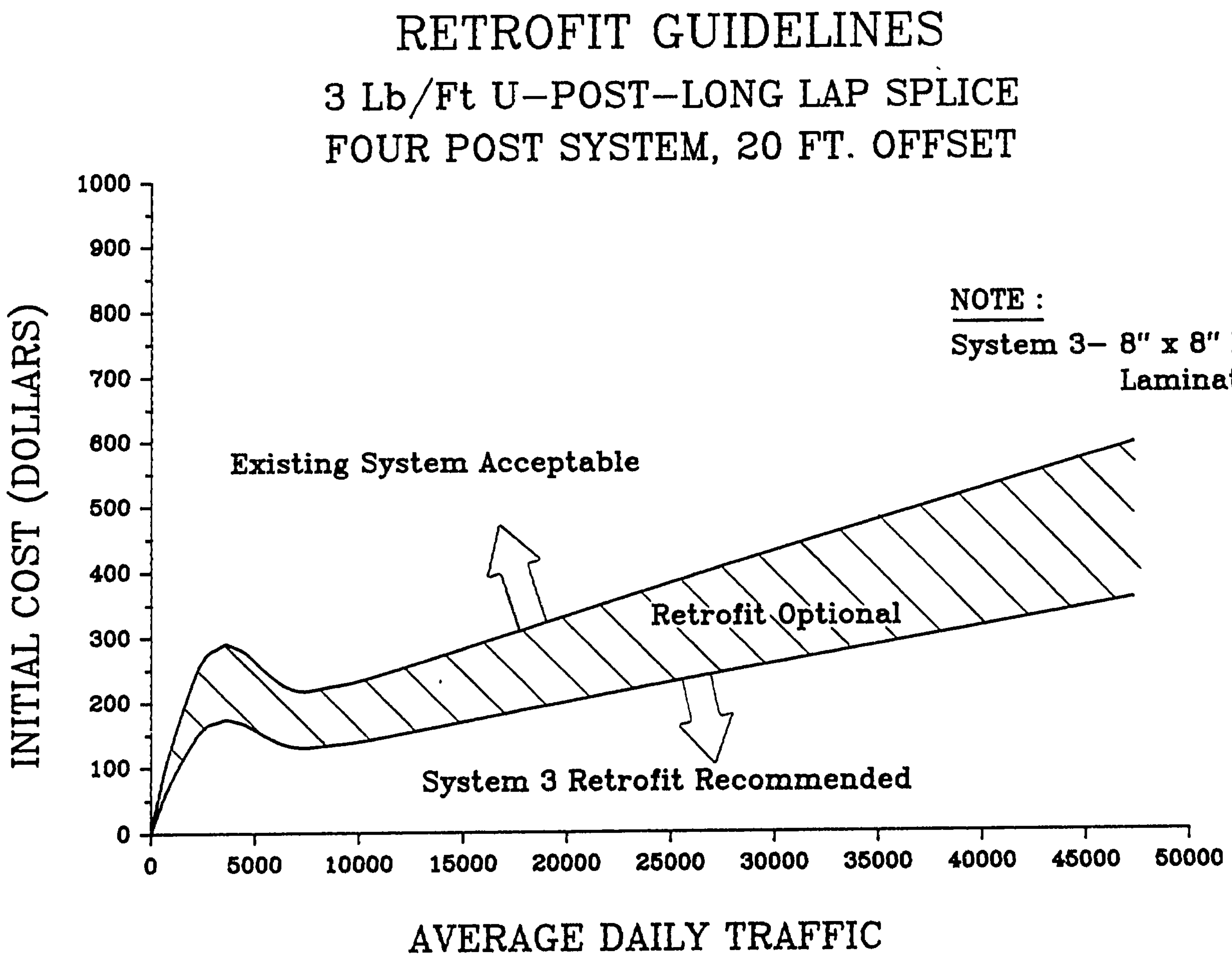

FIGURE B15. U-POST RETROFIT GUIDELINES, PART 0

APPENDIX C

RETROFIT GUIDELINES FOR P2 POSTS

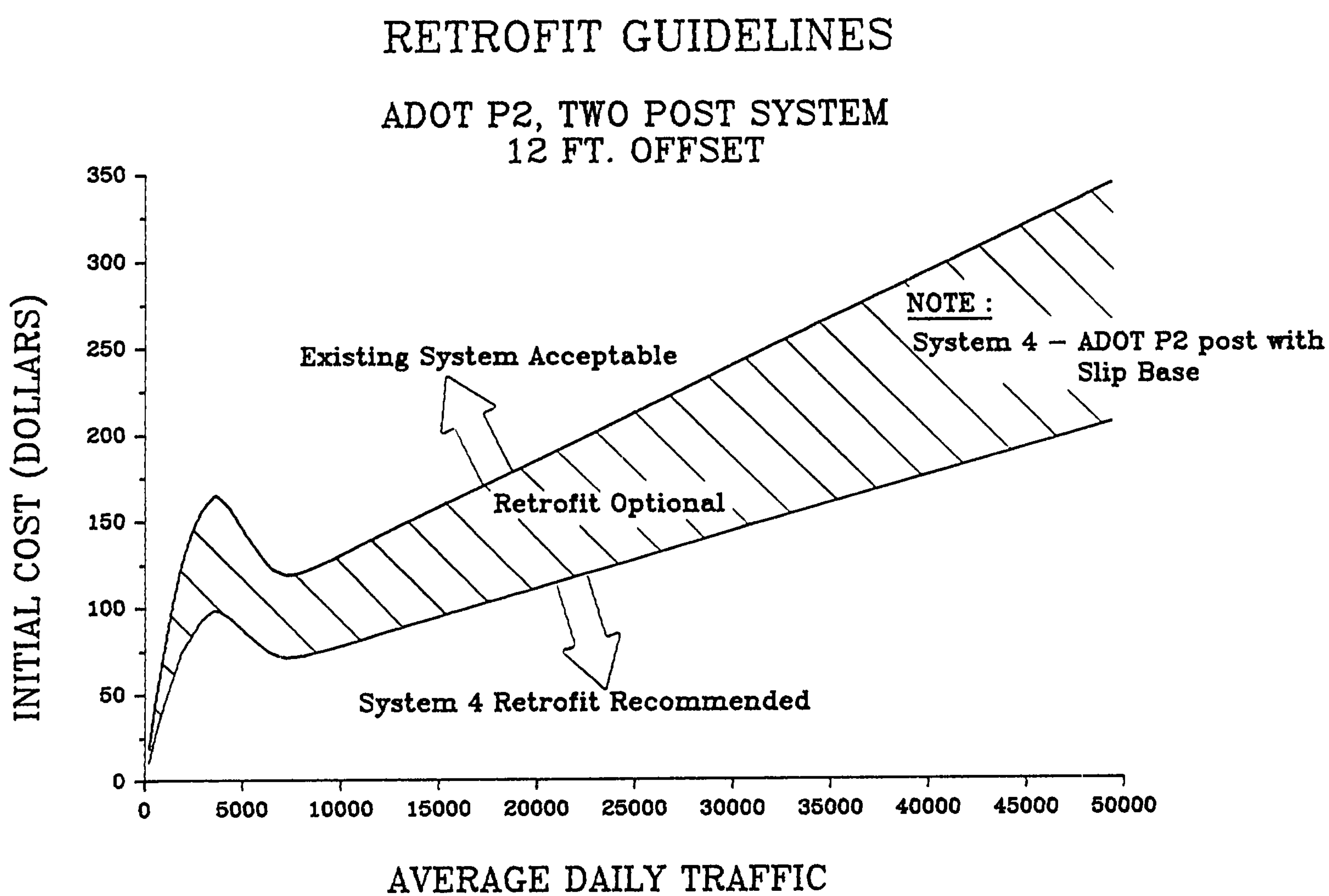

FIGURE C1. P2 POST RETROFIT GUIDELINES, PART A

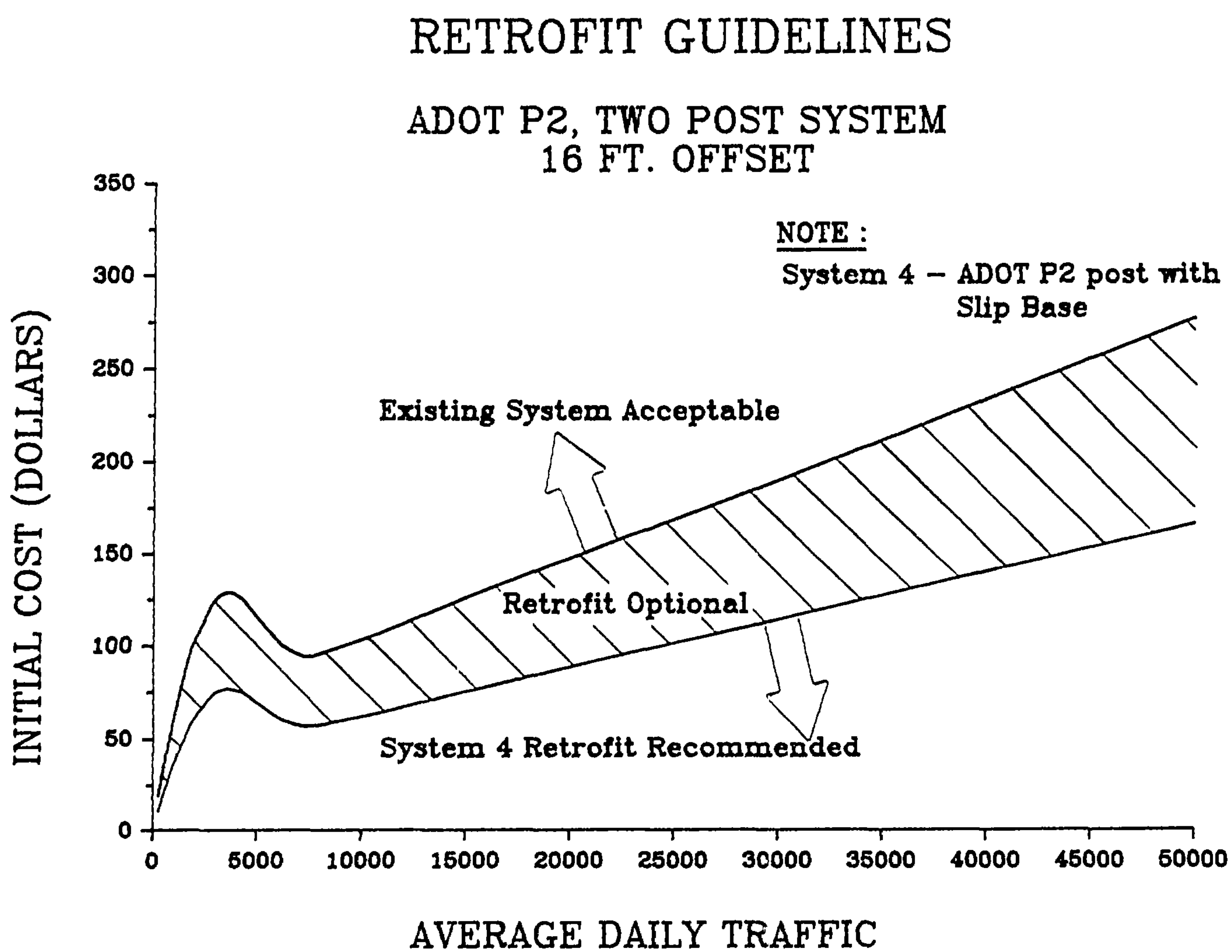

FIGURE C2. P2 POST RETROFIT GUIDELINES, PART B

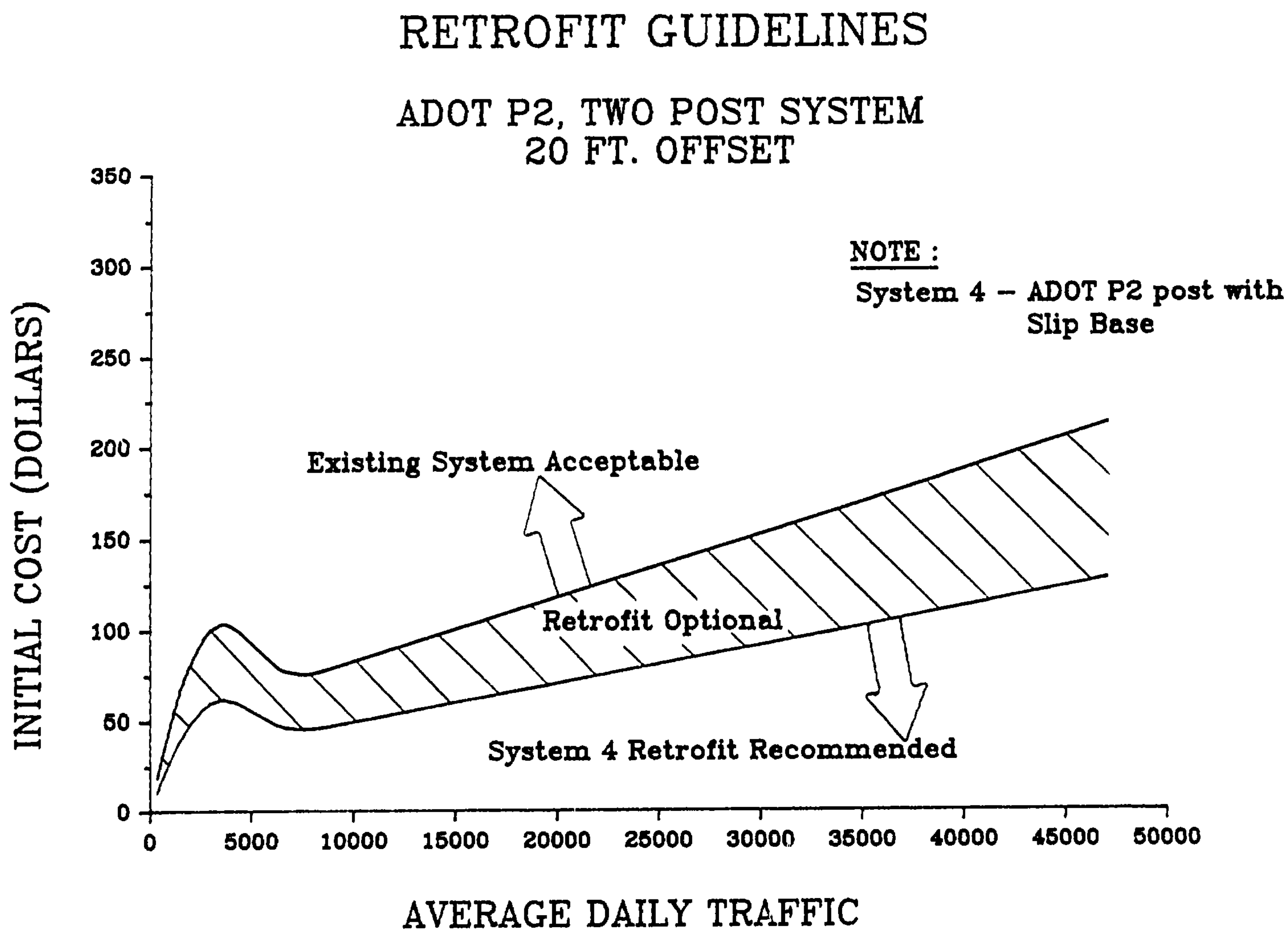

FIGURE C3. P2 POST RETROFIT GUIDELINES, PART C.

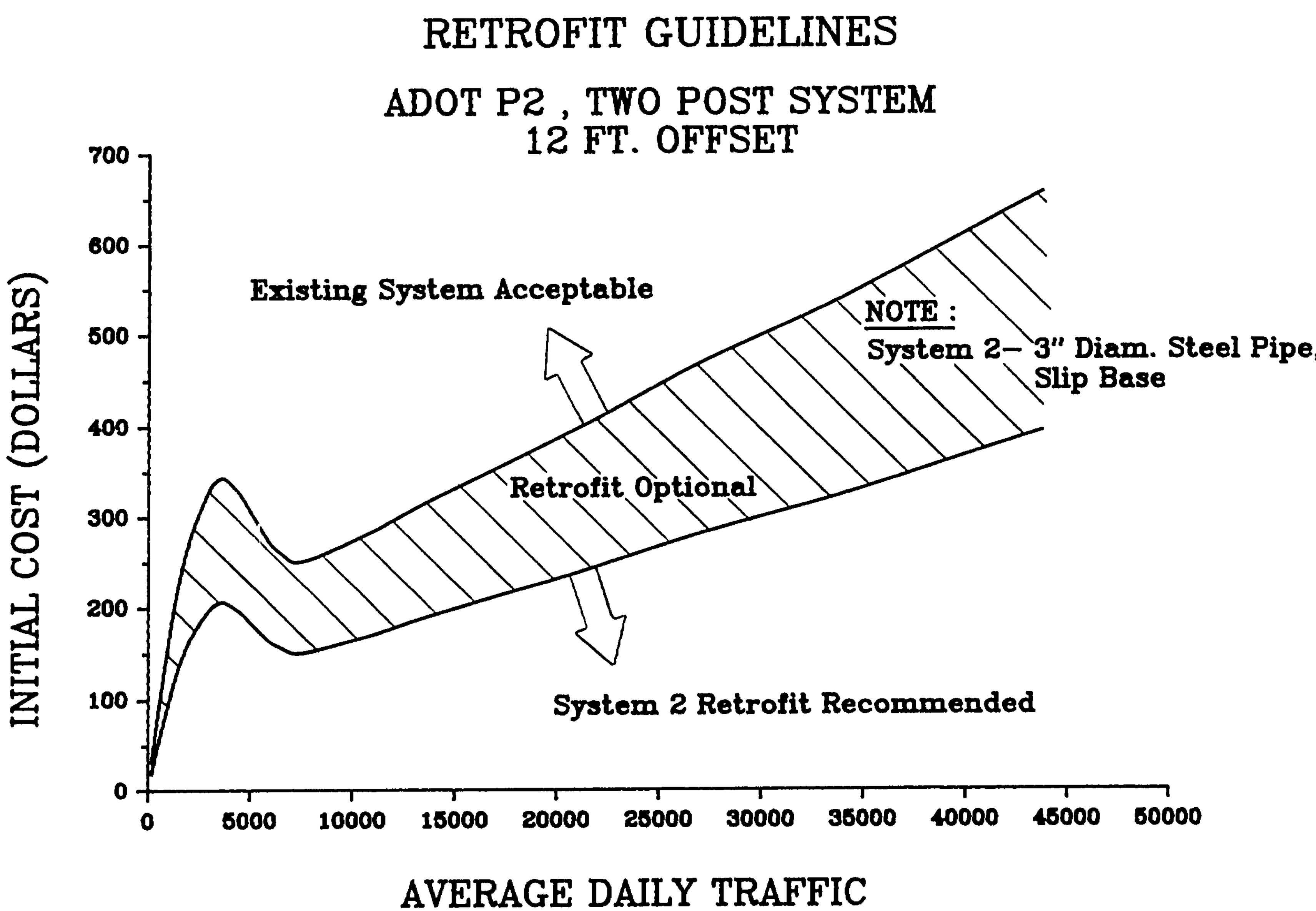

FIGURE C4. P2 POST RETROFIT GUIDELINES, PART D

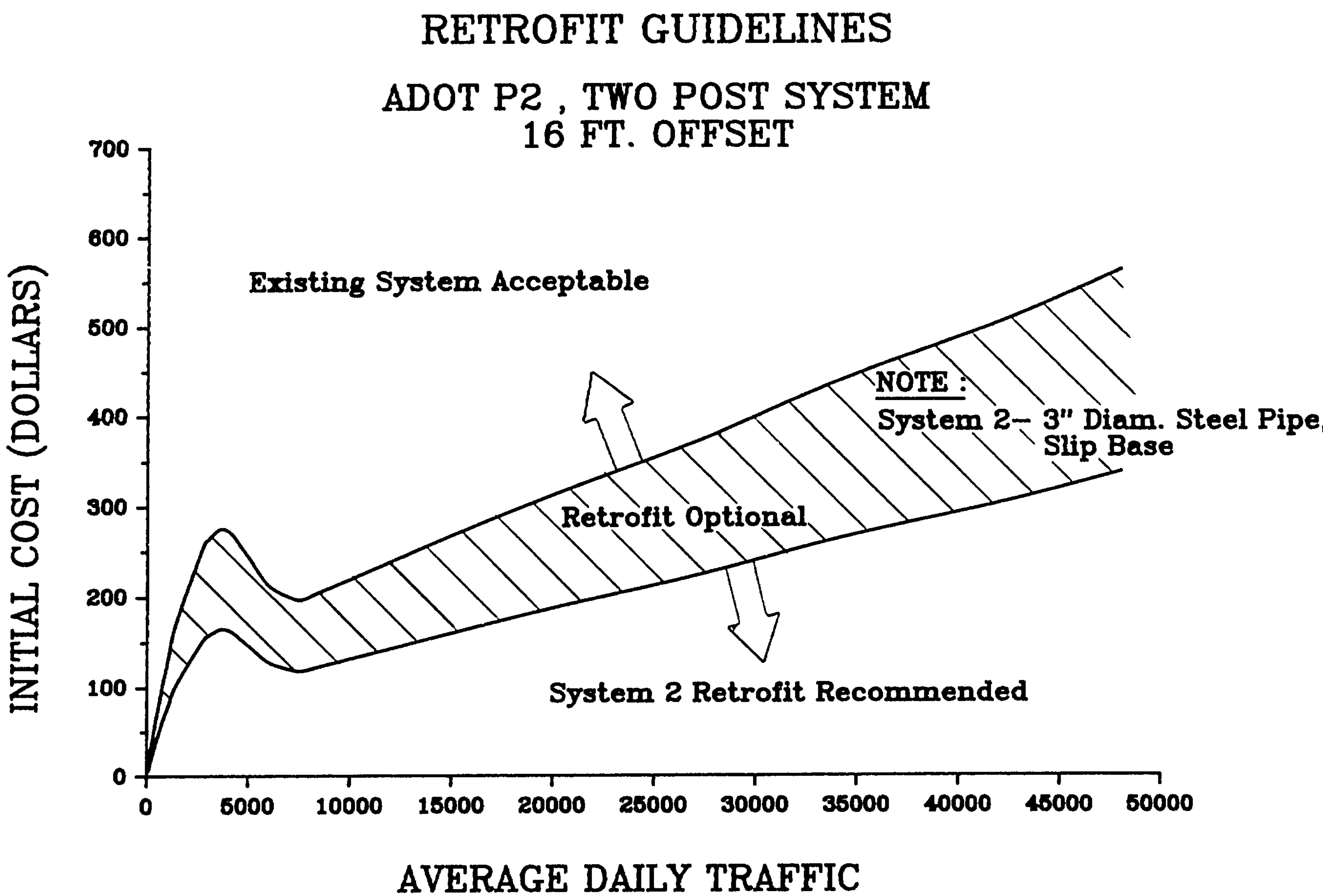

FIGURE C5. P2 POST RETROFIT GUIDELINES, PART E

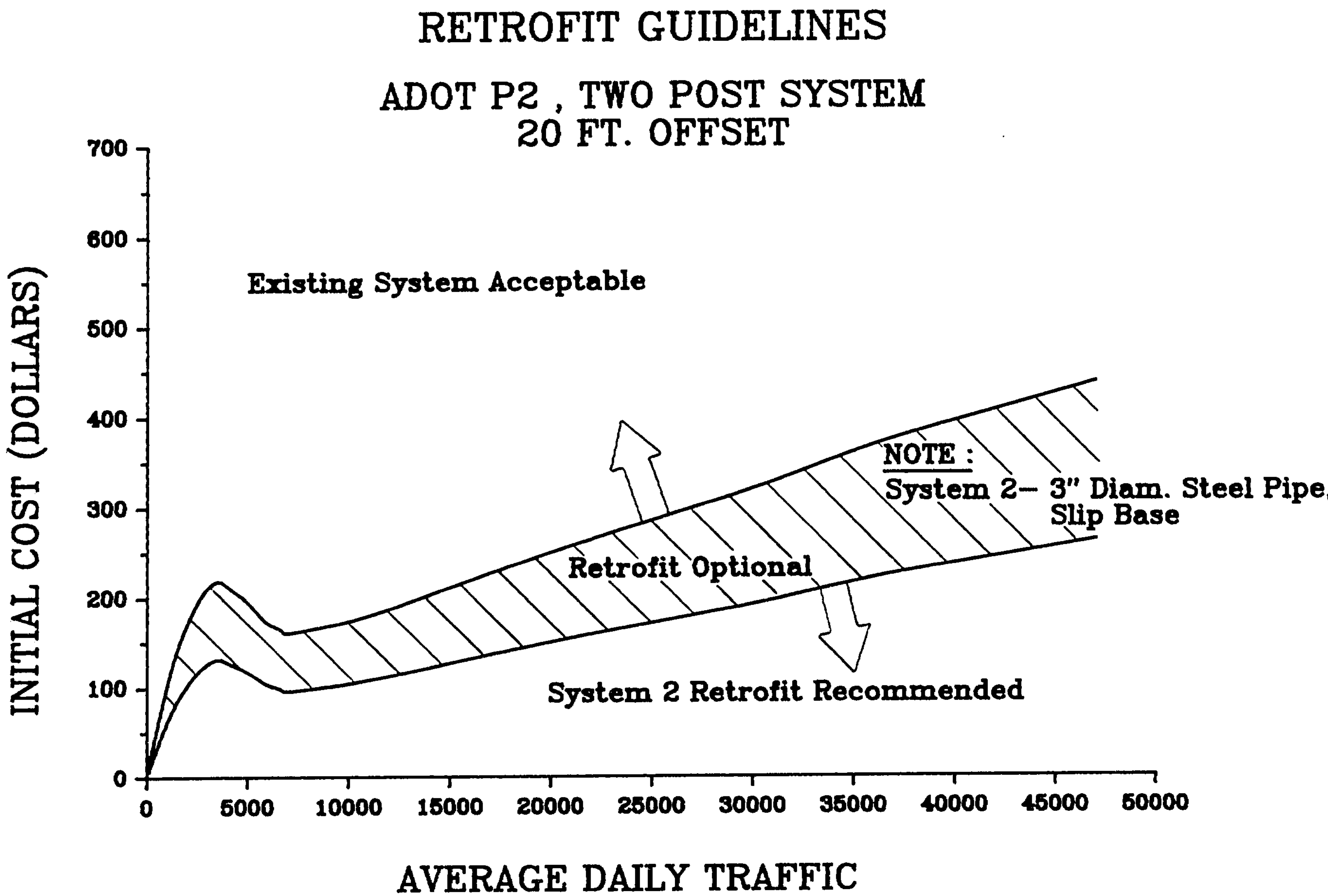

FIGURE C6. P2 POST RETROFIT GUIDELINES, PART F

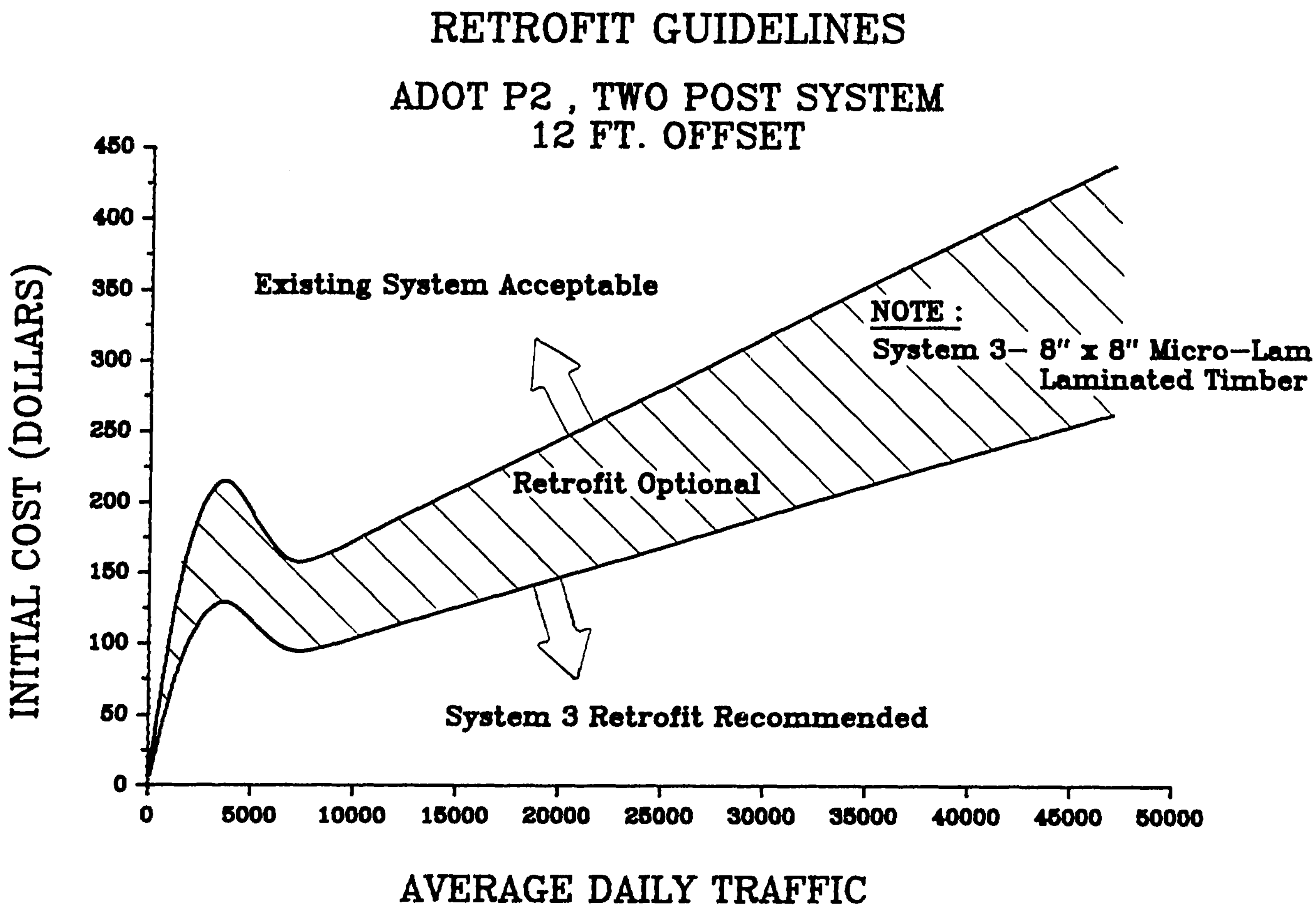

FIGURE C7. P2 POST RETROFIT GUIDELINES, PART G

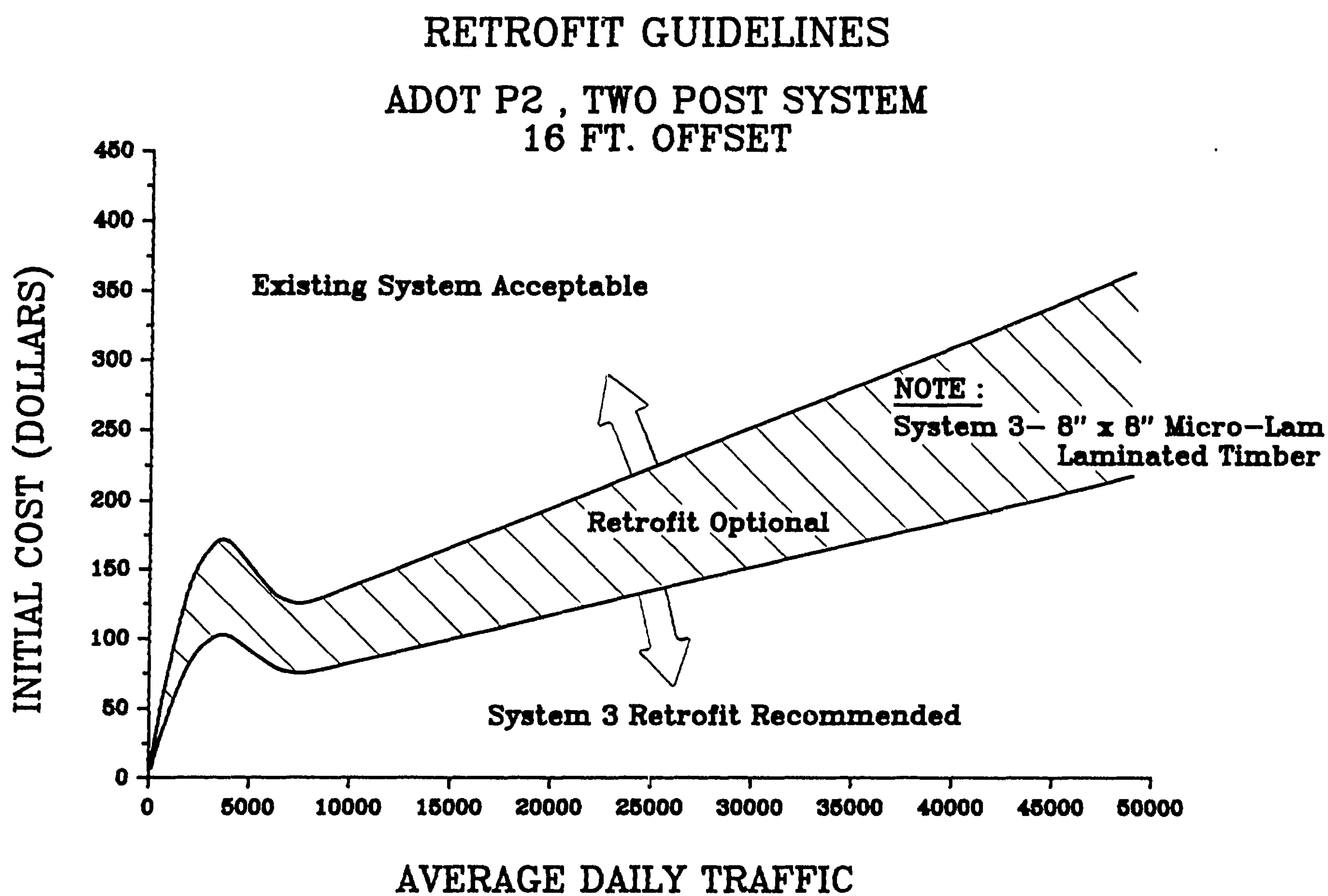

FIGURE C8. P2 POST RETROFIT GUIDELINES, PART H

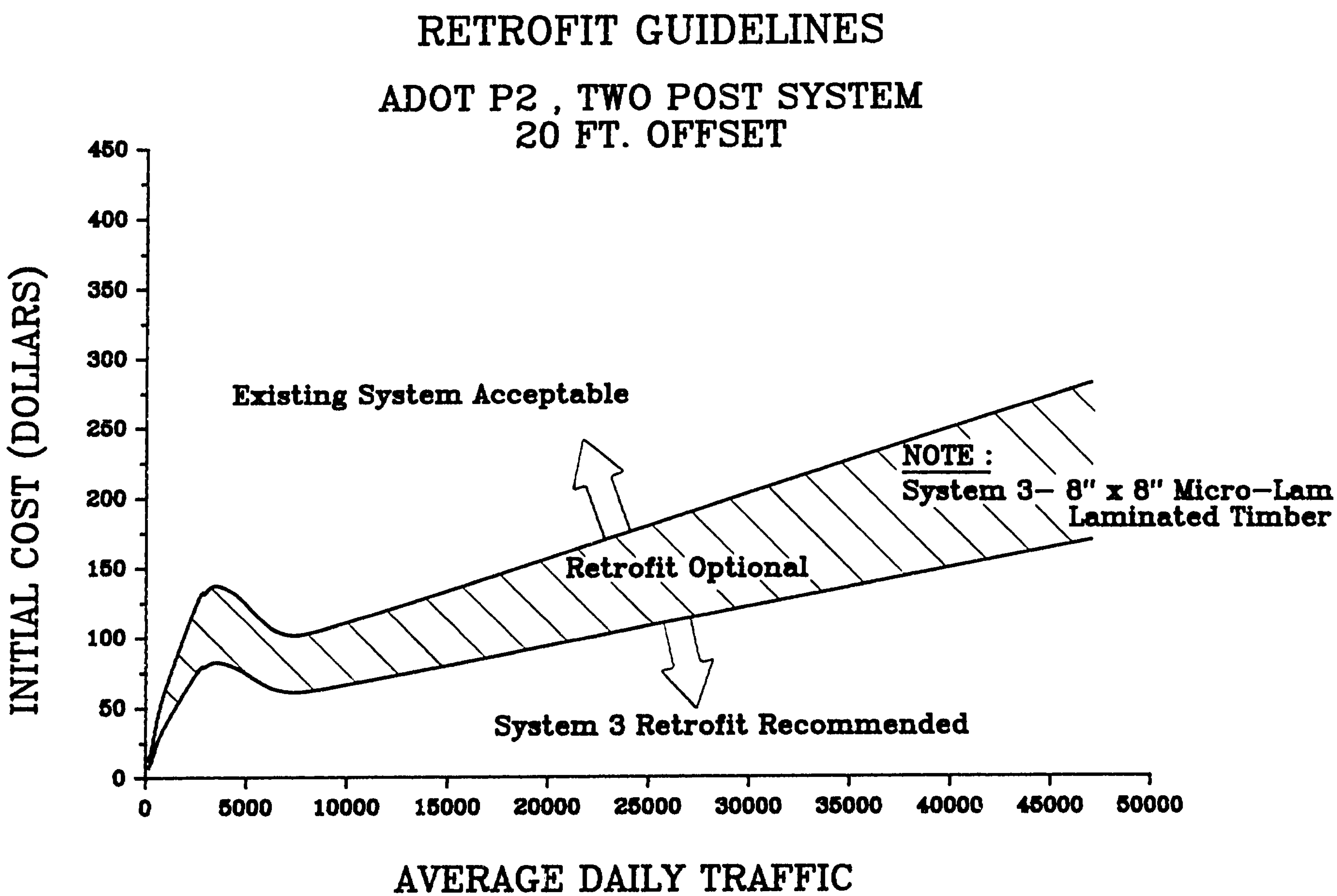

FIGURE C9. P2 POST RETROFIT GUIDELINES, PART I

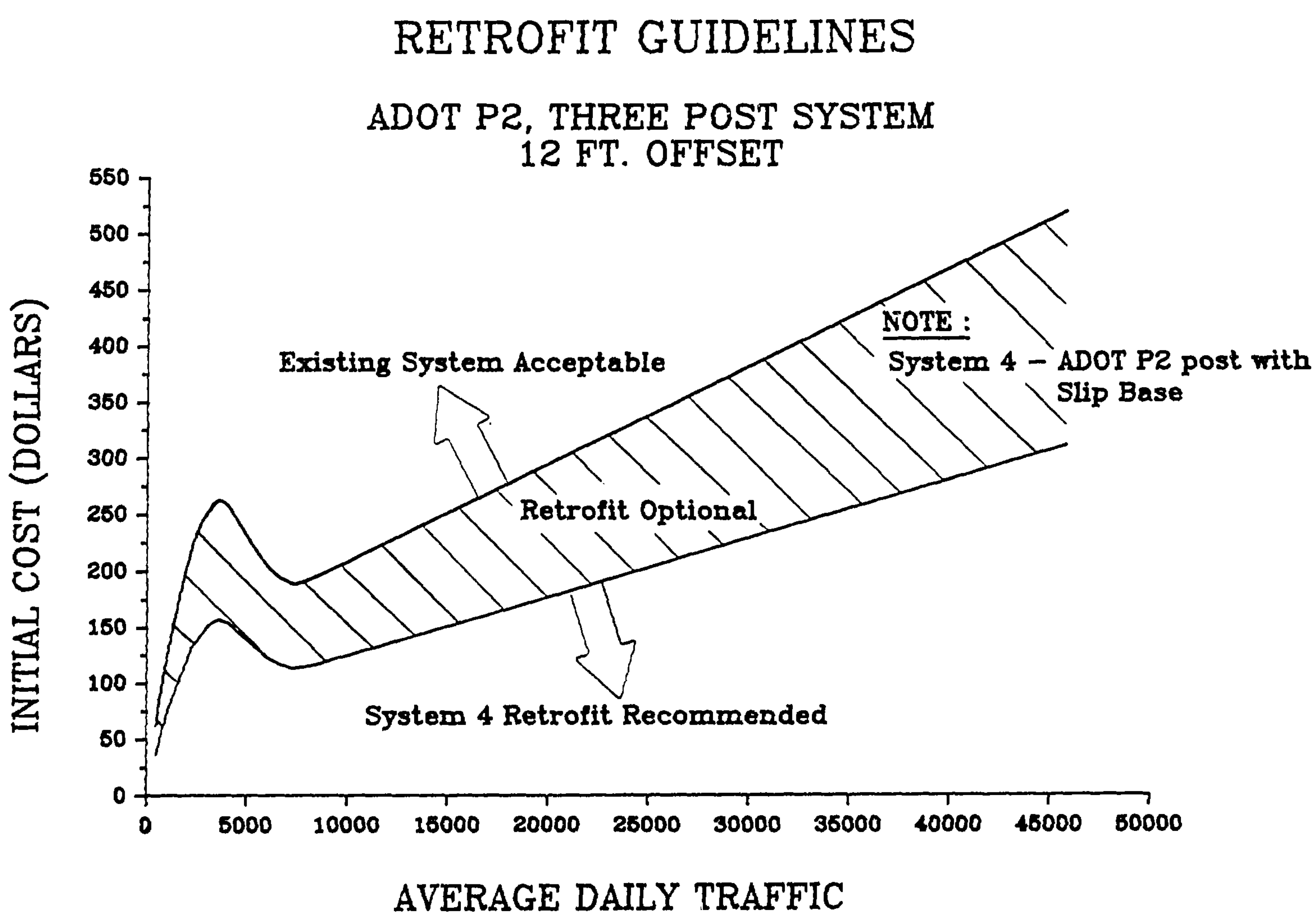

FIGURE C10. P2 POST RETROFIT GUIDELINES, PART J

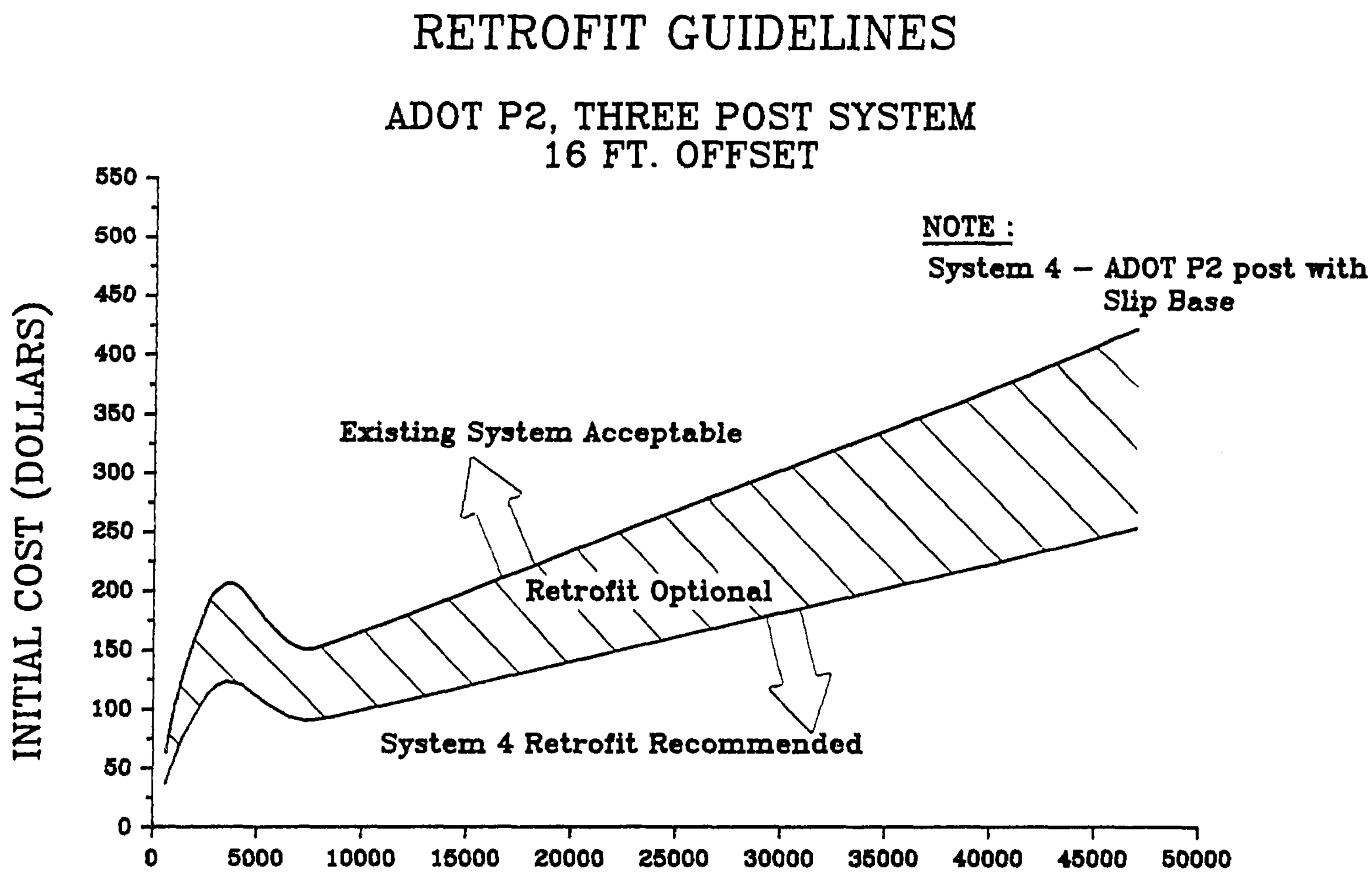

FIGURE C11. P2 POST RETROFIT GUIDELINES, PART K

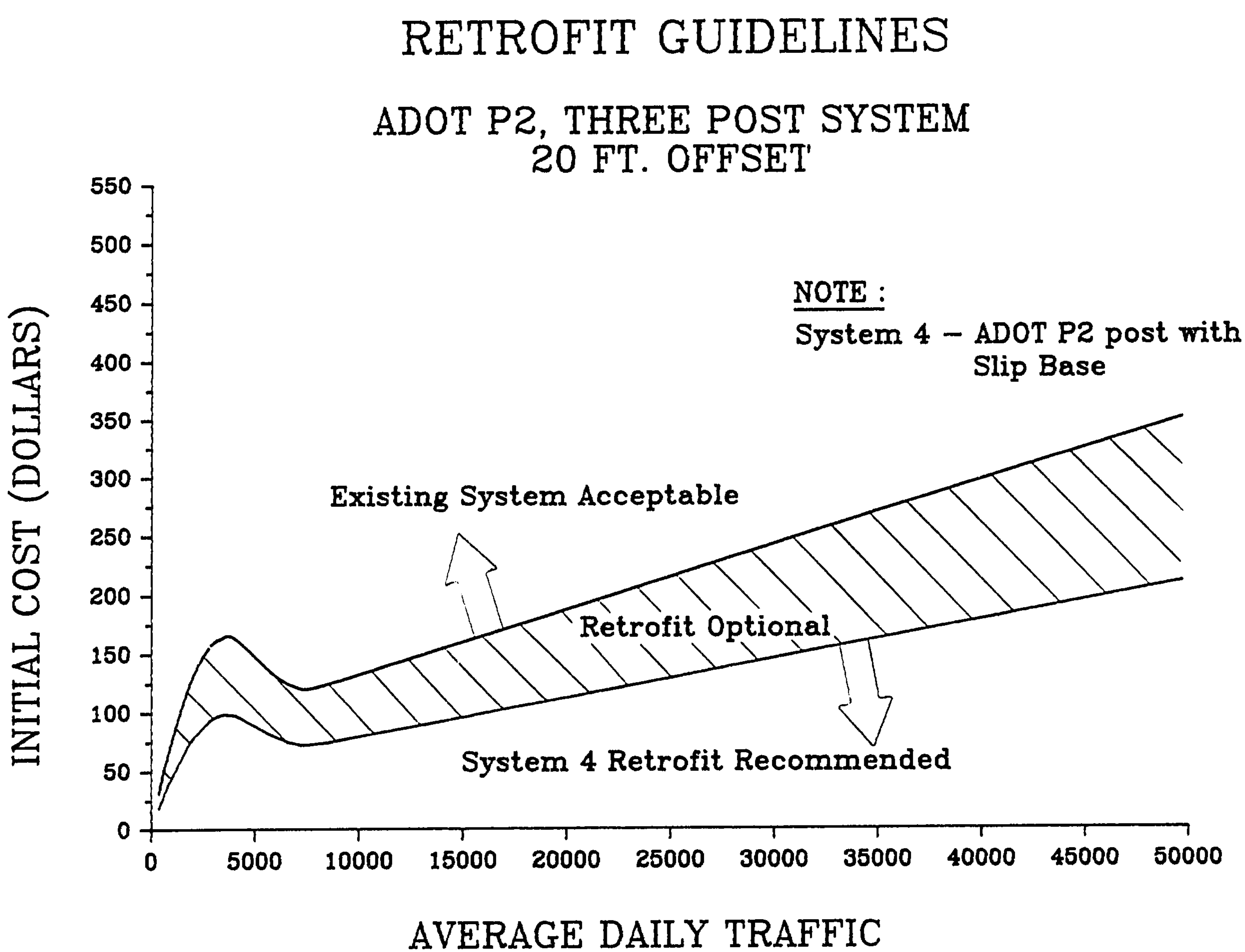

FIGURE C12. P2 POST RETROFIT GUIDELINES, PART L

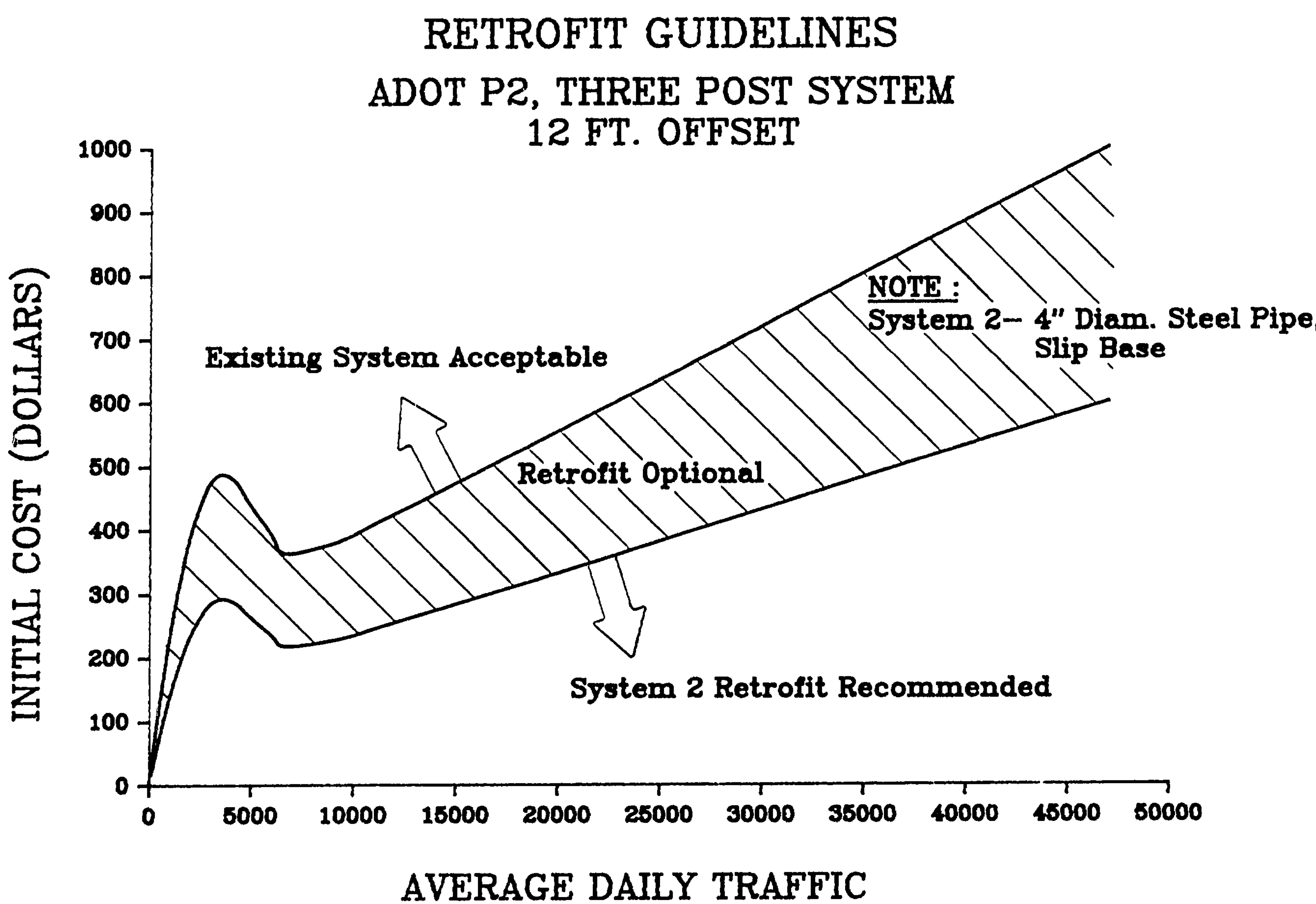

FIGURE C13. P2 POST RETROFIT GUIDELINES, PART M

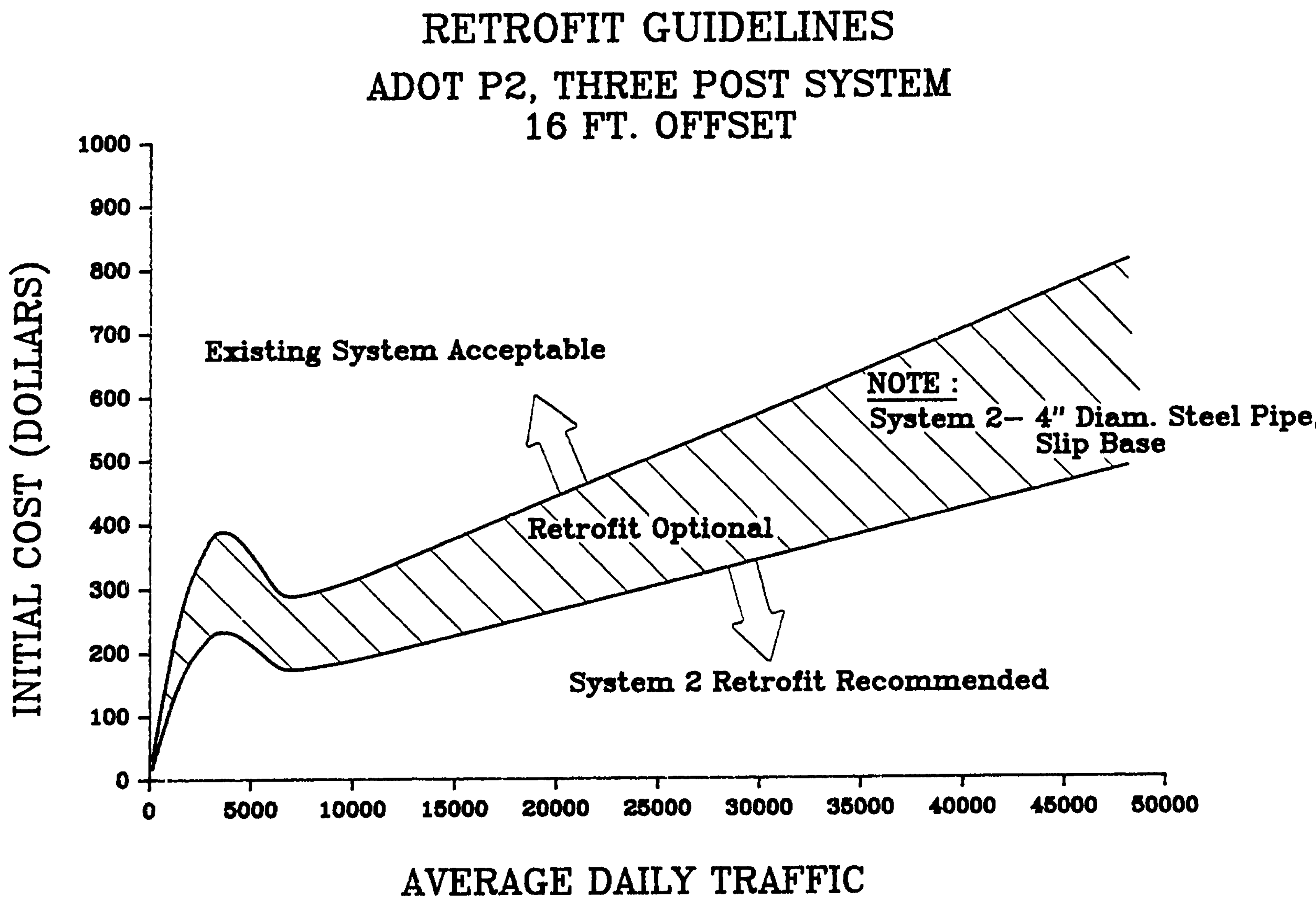

FIGURE C14. P2 POST RETROFIT GUIDELINES, PART N

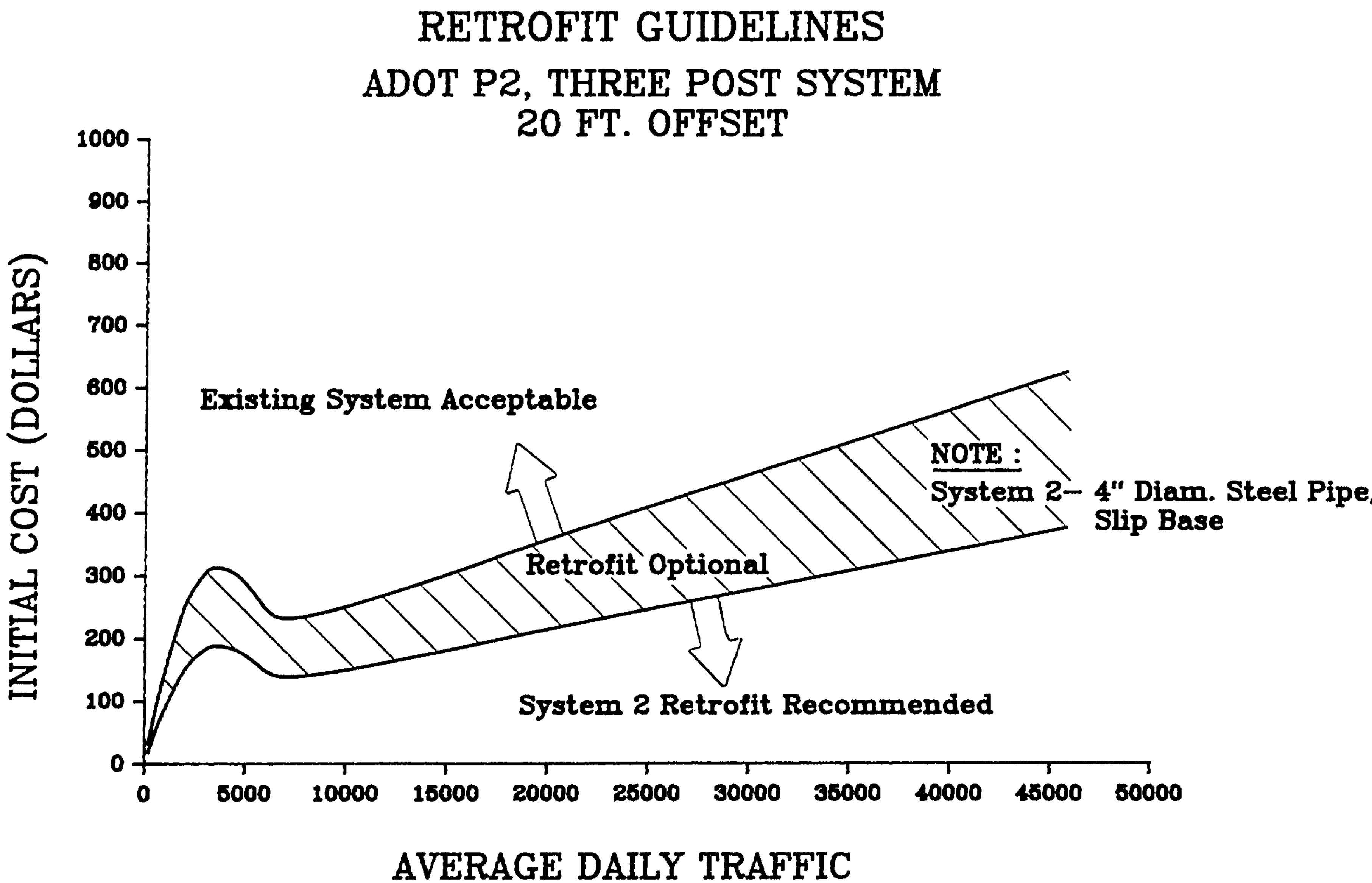

FIGURE C15. P2 POST RETROFIT GUIDELINES, PART 0

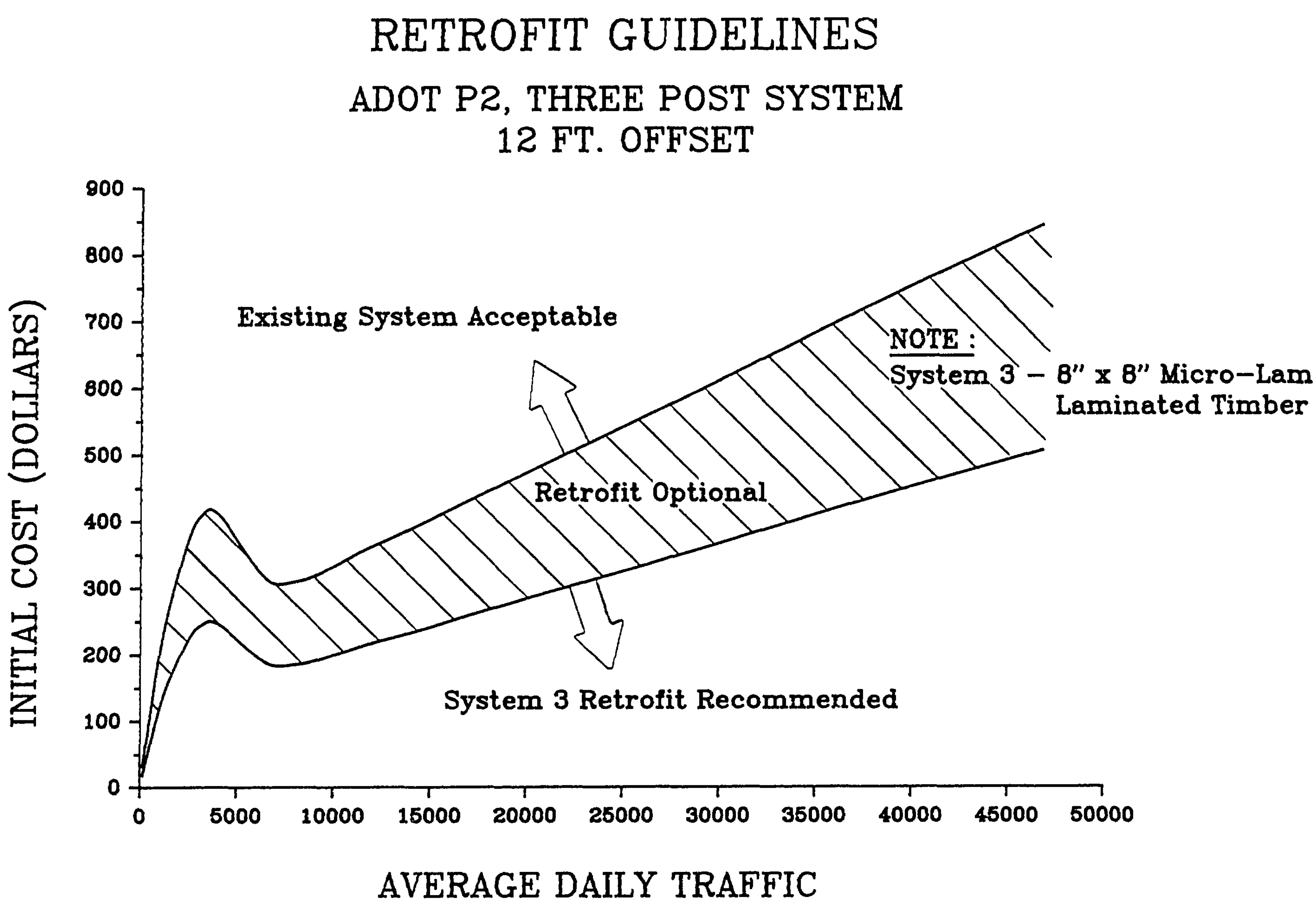

FIGURE C16. P2 POST RETROFIT GUIDELINES, PART P

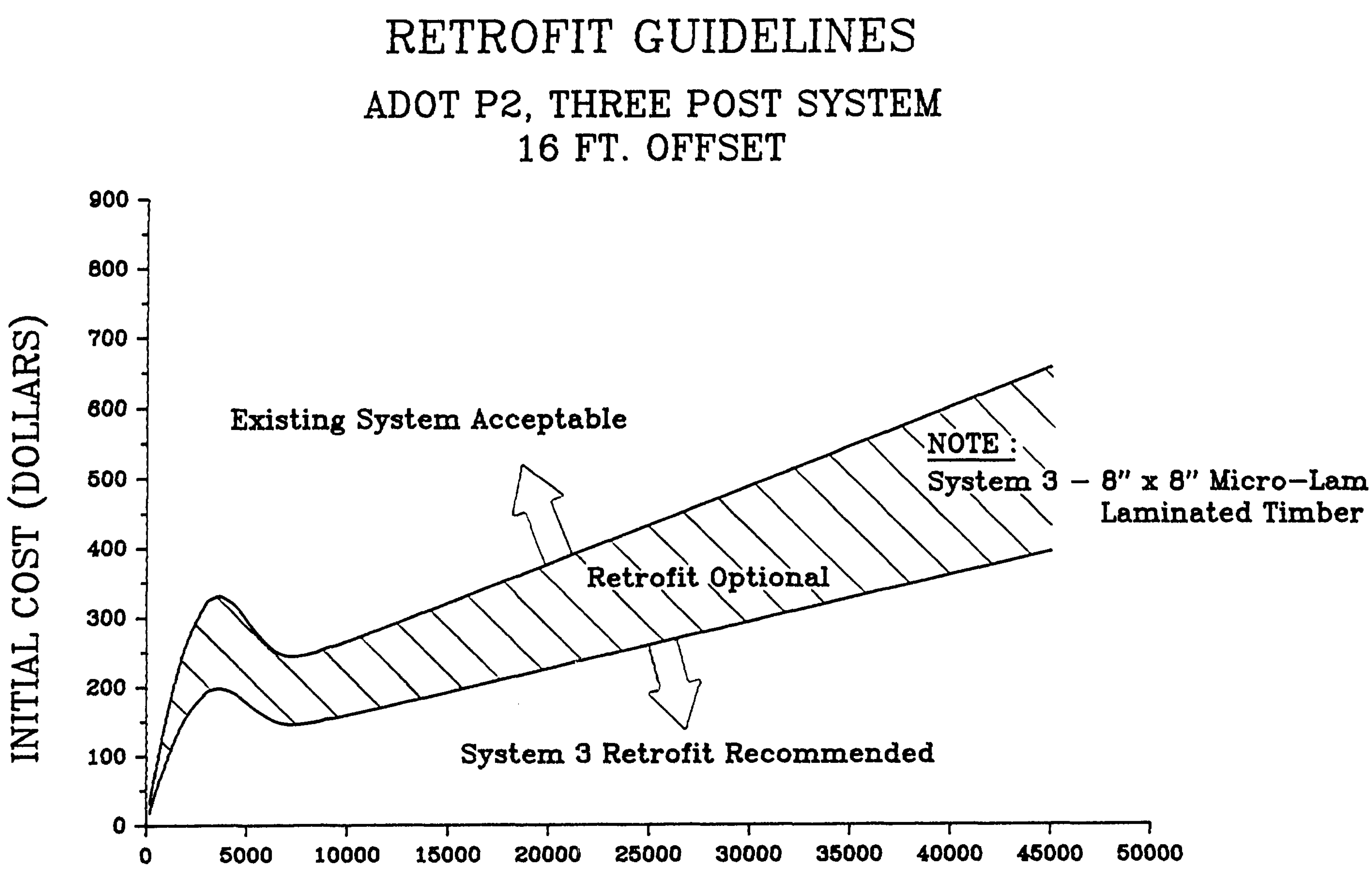

FIGURE C17. P2 POST RETROFIT GUIDELINES, PART Q

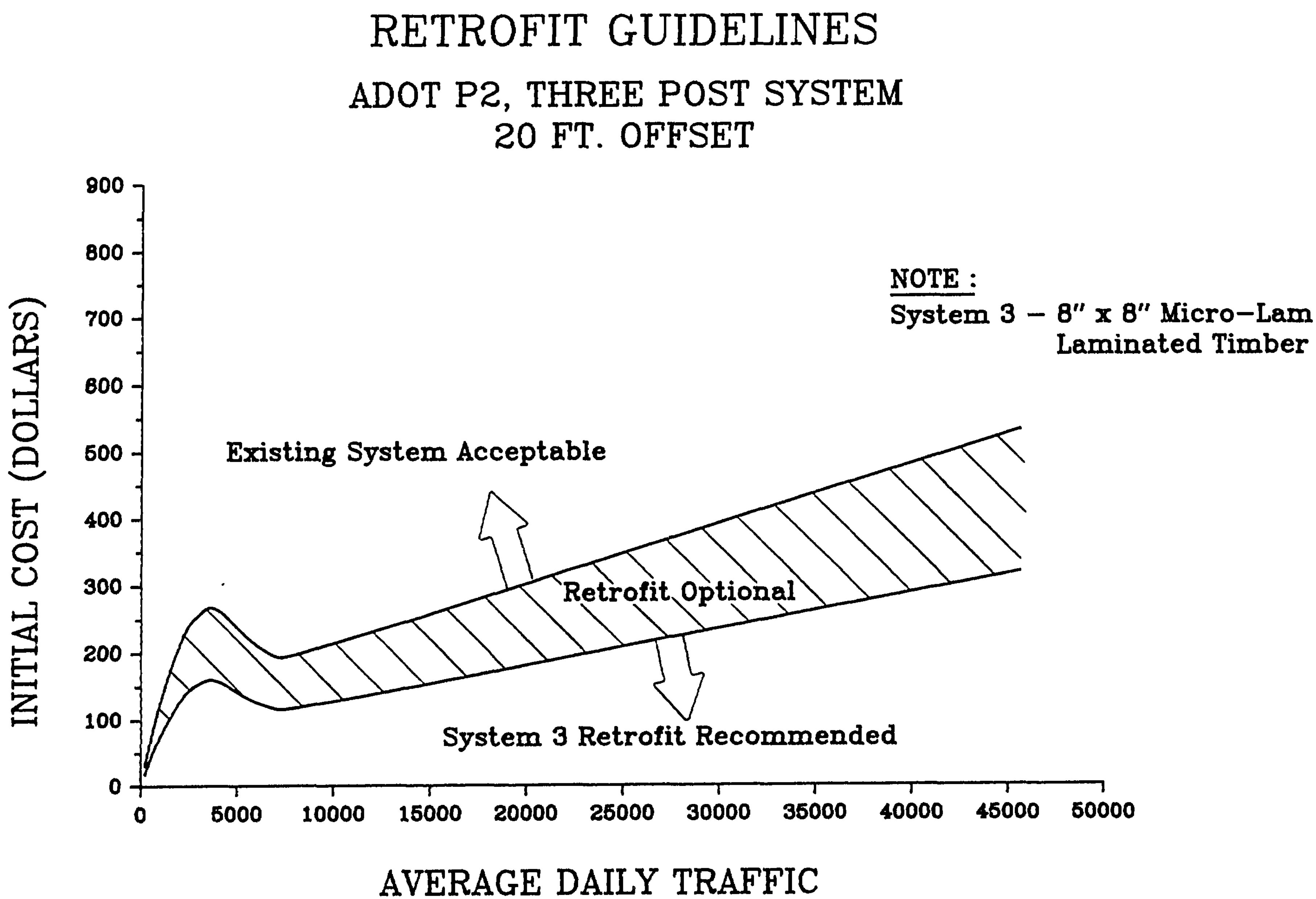

FIGURE C18. P2 POST RETROFIT GUIDELINES, PART R

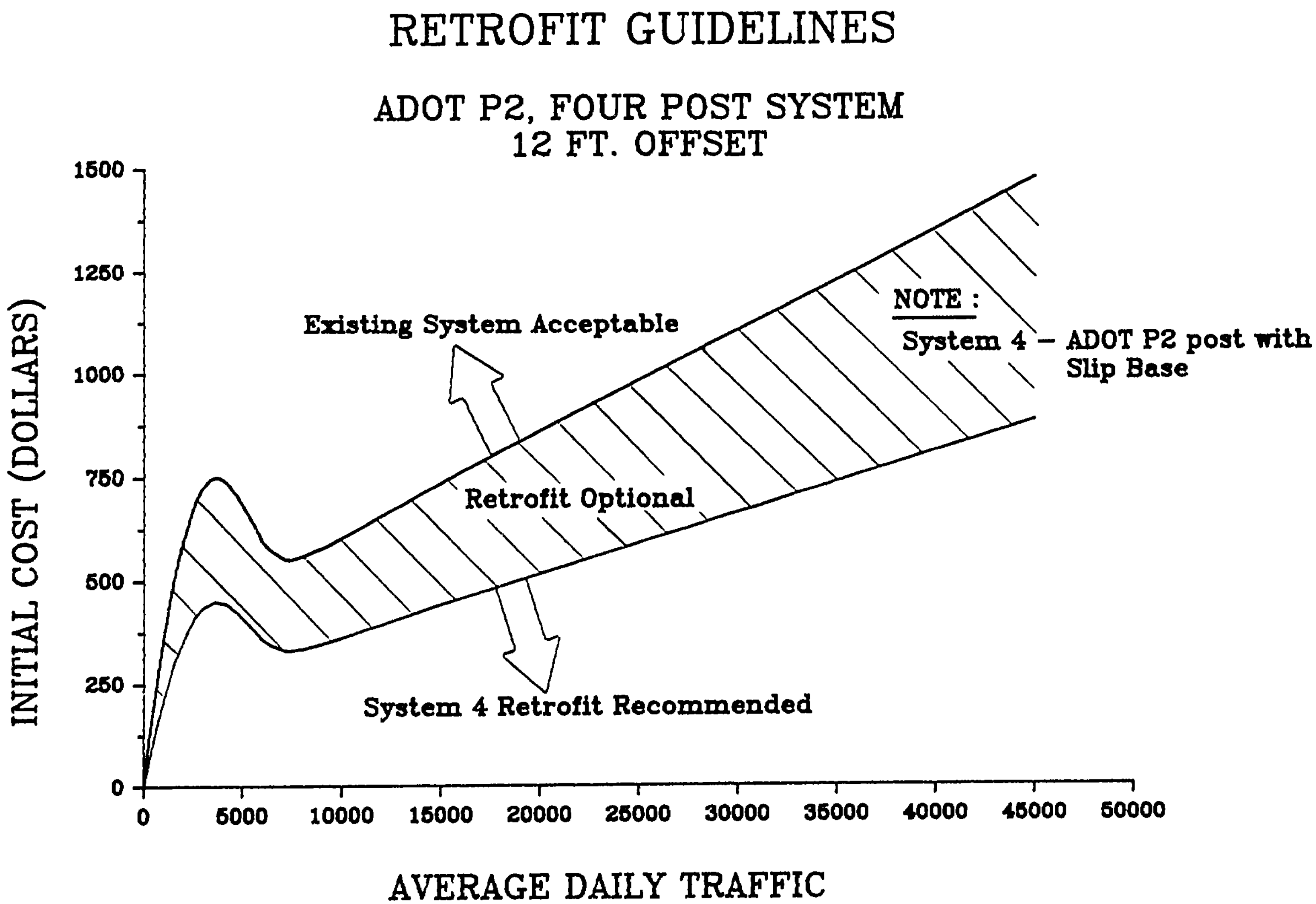

FIGURE C19. P2 POST RETROFIT GUIDELINES, PART S

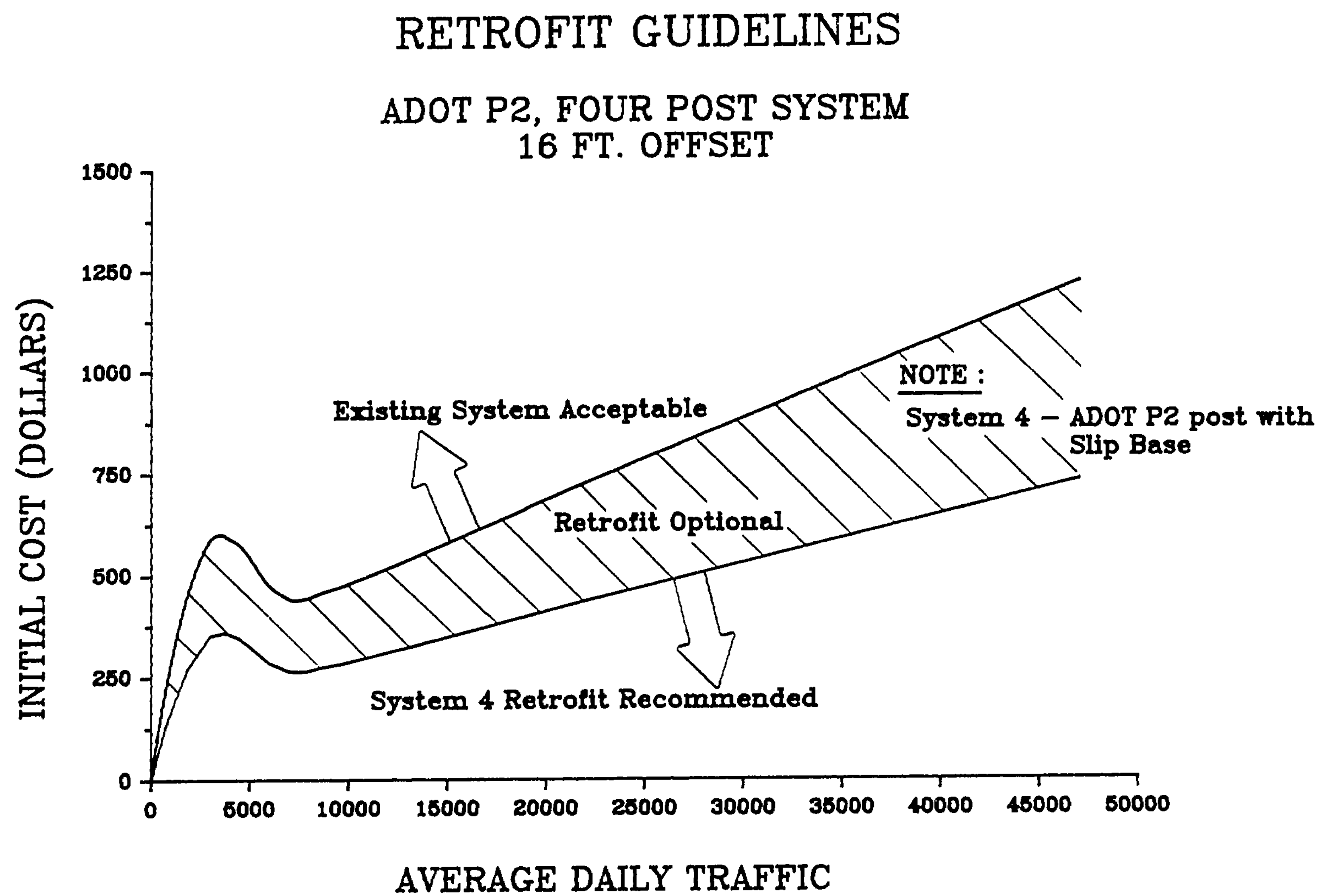

FIGURE C20. P2 POST RETROFIT GUIDELINES, PART T

RETROFIT GUIDELINES

ADOT P2, FOUR POST SYSTEM
20 FT. OFFSET

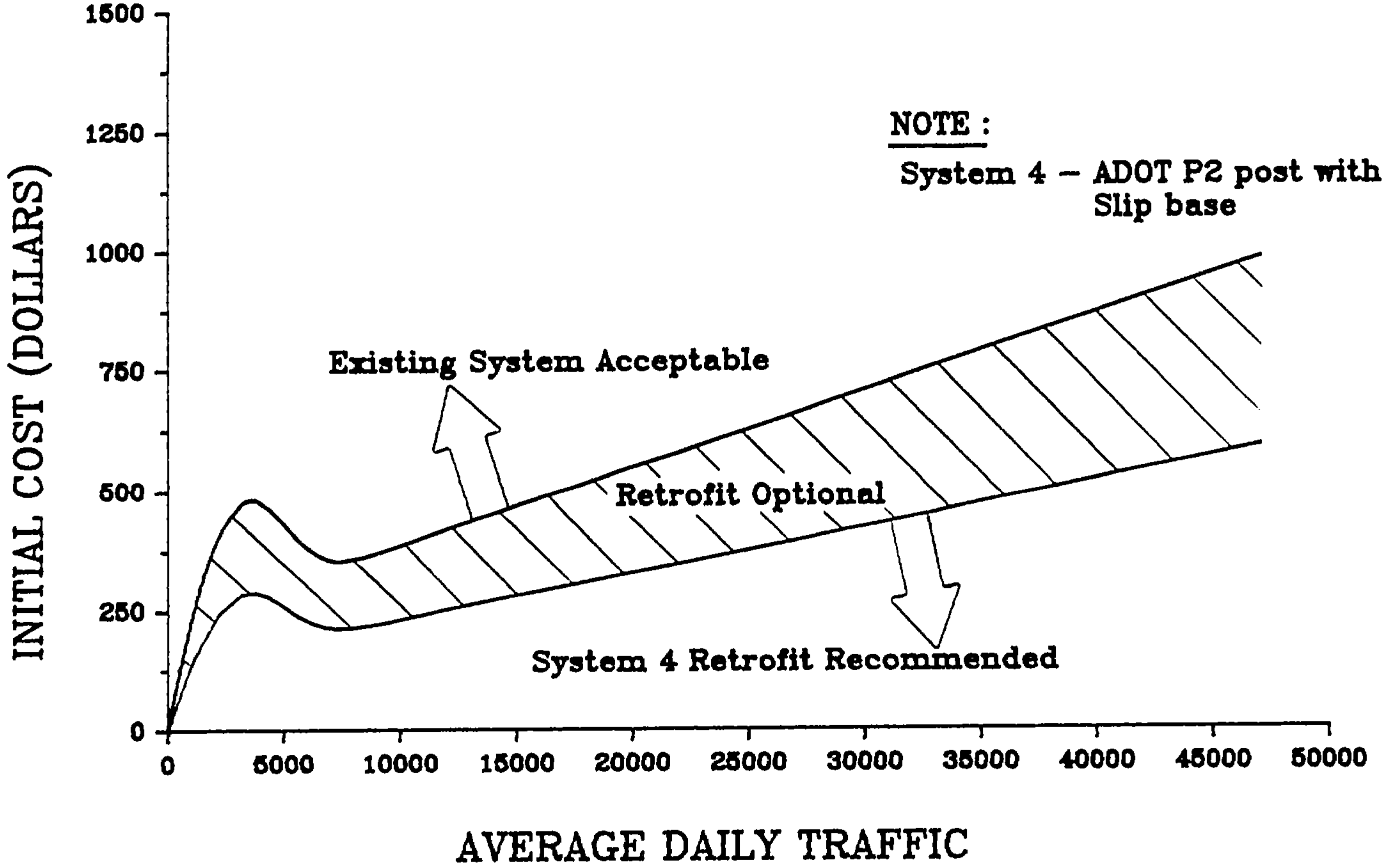

FIGURE C21. P2 POST RETROFIT GUIDELINES, PART U

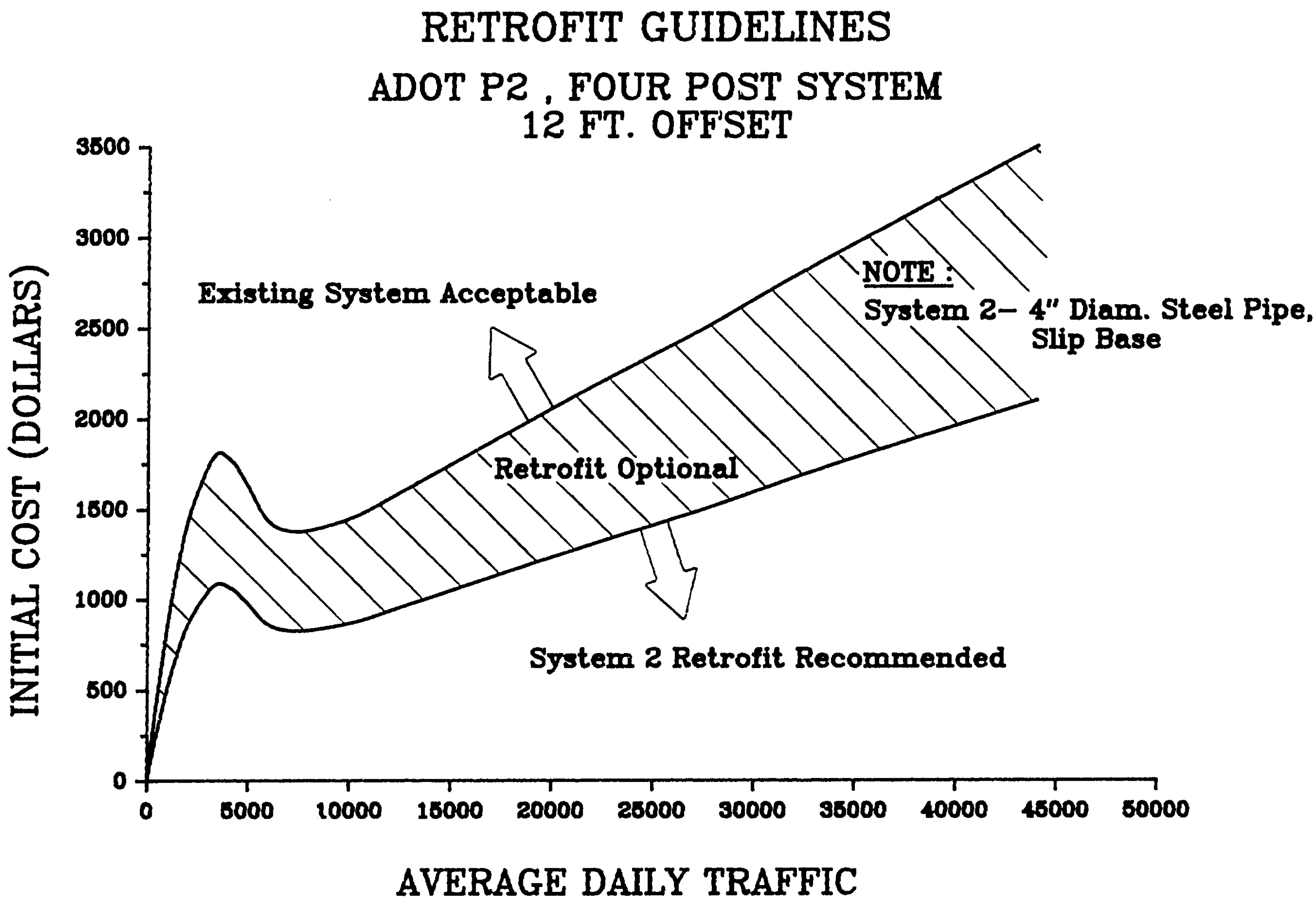

FIGURE C22. P2 POST RETROFIT GUIDELINES, PART V

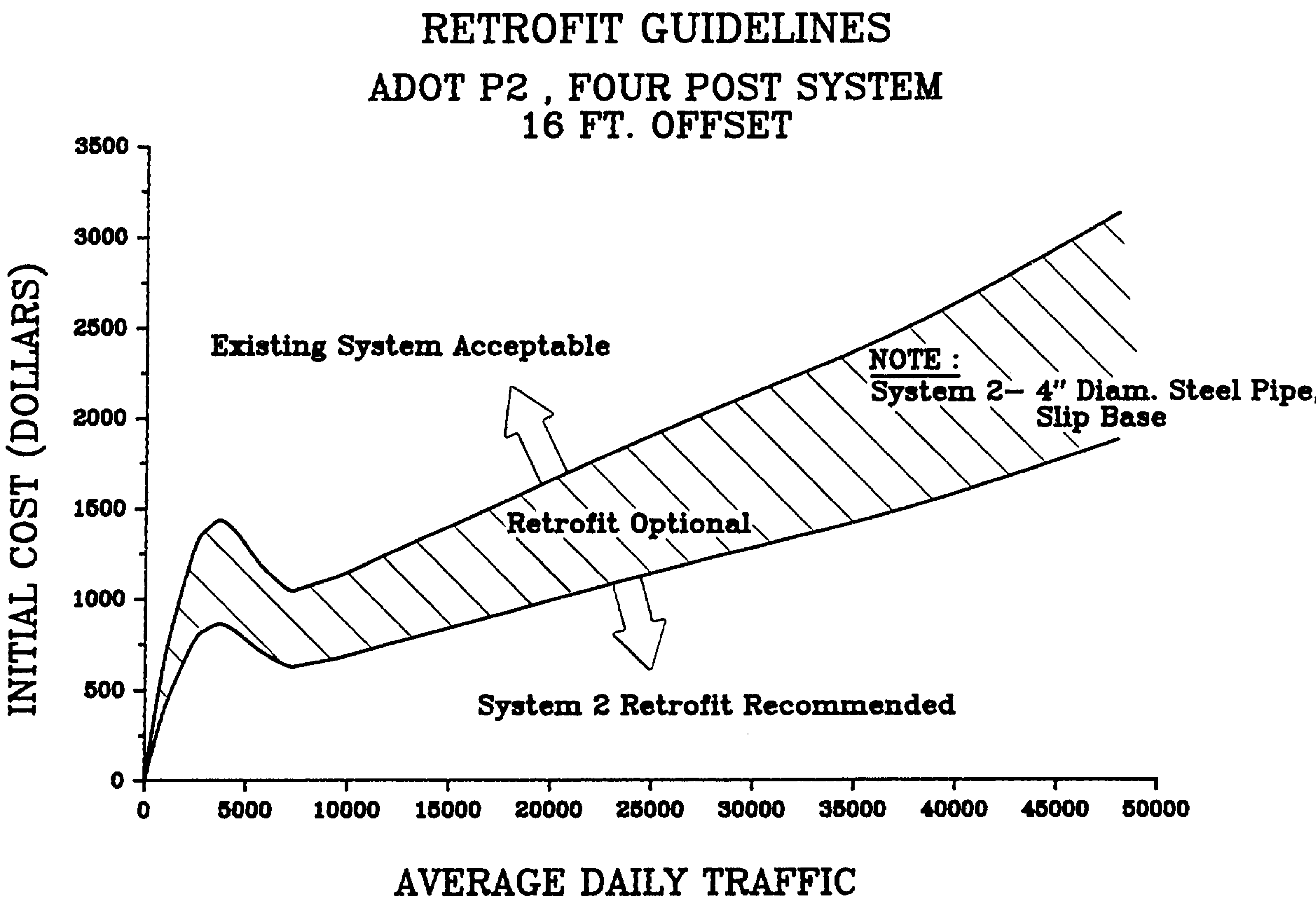

FIGURE C23. P2 POST RETROFIT GUIDELINES, PART W

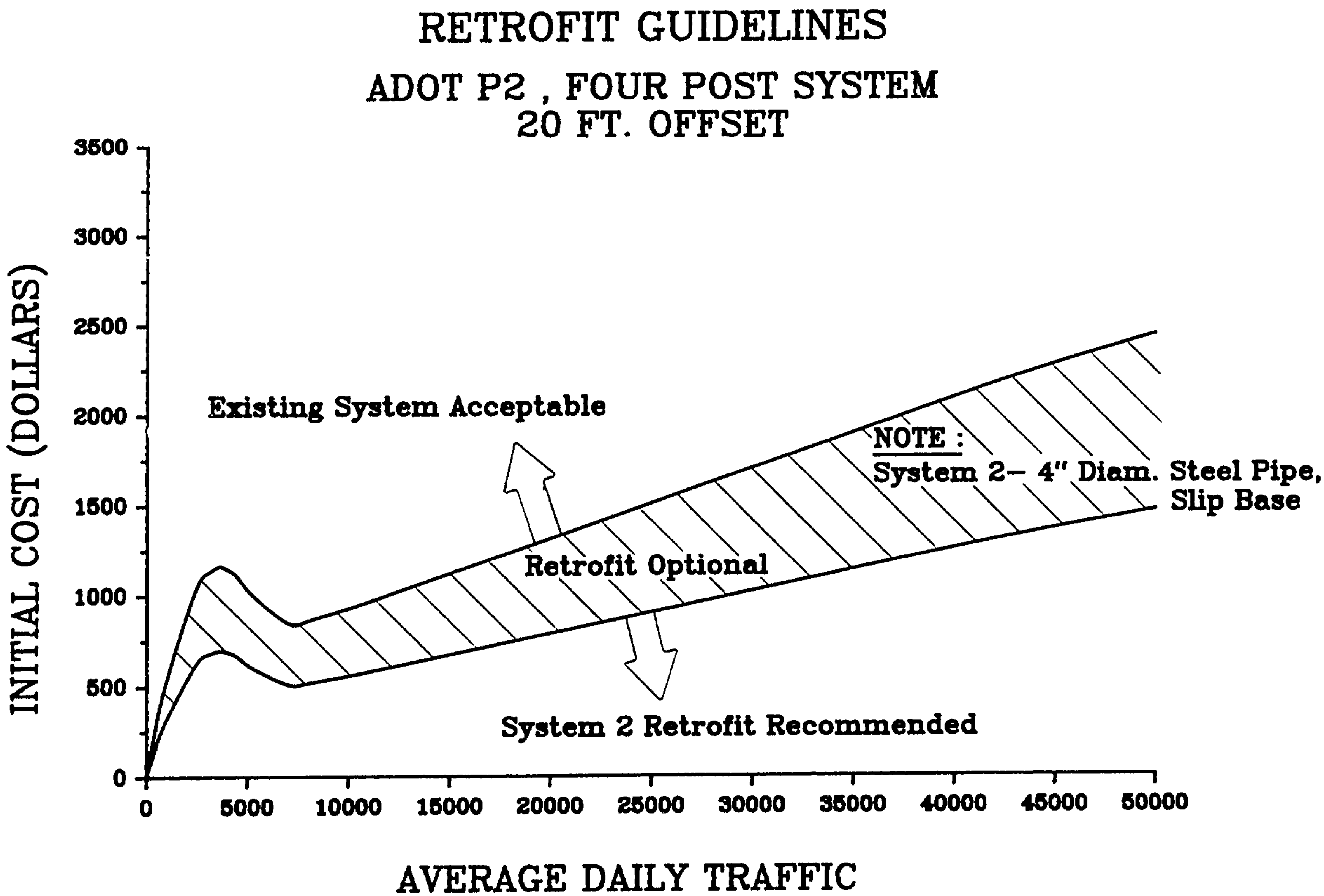

FIGURE C24. P2 POST RETROFIT GUIDELINES, PART X

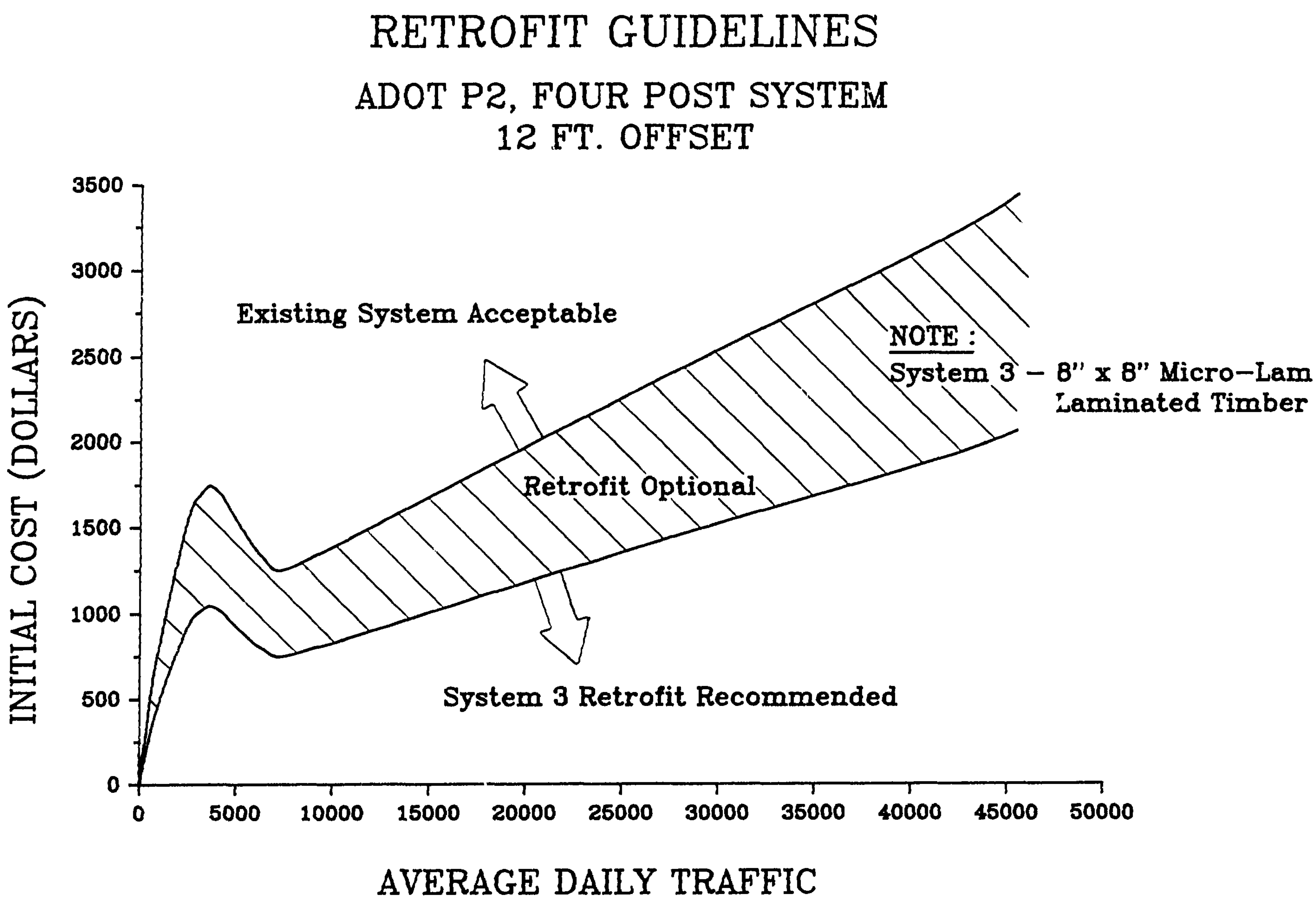

FIGURE C25. P2 POST RETROFIT GUIDELINES, PART Y

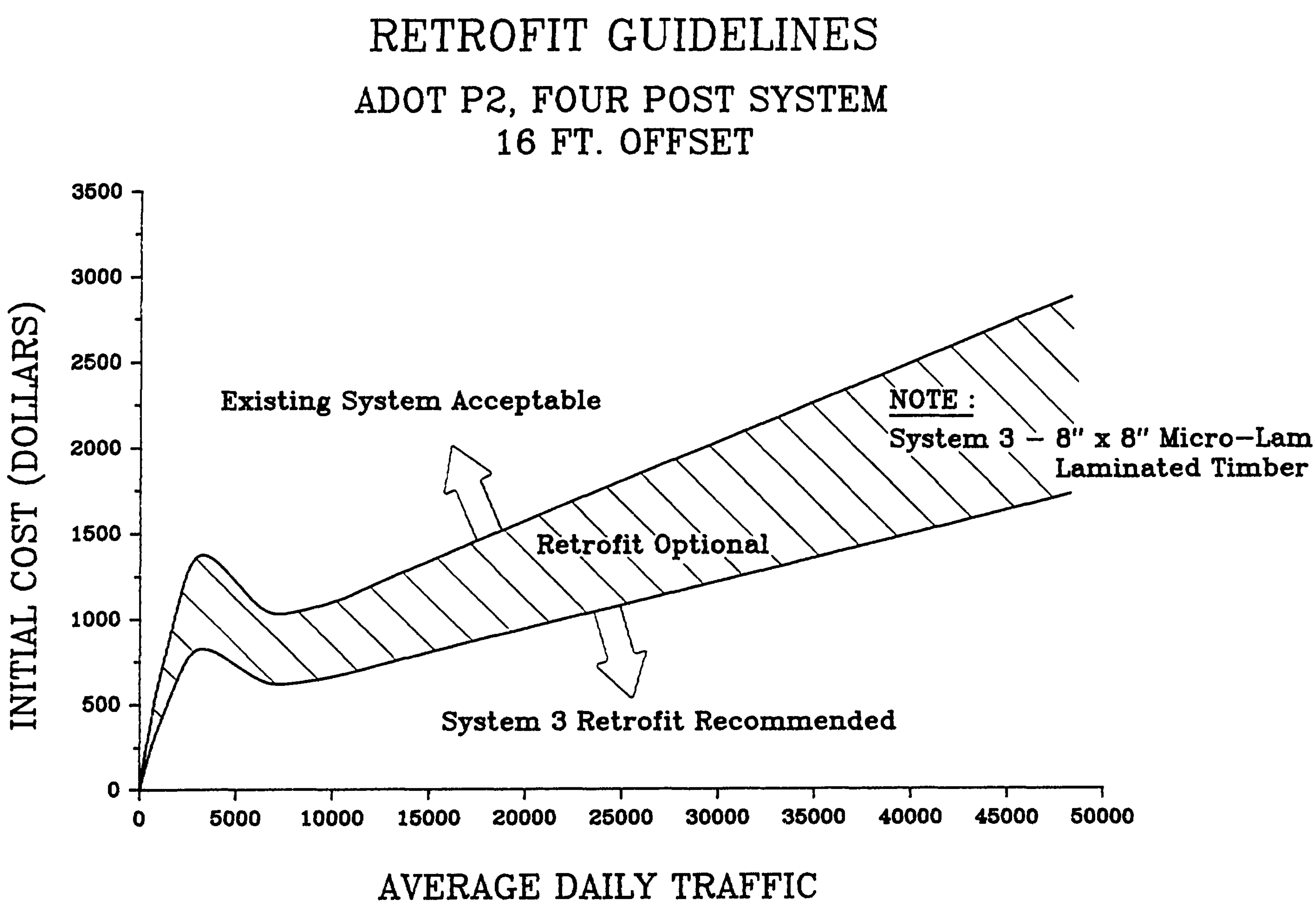

FIGURE C26. P2 POST RETROFIT GUIDELINES, PART Z

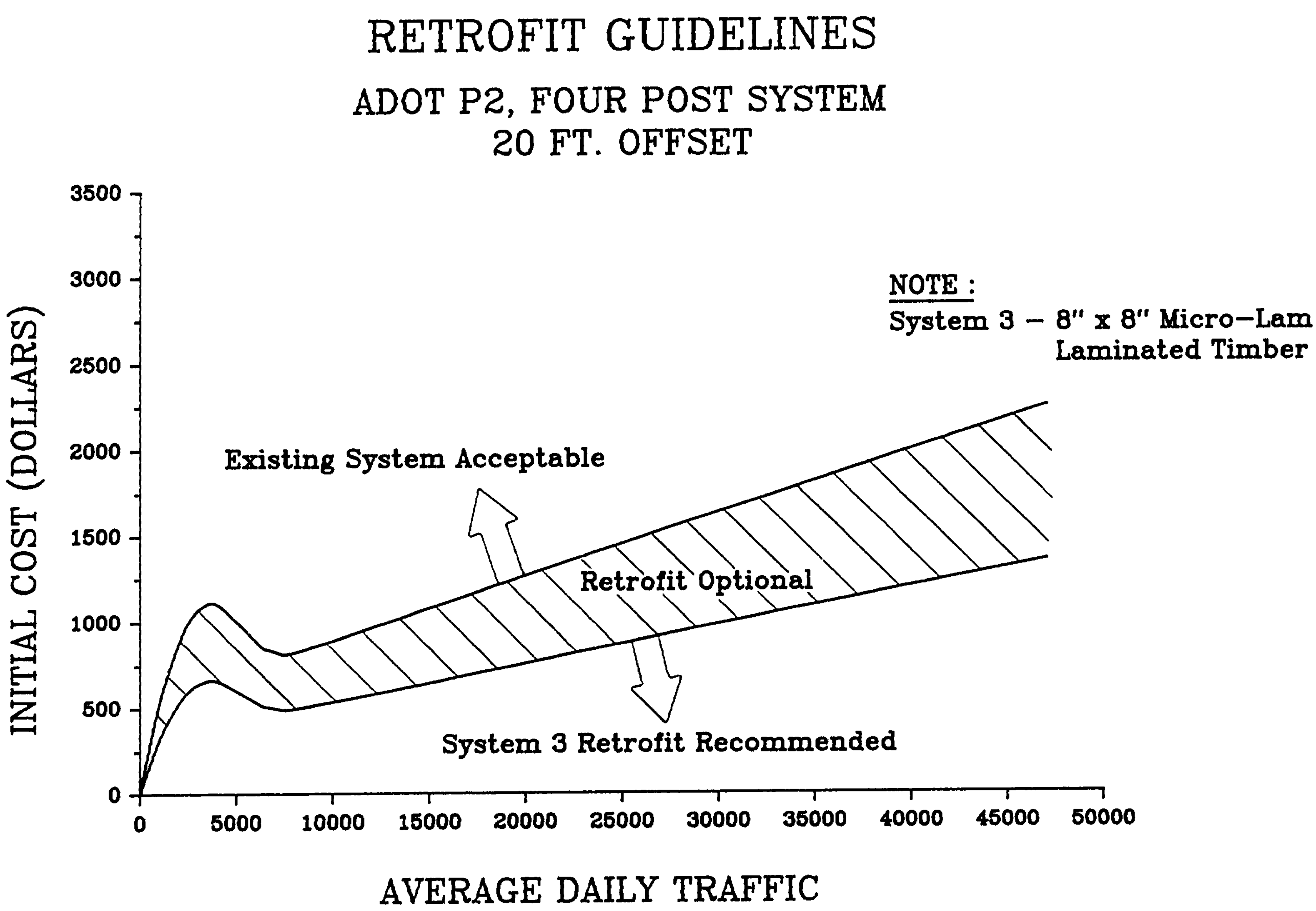

FIGURE C27. P2 POST RETROFIT GUIDELINES, PART AA

A P P E N D I X   D

GUIDELINES FOR NEW INSTALLATIONS

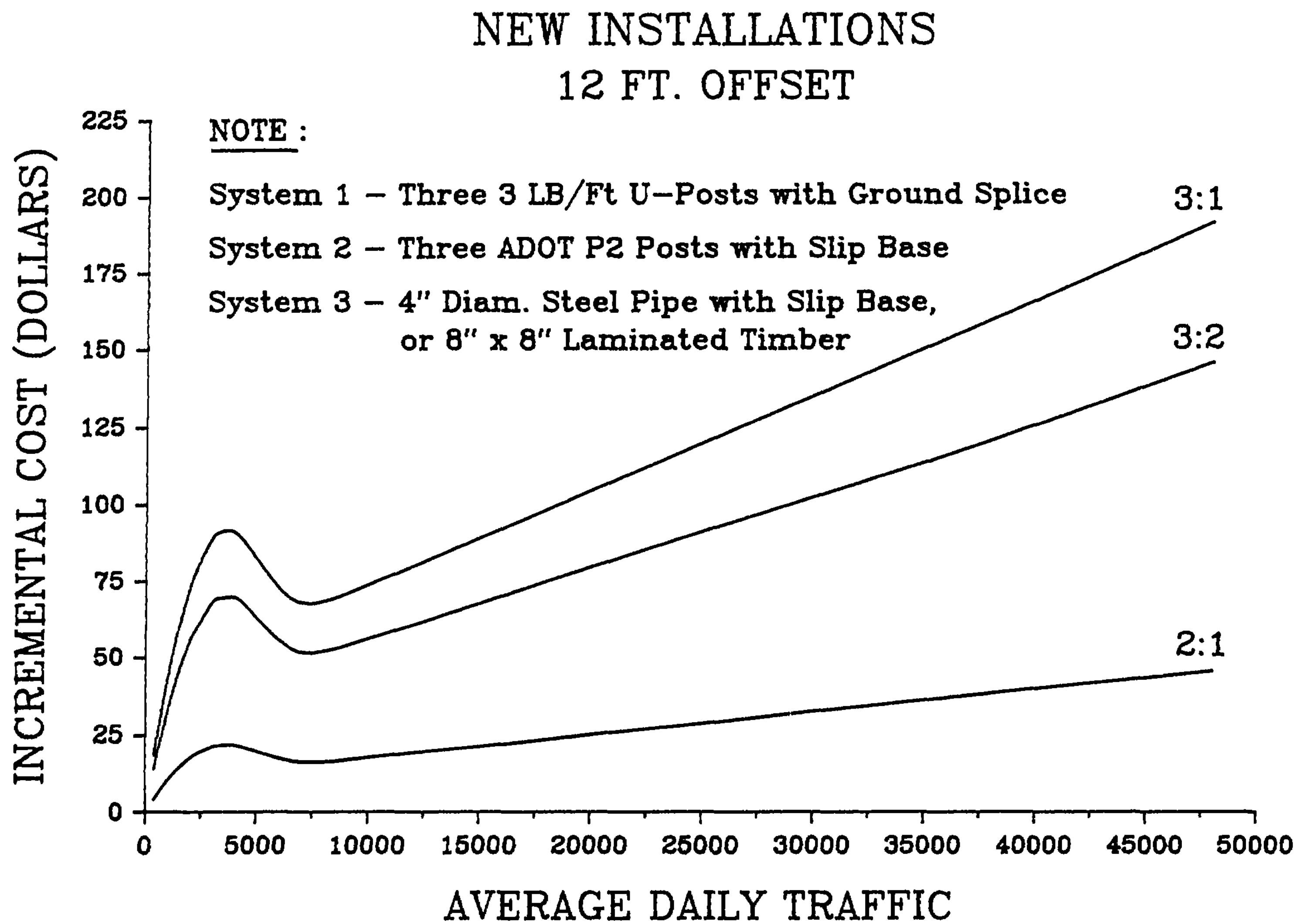

FIGURE D1. NEW INSTALLATION GUIDELINES, PART A

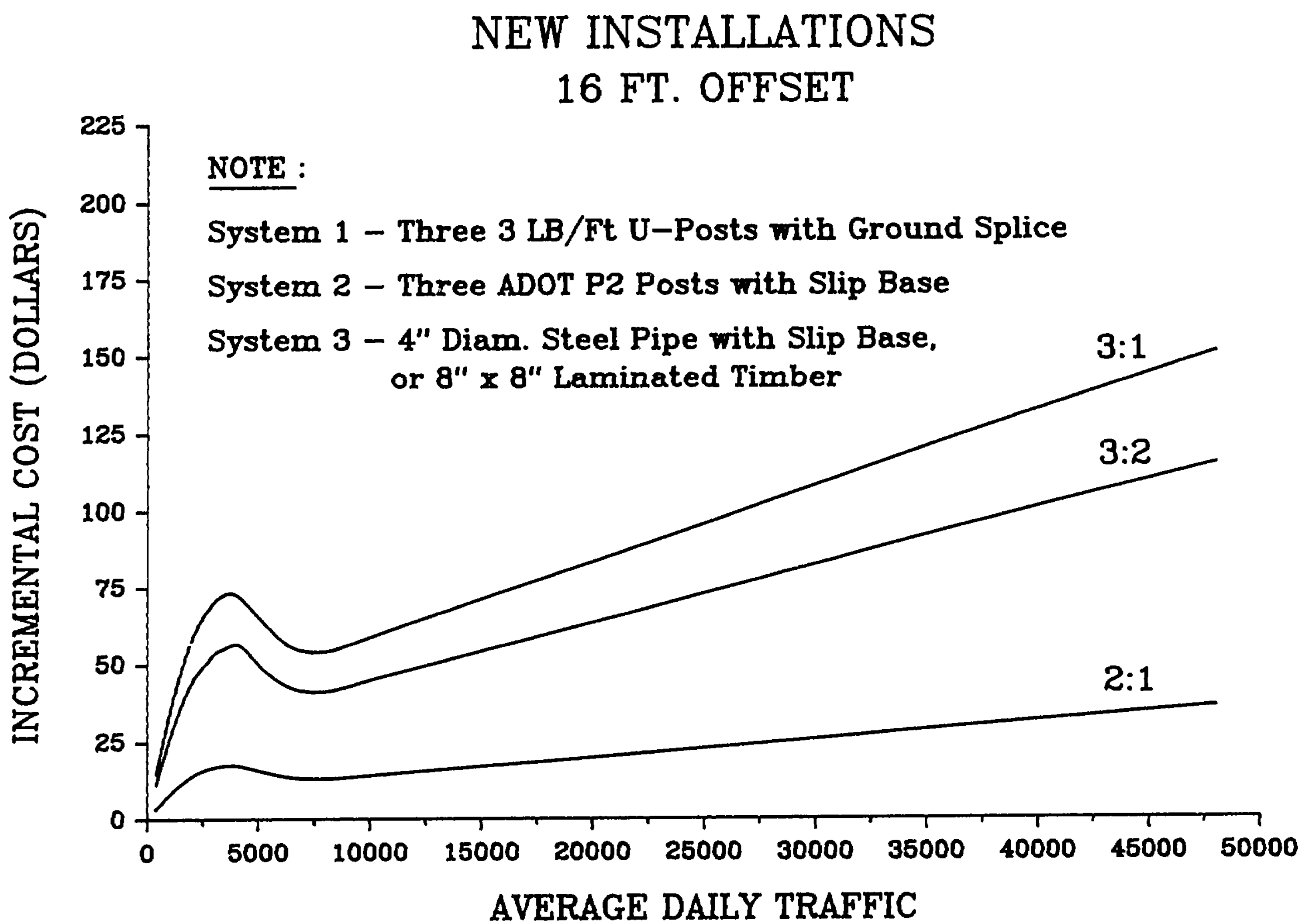

FIGURE D2. NEW INSTALLATION GUIDELINES, PART B

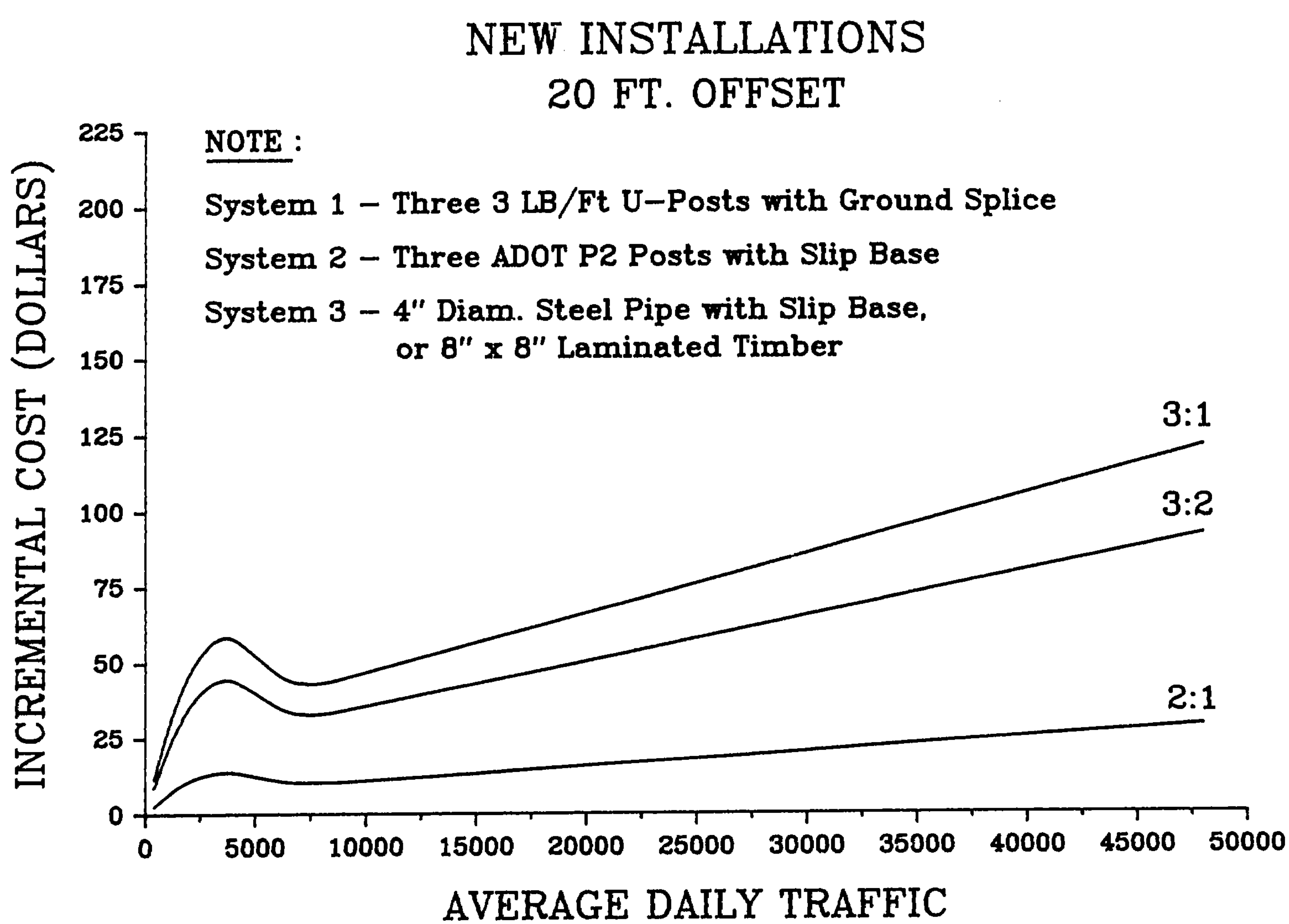

FIGURE D3. NEW INSTALLATION GUIDELINES, PART C