Title: An analysis of movable Barrier Systems for Temporary Traffic Control in Highway Construction.

Course:
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Author(s): A. Louie

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Abstract: The "intangible" benefits and costs involved in three alternatives presented are the cost of traffic delays, the cost of construction delays, the cost of different accident rates or public safety, and the cost of contractor inefficiencies. Based on the educated "guess-work" of the most probable economic effects of a benefit or cost, the Cost-Benefit Analysis leads to choose the alternative: the purchase of the Quick-Change Movable Barrier (QMB) with State funds. When viewed from a replacement decision analysis the same alternative is also chosen because of the dominance of this alternative in internal rate of return over the other three alternatives.

AN ANALYSIS OF MOVABLE BARRIEER SYSTEMS FOR TEMPORARY TRAFFIC CONTROL IN HIGHWAY CONSTRUCTION

Art Louie

EMP - 9363

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EMGT 535 Term Paper

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INTRODUCTION TO THE ANALYSIS

The Oregon Department of Transportation is responsible to preserve, maintain, and operate the transportation system in the State of Oregon. The Construction program is an integral part of fulfilling that responsibility. It is through the construction activities that new transportation systems are realized, safety and pavement preservation are accomplished, and operational improvements are made to the existing transportation network. The majority of the ODOT construction program consists of operational improvements to existing facilities. This requires that construction activities must be carried out next to existing traffic. Therefore, safety of the construction workers and the traveling public is of the highest priority in the State.

To accomplish construction work next to existing traffic, it is necessary to separate the construction activities from the traffic by the setting up of a temporary work zone. The work zone can be separated from the traffic in the following ways:

Alternative 1 - Use temporary warning signs and plastic tubular markers

Alternative 2 - Use standard pin-and-loop concrete barrier

Alternative 3 - Purchase and use a new technology system known as the Quickchange Movable Barrier System (QMB).

As part of the West Side Light Rail construction projects, the Oregon Department of Transportation has elected to purchase the Quickchange Movable Barrier System (QMB) as part of the Cedar Hills Blvd. Interchange - S.W. 76th Ave. project on the Sunset Highway. This project has 4 stage construction changes with multiple moves of traffic per change. The QMB is designed to move concrete barrier quickly and efficiently with the use of a traveling Transfer and Transport Vehicle (TTV). The QMB will be the property of the prime contractor for the duration of the Cedar Hills project or about 2 years and then the ownership will revert to the State.

This analysis looks at the decision to purchase the QMB from the viewpoint of Engineering Economics. To what extent should the Oregon Department of Transportation invest in temporary traffic control in highway construction projects? How much can ODOT compromise work zone and public safety in highway construction projects before the purchase of the QMB is justified? What factors involved in work zone safety are the most sensitive in our decision regarding temporary traffic control?

To answer these questions the three alternatives were evaluated over an 8 year life cycle for a QMB using the traditional benefit-cost analysis and a replacement decision with a sensitivity analysis. Cost data were obtained from quotes from vendors, average costs compiled by the ODOT Cost Analysis Unit, average accident rates and costs of accidents from ODOT records and AASHTO (American Association of State Highway and Transportation Officials) studies, and strategic information from the "Oregon Benchmarks" published by the Oregon Transportation Commission. These references are listed in the "Index" attached to this analysis.

The Cedar Hills Blvd.-S.W. 76th Ave. Project

This project is one of a series of 9 projects composing the total Westside Corridor Project on the Sunset Highway, Highway 26 in Washington County. The Westside Corridor Project is a joint project of the Oregon Department of Transportation and the Tri-County Metropolitan Transit District. The project seeks to improve transportation in the Westside Corridor through a combination of highway improvements and a light rail line connecting Beaverton, Hillsboro, and some Washington County areas with Downtown Portland and, via the existing MAX Light Rail line, the eastside Portland area and Gresham.

The Cedar Hills Blvd.-S.W. 76th Ave project will widen the eastbound Sunset Highway to four lanes from Cedar Hills Boulevard Interchange to Highway 217 Interchange. The outside fourth lane will be dropped at the Sunset Highway eastbound to Highway 217 southbound exit ramp. Three through lanes will continue east of the Highway 217 Interchange. The Sunset Highway westbound will be widened to four lanes from S.W. 76th Avenue to Highway 217 Interchange by the Tri-Met tunnel contractor. This added lane will be built to subgrade by the tunnel contractor, but paved under this contract. The outside fourth lane, an exit only lane, will be dropped at the Highway 217 interchange as it approaches the Sunset Highway westbound to Highway 217 southbound exit ramp. This ramp will retain its existing two-lane configuration. Three through lanes will continue west of Highway 217 Interchange. The two Sunset Highway structures crossing Highway 217 will also be widened to accomodate the widening of the Sunset Highway. The Sunset Highway westbound exit ramps to S.W. Barnes Road and Highway 217 will be rebuilt into two separate exit ramps. Traffic will be maintained on both ramps during the construction of the LRT crossing underneath the exit ramp to Highway 217 southbound.

The Cedar Hills Blvd.-S.W. 76th Ave. project will take appoximately 2 years. There are 8 stage construction plans for the Sunset Highway where traffic will be relocated to accomodate the construction activities. The ODOT will be purchasing a Quickchange Movable Barrier System for this project to accomplish the estimated 8 moves of the temporary barrier. The QMB will move the barrier with a minimum of disruption to the traffic. As shown on Table 2, the maximum Directional Peak Hour Traffic Volumes in the Sunset Corridor is 4390 vehicles per hour during the westbound PM peak. During the peak hours, the occupancy per vehicle on the Sunset Highway is only 1.18 persons per vehicle. The number of vehicles with only one occupant is slightly more than 80%, while 16-18% of the vehicles have two occupants and only 1-2% of the vehicles carry three or more occupants.

During construction, the Sunset Highway lanes will consist of two 11 foot travel lanes with 2 foot shoulders. In addition, the staging of the construction in the vicinity of the Sunset/Highway 217 interchange will require realigning the travel lanes first to the north and then to the south to allow for the construction of the LRT undercrossing structure beneath the Sunset Highway. The effect of the narrow lanes and narrow shoulders, realignment of the travel lanes, and the construction activity adjacent to the highway creates a reduction in carrying capacity of the Sunset Highway.

* "Westside Corridor Project, Construction Management Plan", Oregon Department of Transportation, 1993

Table 2:
Directional Peak Hour Traffic Volumes in the Sunset Corridor

	EASTBOUND VOLUME	WESTBOUND VOLUME	EASTBOUND CAPACITY	WESTBOUND CAPACITY
Cornell Road				
A.M.	990	100	1,100	950
P.M.	220	800	1,100	950
Barnes / Burnside				
A.M.	1,150	360	1,550	1,150
P.M.	540	1,130	1,550	1,150
Sunset Highway				
A.M.	4,100	3,540	4,390	4,390
P.M.	3,970	4,390	4,390	4,390
Canyon Road				
A.M.	1,200	460	1,500	1,500
P.M.	770	1,090	1,500	1,500
Beaverton-Hillsdale				
A.M.	1,200	800	1,400	1,400
P.M.	1,300	1,290	1,400	1,400

The capacity figures shown are for each direction.

CALCULATION OF TRAFFIC DELAY COSTS

Alternate 1

Assume 55 mph normal running speed, 45 mph running speed in the construction work zone, 10% 3-S2 trucks, 5% single unit trucks, and 100,000 average daily traffic. From Fig. 20*,

1977 costs updated to 1993 costs:

Traffic Delay Costs = $2.00 x 2.06 x (F/P, 10%, 16) per 1000 vehicles per day

= $1893 per day

Alternate 2, 3A, and 3B

Assume 55 mph normal running speed, 50 mph running speed through the construction work zone, 10% 3-S2 trucks, 5% single unit trucks, and 100,000 average daily traffic. From Fig. 20*,

1977 costs updated to 1993 costs:

Traffic Delay Costs = $1.00 x 2.06 x (F/P, 10%, 6) per 1000 vehicles per day

= $947 per day

* "A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements, 1977", American Association of State Highway and Transportation Officials.

BENEFIT–COST RATIO WORKSHEET

ION Cedar Hills Blvd. Int. - SW 76th Ave REGION ______ DATE ______
HIGHWAY NO. Sunset HWY. NAME ______ M.P. FROM ______ TO ______
COUNTY ______ CITY ______ STUDY PERIOD ______ TO ______
PROJECT DESCRIPTION Alternative 1 - Tubular Markers and Signs

Daily

1. Reported PDO Accidents 0.1
   Unreported PDO Factor (X 2.0)
   Total All PDO Accidents 0.2
   Reduction Factor (X 0.8)
   Total Preventable PDO Accidents 0.16 @ $4,200/ea[1] = $672

2. Reported Injury Accidents 0.03
   Reduction Factor (X 0.8)
   Total Preventable Injury Accidents 0.024

   Reported Fatal Accidents 0.003
   Reduction Factor (X 0.8)
   Total Preventable Fatal Accidents 0.0024

   Total Preventable Injury and Fatal Accidents 0.0264 @ Weighted Cost $35,800 /ea = $945

$1617/day

WEIGHTED COST[2] PER INJURY OR FATAL ACCIDENT

Highway/Street Type	Urban[3]	Rural
Interstate or Other State Frwy	$35,800	$64,100
Other State Highway	$37,800	$72,100
County/Local	$40,000	$56,800
City	$34,300	N/A

______ Months Total Cost = ______

Annual Benefits = Total Accident Cost X 12 / Total Months = ______

Estimated Project Cost = ______

B/C Ratio = Annual Benefits X Series Present Worth Factor (20 years @ 10%) / Estimated Project Cost

B/C Ratio = (______) X 8.513564 / (______) = ______

Notes:
1. Costs per accident based on 1991 National Safety Council values.
2. Weighted costs were calculated using accident data from the 1987-1989 Oregon Traffic Accident Summaries.
3. Urban is classified as being within urban growth boundries if existing, otherwise within city limits.

PRESENTATION OF THE ALTERNATIVES
IN SETTING UP TEMPORARY WORK ZONES

- Alternative 1 - Temporary warning signs and plastic tubular markers

Description:

To achieve a diversion of traffic away from the construction work zone by using this alternative, a minimum of two warning signs are used with a line of tubular markers placed every 25 feet along the taper leading into the work area, every 50 feet along the work zone and every 25 feet leading out of the work area. Temporary striping and delineators can be used for enhanced nighttime visibility.

The average rate of setting up and removal is 1 mile per crew hour. The installation crew usually consists of two vehicles, one flatbed truck for carrying the signs and the tubular markers and one shadow vehicle for providing traffic control. There are usually no more than three individuals with the installation crew.* After the initial setup, the Contractor maintains the signs and tubular markers by realigning and replacing them as the project progresses. When the project moves into another stage, the Contractor removes the tubular markers and signs and sets them up again to mark the next temporary work zone.

Advantages:

This type of temporary traffic control is relatively inexpensive to install and maintain. It can be established and removed quickly. The materials are readily available and easily replaceable. No specialized equipment or labor is necessary to set up this type of work zone.

Because of its relative simplicity and lack of specialized equipment and labor, the setting up and taking down of temporary work zones by this alternative has been ideal work for the Disadvantaged Business Enterprises (DBE)**. The performance of this work by the DBE's help prime contractors to meet their DBE utilization goals for Federal-Aid contracts.

The use of tubular markers and signs provide greater access for the prime contractor to their work area and for the travelling public to access the roadside businesses across the work area than do the other two alternatives. For this reason, most construction in urban highways and streets where there is limited or no access control uses tubular markers and signs to mark out the temporary work zone.

Disadvantages:

Tubular markers are inherently less safe for the separation of work zones than the use of concrete barriers. Tubular markers do not provide a positive redirective barrier to prevent head-on collisions in a two way traffic configuration. Therefore, the use of tubular markers for the separation of temporary work zones is limited to secondary highways, urban streets, and other low speed facilities. They are expressly prohibited from use in two-way

* "Means Cost Data, 1992"

** Disadvantaged Business Enterprises consist of Historically Underutilized Businesses (HUB) or minority-owned enterprises, women-owned enterprises and sheltered businesses for the disabled.

PRESENTATION OF THE ALTERNATIVES
IN SETTING UP TEMPORARY WORK ZONES

- Alternative 2 - Standard Pin-and-Loop Concrete Barrier

Description:

The Oregon Department of Transportation standard concrete barrier is 2'-9" tall, 9" wide at the top and 2'-0" wide at the base, and comes in pieces 12'-6" long. To separate a work zone from the public traffic or to separate traffic on a divided highway, the concrete barriers are placed end-for-end in a string and attached together with the use of a shear pin through steel loops cast into the ends of the barriers. The barriers must be placed on an asphalt concrete or portland cement concrete paved surface that is 1' wider than the base of the barrier as the barrier cannot resist the impact of a vehicle collision without a solid foundation.

The placement of pin-and-loop concrete barrier is relatively slow. The average rate of placing barrier is 1000 lineal feet in an 8 hour period. The installation crew usually consists of one or more semi-tractors with flatbed trailers to haul the barrier to the job site, one crane truck or forklift to unload and place the barrier, and two shadow and sign vehicles for traffic control. The installation crew usually consists of one equipment operator and four laborers, assuming that the semi-tractors come with their own operators.* The placing operation normally requires a minimum of 8 feet working room on one side of the final barrier position. Normally, this requires a travel lane closure on the highway. To minimize disruption to the existing traffic, many contracts require the contractor to place barrier at night. This increases the cost of placement because of the need to pay premium labor rates during the night shift.

As the construction progresses, the string of concrete barrier is dissassembled and moved sideways to accomodate the varying widths of the construction work zone. This requires the same crew complement to pull the pins at the ends of the barrier, move the barrier to its new location, and reinstall the pins. The production rate for this operation is 1200 lineal feet per 8 hour period.* Because this operation takes just as much room on the highway as the installation, barrier moves are usually performed at night.

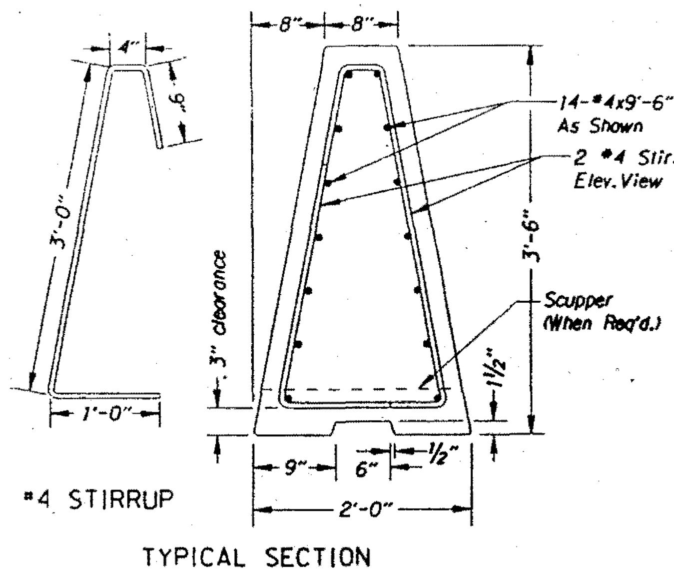
Advantages:

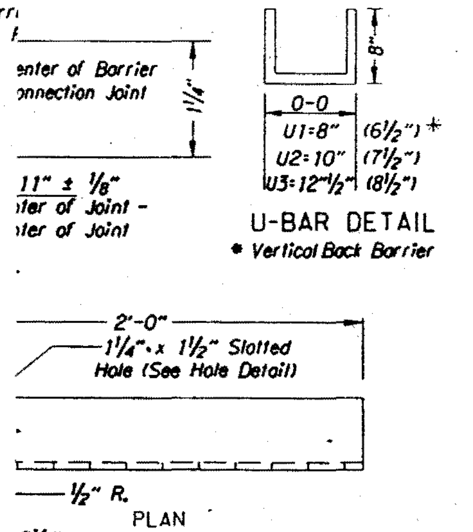
The string of pin-and-loop concrete barriers provides a positive redirective device separating the public traffic from the construction activities in a construction work zone. Therefore, the concrete barriers are inherently more safe than the use of tubular markers for separating a temporary work zone. Because of the ability of the concrete barrier to redirect an out-of-control vehicle, the construction workers are safer and productivity tends to increase. Also, traffic tends to travel faster through the construction zone because of the positive barrier thus lowering delay costs to the motorists.

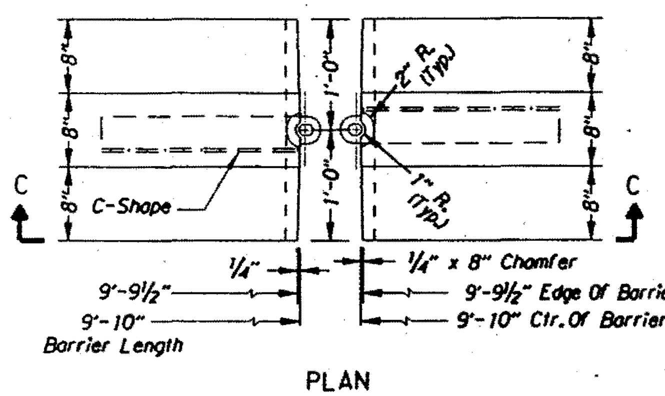
The contractor is allowed to salvage or use temporary concrete barrier as permanently placed barrier provided that the barrier is in new or like new condition. This gives a large percentage of the lineal feet of concrete barrier a dual purpose and use. The economy of this dual use is reflected in the unit bid prices for temporary concrete barrier in projects with and without permanent concrete barrier.

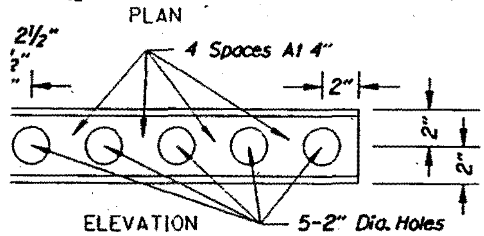
* "Means Cost Data", 1992

P R E C A R



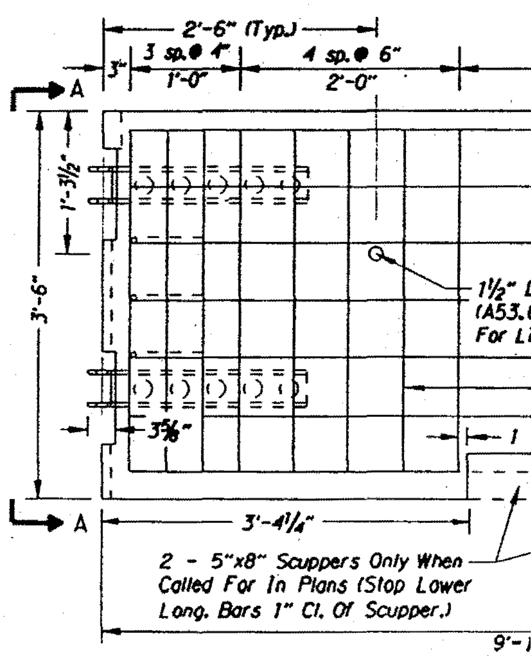






PERFORATED C-SHAPE

Cut From TS 8x4x.3125 (A501 Or A500 Grade A Or B). Hot Dip Galvanize After Fabrication. (See Note 7 For Casting Instructions.



2 - 5"x8" Scuppers Only When Called For In Plans (Stop Lower Long. Bars 1" Cl. Of Scupper.)

d workmanship shall conform to the Standard
for Highway Construction of the Oregon
ransportation.

steel shall conform to ASTM Specification
All bars shall be full length as shown and
2" clear of the nearest face of concrete
herwise.

all be Class 3300 -1½", or ¾".

steel including fasteners shall be hot-dip
r fabrication.

recast Single Slope Median Barrier is restricted
urvatures. (radii greater than 820')

es with ¾" radius.

ape shall be placed in location shown to a
".

ier weight is 6900 lbs. per 9'-10" unit length.
cal Backed Barrier Weight Is 5500 lbs.

CEDAR HILLS BLVD. INTCHGE. - S.W. 76TH AVE. SEC.
SUNSET HIGHWAY
WASHINGTON COUNTY

FEDERAL HIGHWAY ADMINISTRATION		PROJECT NUMBER	SHEET NO.
REGION 10	OREGON DIVISION		2B-9

27-APR-1993 14:11

/usr/sid/06597.dlz

Because of its unique shape, the "T"-shaped barrier cannot be reused as a permanent concrete barrier. When the barrier is not being used it must be stored. In the Portland Metropolitan area, storage facilities are rare and costly.

The Transfer and Transport Vehicle (TTV) is a unique piece of equipment that requires specialized training to operate and maintain. ODOT does not have that expertise at this time and personnel must be trained. The TTV also must be stored when it is not being used. The storage cost would be the same as for other large equipment owned by the ODOT Maintenance forces.

Components of the Cost Comparison Model for Alternative 3:

There are two methods of obtaining the QMB. The first method is to purchase the barrier system through the construction contract, i.e. the contractor bids on furnishing and operating the QMB through the life of the contract. The Federal Highway Administration purchases the initial system and ODOT will buy the system from the FHWA after the end of the contract. The second method is for the State to purchase the QMB outright and operate the QMB for the construction projects throughout the State.

3A. Buy the barrier through the contract

I = Initial cost which includes the purchase, markup, mobilization, testing and maintenance of the TTV, and installation of the "T" top barrier. From the vendor, the initial cost of the TTV and 6000 lineal feet of the "T" top barrier is $750,000. Since the FHWA pays the initial cost of the QMB, it is not counted as a cash outlay to the State for the purposes of this analysis.

M = Maintenace cost in years 3 through 8 is $25,000 per year. The maintenance cost for the first 2 years is included in the the Cedar Hills bid price for the QMB.

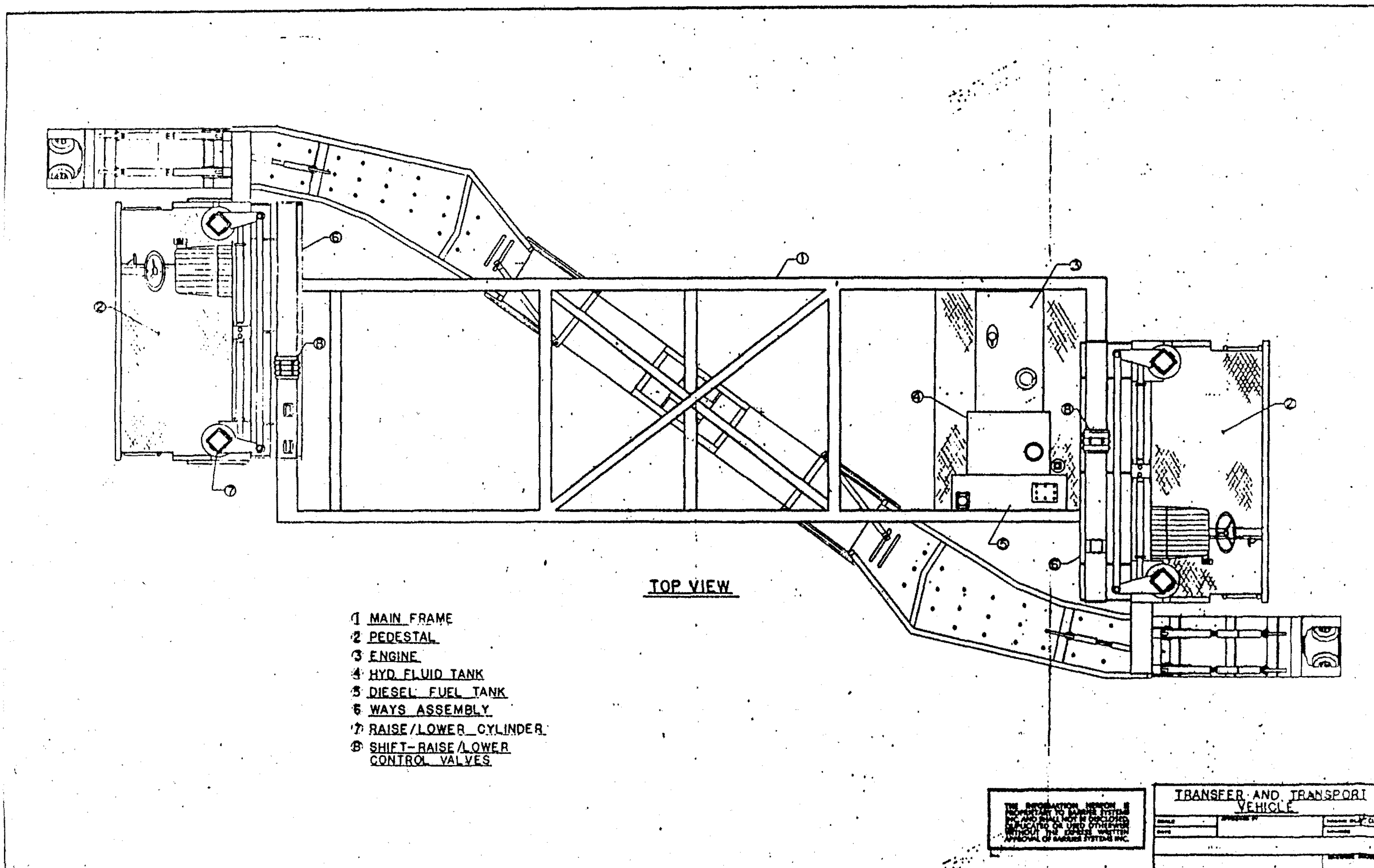
D = Delay cost to motorist. See *Calculation of Traffic Delay Costs.*

S = Safety cost to motorists and workers. See *Benefit-Cost Ratio Worksheet.*

DC = Delay of construction cost. The QMB can move barrier at speeds of 1 mile per hour. The potential delay would be $5000 per day x 6000 lineal feet x 18 barrier moves divided by 5280 lineal feet of barrier moved per hour divided by 8 hours per day. The delay cost may be as high as $13,000.

MC = Moving cost, i.e. the total cost of moving of the "T" top barrier with each stage construction change in the Cedar Hills Blvd.-S.W. 76th Ave. project is $2.25 per lineal feet x 6000 feet x 8 barrier moves or $108,000 or $54,000 per year.

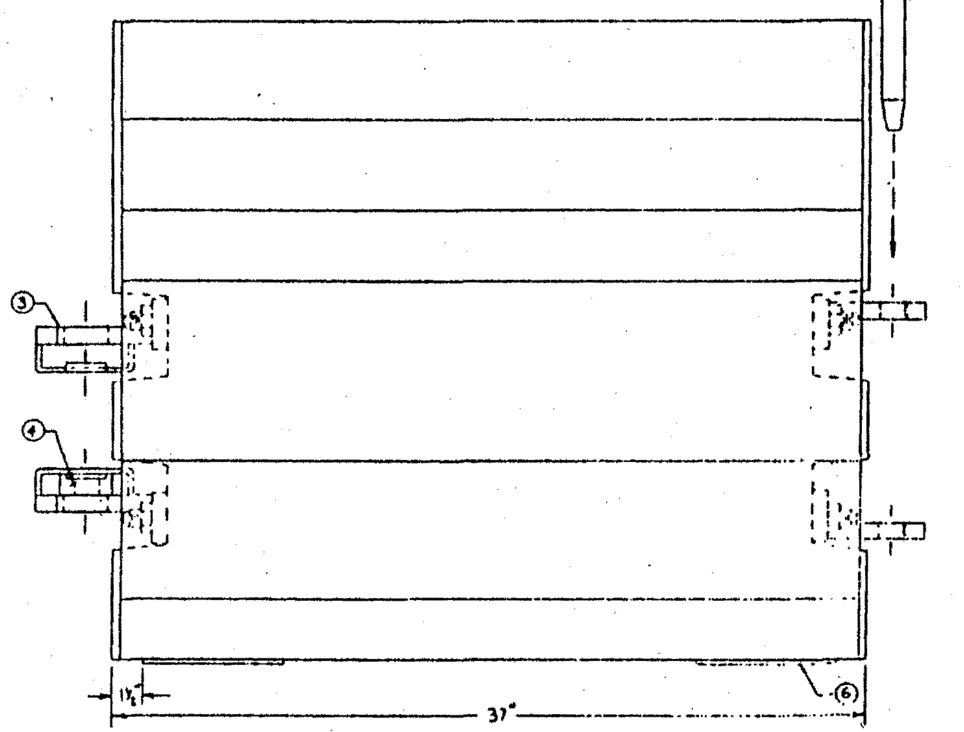
Sa = Salvage value paid to Federal Highway Administration for the ownership of the QMB after year 2 is $562,500 assuming straight line depreciation. This is a cash outlay from State monies.

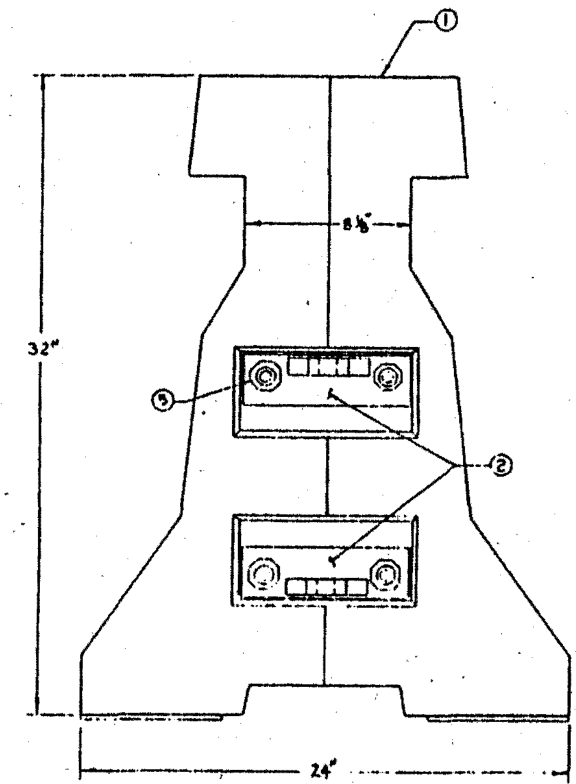


CORAL SALES COMPANY
P. O. BOX 577
CLACKAMAS, O[illegible]GON 97015

BARRIER S[illegible]STEMS INC.

Item	Qty.	Description	Dwg #.	Rev.
(1)	1	Barrier Module, Const.	861222	O
(2)	2	Hinge, Male	860425-1	F
(3)	2	Hinge, Female	860424	J
(4)	1	Shear Plate Assy.	870123	O
(5)	8	Fastening Assy.	870616-2	O
(6)	4	Skid Pad Assy.	870611-1	O
(7)	1	Hinge Pin	870308	C





Barrier Systems Inc.		
Scale ⅛" = 1'	Approved by:	Drawn by M.C.
Date:		Revised
Barrier, Series 200		
		Drawing number 870616

CORAL SALES COMPANY
P. O. BOX 577
CLACKAMAS, OREG 7015

BENEFIT-COST ANALYSIS

The Benefit-Cost analysis for the 3 alternatives for temporary traffic control is made more difficult because of the intangible benefits and costs involved in all three alternatives. As stated by Lee G. Anderson*,

"Benefit -cost analysis is not a matter of just adding up all of the effects of a project and labeling all those that appear good as benefits and those that appear bad as costs. This can result in counting things that do not properly belong, in double counting of others, and sometimes in misspecifications so that a cost becomes a benefit or vice versa. Nor is it the mere recording of the financial transactions of the project. Benefits do not always result in revenues nor can all dollar outlays be considered a social cost." *page 15, "Benefit-Cost Analysis: A Practical Guide"*

According to Lee G. Anderson*,

"One way to incorporate intangible effects into a benefit-cost analysis-other than merely identifying them-is to answer the following question. Does it appear likely in any particular instance that the values affected by the intangible effects could have been large enough, if they had in fact been quantified, to have substantially altered the findings of the benefit-cost study?" *page 110, "Benefit-Cost Analysis: A Practical Guide"*

Another technique is the use of Iso-Value curves that relate the possible dollar value of intangible effects with the probability of the intangible effect occuring. The higher the probability of the intangible effect occuring, the higher value of the intangible effect. However, as stated by Lee G. Anderson*

"It should be made clear that the selection of which combinations of p and IC appear to be plausible may involve little more than educated guesses. Intangibles, by definition, are those effects that were not quantifiable through the application of conventional economic measurement techniques. Thus, the assignment of probable values to intangibles is almost certainly going to involve a considerable amount of guesswork. At a minimum, the analyst should clearly indicate which judgments are based largely upon guesswork." *page 113, "Benefit-Cost Analysis: A Practical Guide"*

The intangible effects of all three alternatives are:

D = Delay to traffic costs. Probability of occuring; high.

S = Safety cost to the workers and traveling public. Probability of occuring; high.

LE = Loss of efficiency cost to the contractor due to "unsafe" working conditions. Probability of ocuring; medium.

DC = Delay of contractor in moving the temporary concrete barrier. Probability of occuring; low.

* See References

REPLACEMENT DECISION ANALYSIS

In the paper titled "Capital Budgeting Practices in Large U.S. Cities" by Aman Khan*, Florida State University, the most widely cited techniques for capital budgeting for projects by large city governments was the use of the benefit-cost ratio, 59% of respondents; the net present value method, 31.5% of respondents; the internal rate of return, 7.4% of respondents; and the payback period, 1.8% of respondents. Informal methods such as brainstorming, voting, and numerical weightings based on arbitrary scales were also used. In the following replacement decision analysis, we will be using the internal rate of return (IRR) for the differences in each alternative and compare the IRR to the minimum acceptable rate of return (MARR).

What is the MARR for a public works project? According to Mr. Khan:

"The selection of an appropriate discount rate is an important question for which there is no fully satisfactory answer. Ideally a discount rate should equal the opportunity cost of capital. This determination is not a major problem for private sector firms, because the opportunity cost of capital is the price that the firms must pay for capital, i.e. the market rate of interest. The public sector situation is more complicated. Resources invested in the public sector are those withdrawn from private consumption and investment via taxes. Therefore, the return on public investment should be at least equal to the return forgone in the private sector. Those who favor this approach suggest a public rate equal to a weighted average of private rates. However, market rates may not be fully appropriate. Social opportunity costs may differ from private opportunity costs (because of social values, externalities, public goods, and the like). Also private interest rates reflect tax effects that do not apply to public investment returns and often reflect a risk factor that is less important in public investment. As such, it is necessary to make adjustments for these factors." *page 11, "Capital Budgeting Practices in Large U.S. Cities".*

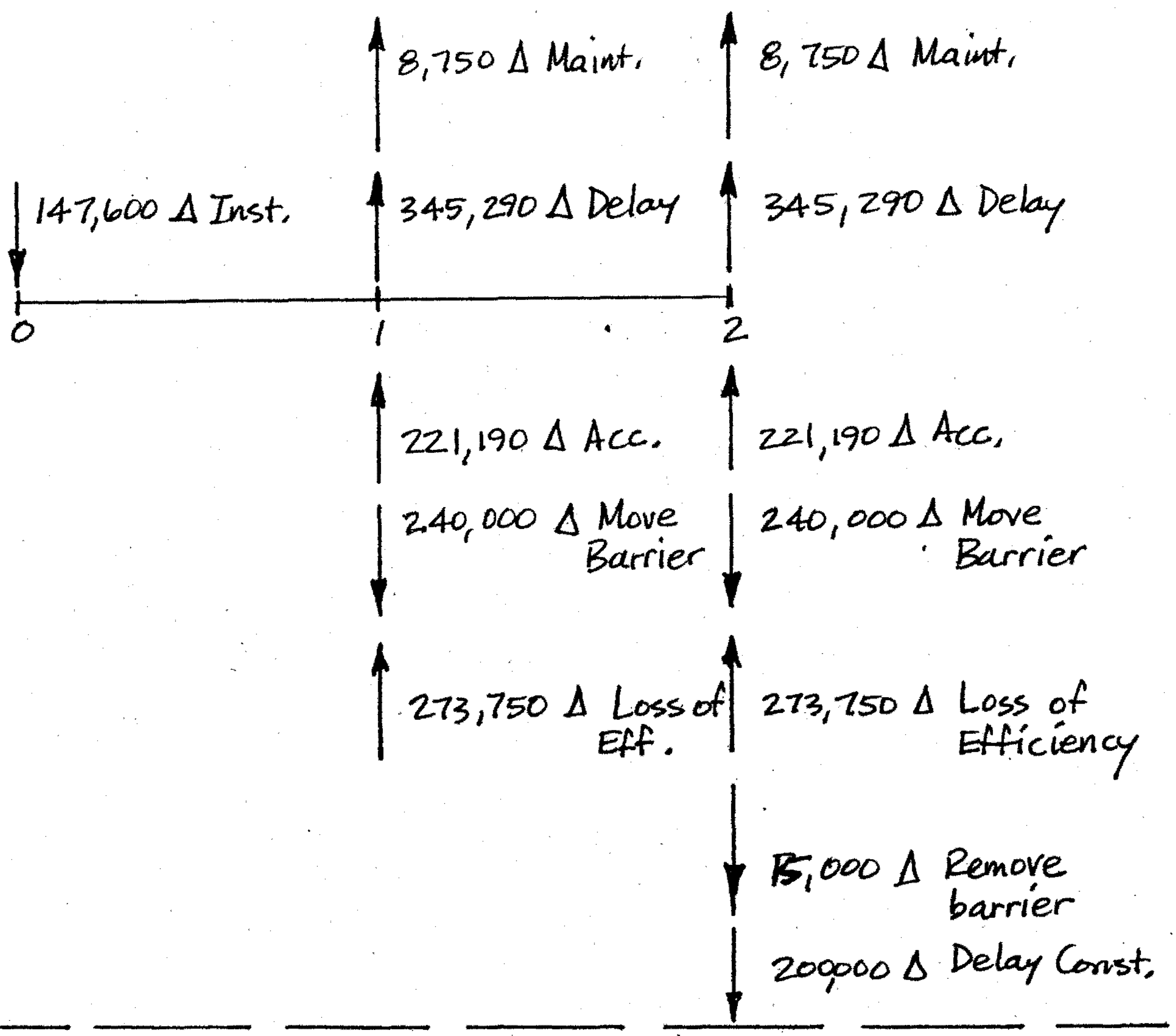
Because the Cedar Hills Blvd.-S.W. 76th Ave. project is a federally-funded project, the Office of Management and Budget require a Minimum Acceptable Rate of Return on federally funded projects of 8% to 12%*. The Oregon Department of Transportation requires an internal rate of return of 10% in any Benefit-Cost ratio analysis for new projects**. For this project, we will use the Minimum Acceptable Rate of Return as 10%.

The replacement decision analysis compares the differences in costs for each alternative over a 8 year life span. Each alternative will be compared in turn to determine the dominance of one alternative to the next. As shown by the Benefit-Cost Ratio analysis, Alternative 3B is the preferred alternative.

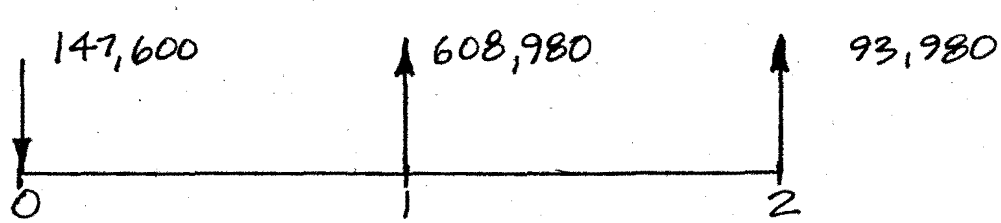
The Oregon Department of Transportation has already decided to purchase the QMB under Alternative 3A. This replacement decision analysis determines if Alternative 3A is the most economical alternative. This comparison assumes that other projects are available in the construction program that have the same attributes as the Cedar Hills Blvd.-S.W. 76th Ave. project.

Alternative 1 vs. Alternative 2, Incremental Differences $

Δ:



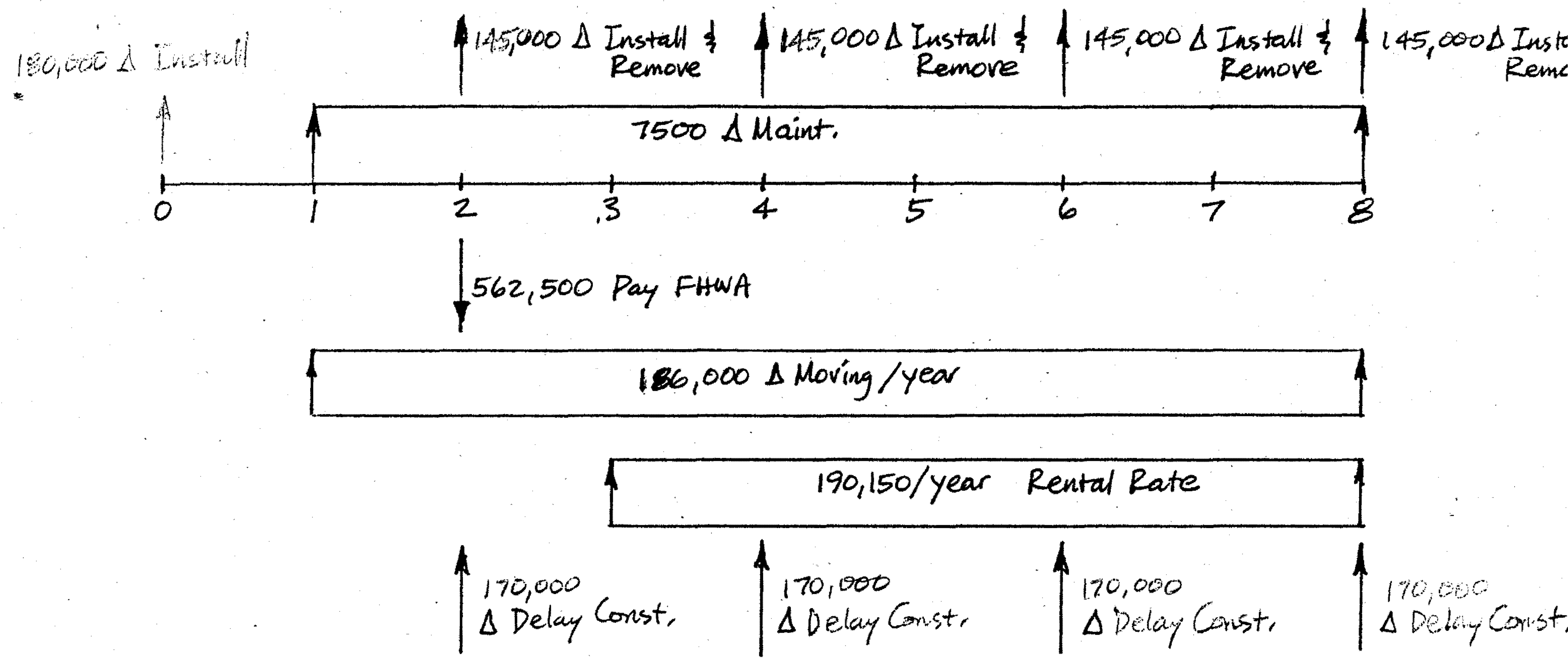
Δ: Cash Flow



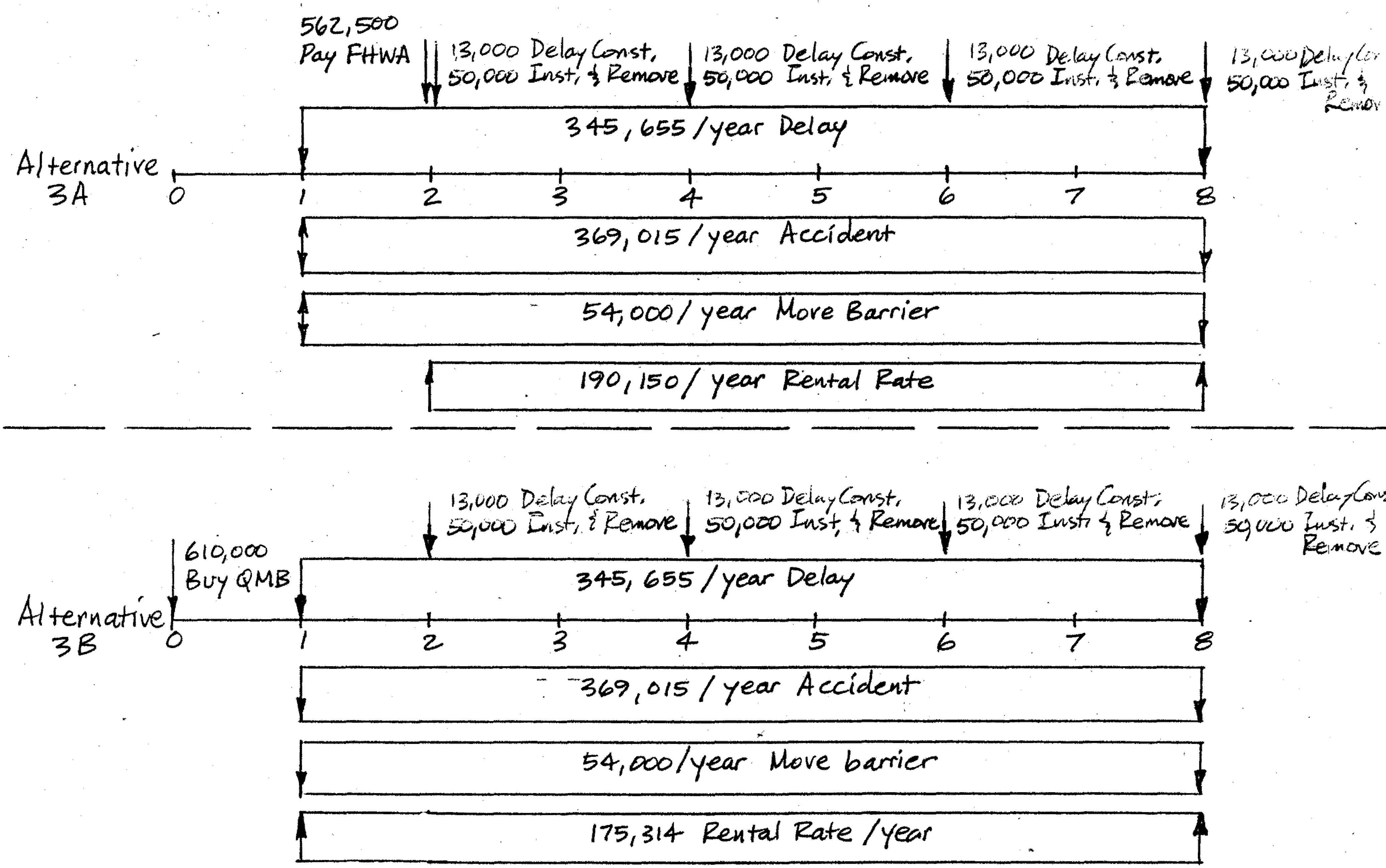
From CASH Software, Addison-Wesley Publishing Co.
IRR = 314.12% > MARR of 10%, Prefer Alt. 2 to Alt. 1

Alternative 2 vs. Alternative 3A, Incremental Difference $

Δ:



Alternative 3A vs. Alternative 3B, Incremental Difference $



SENSITIVITY ANALYSIS OF INTANGIBLE EFFECTS

James T. Luxhoj, Rutgers University, and Marilyn S. Jones, Virginia Polytechnic University* introduced four groupings of assumptions in replacement modeling. These are structural, realistic, descriptive, and simplifying. In this analysis of *Movable Barrier Systems for Temporary Protection and Direction of Traffic Control in Highway Construction,* my structural assumptions were that interest is constant over the study period; the system composed of well-defined cash flows; avoided costs were considered a cash flow; four projects similar to the Cedar Hilld Blvd.-S.W. 76th Ave. project were available to be placed in a series for analysis, and depreciation for the QMB was straight-line. The realistic assumptions were the use of actual bid prices for items of work, and the actual constraints of the Cedar Hills project. The descriptive assumptions were the QMB was to be purchased new; there is a finite planning horizon of 8 years; each cost component is independent of the others (although not entirely true as delay costs and accident costs are related); and the QMB has no breakdowns and has 100% utilization throughout the planning horizon. The simplifying assumptions were the description of the intangible effects as a simple percentage increase or decrease from a base number.

Are there some intangible effects in our model that will change our decision to purchase the Quickchange Movable Barrier System? The four intangible effects are the costs of delay to traffic; the costs of delay of the contract due to moving barrier; costs of increased accidents in the work zone; and the cost of lost contractor efficiency in working behind tubular markers instead of barrier. To answer this question, I reviewed the Δ : Cash Flow model of Alternative 1 versus Alternative 2; Alternative 2 versus Alternative 3A; and Alternative 3A versus Alternative 3B to their sensitivity to the intangible effects.

* "A Framework for Replacement Modeling Assumptions", The Engineering Economist, Volume 32-Number 1, Fall, 1986.

- Alternative 2 versus Alternative 3A

The intangible effect between these two alternatives is the delay in construction cost. Assuming that the delay in construction cost was zero, i.e. no increased or decreased delay in construction using the QMB versus the standard pin-and-loop barrier, the difference in the installation, maintenance, moving, and removing cost of the standard pin-and-loop barrier would justify the purchase of the Quickchange Movable Barrier. All avoided costs would generate a positive cash flow using Alternative 3 over Alternative 2.

- Alternative 3A versus Alternative 3B

There are no differences in the intangible effects in these two alternatives. However, looking at the possible purchase cost of the QMB between $550,000 to $750,000, we would still choose 3B over 3A. If the ODOT had to pay the maximum price of $750,000, the internal rate of return would still be greater than the minimum acceptable rate of return.