EVALUATION METHODOLOGY FOR SELECTION OF AN INTERCHANGE CONFIGURATION

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The selection of pertinent evaluation criteria is fundamental to the evaluation methodology for deciding on an interchange configuration. The criteria chosen should measure differences between alternative interchange designs. If no such criteria exist, then there is no difference between the alternative designs, and the interchange configuration with the lowest initial cost should be selected. The initial cost was used as the cost indicator for each alternative interchange design. The initial cost was selected because it is easily obtained and does not include some of the uncertainties associated with calculation of road-user costs. The next step is the development of an effectiveness profile for each alternative interchange design. An effectiveness profile is a graphical technique that shows each alternative's effectiveness rating for every evaluation criterion. It is based on the cost-effectiveness approach of economic analysis and is the accumulation of several cost-effectiveness plots into a single graph. The final step is to analyze the initial cost and the effectiveness profile for each alternative interchange configuration. This analysis will provide the decision-maker with the necessary information to select an adequate interchange configuration for the given conditions.

•INTERCHANGES are the weak links in any freeway system because of the vehicular turbulence associated with the inherent merging, diverging, and weaving maneuvers. If the interchanges operate efficiently, then traffic on the freeway will probably flow smoothly.

It does not seem probable that many more miles of new freeway will be built, especially in urban areas. However, those that are built will have to pass a stringent ecological test. The same is true for the rehabilitation of existing freeways, which have become corridors lined with intense land development. Many of the existing interchanges need upgrading and yet, with the adjacent land development, there is no easy way to alter these interchange configurations. An interchange's impact on the community and its traffic operational requirements are opposing forces with which the interchange design engineer must work. He must somehow relate these two forces and arrive at an acceptable interchange configuration. This is the most difficult part in the design of an interchange.

INTERCHANGE SELECTION PROCESS

The purpose of this paper is to present an evaluation methodology that will assist the practicing design engineer in selecting an interchange configuration for a particular location. The total decision-making process recommended to select an interchange type is shown in Figure 1, which demonstrates that the interchange design engineer should be involved not only in the route location study for a new facility but also in the planning study for the rehabilitation of an existing facility. The interchange design engineer can provide valuable inputs to both of these preliminary highway design phases by evaluating the feasibility of the interchange locations and developing preliminary interchange types for these locations. The involvement of the interchange design engi-

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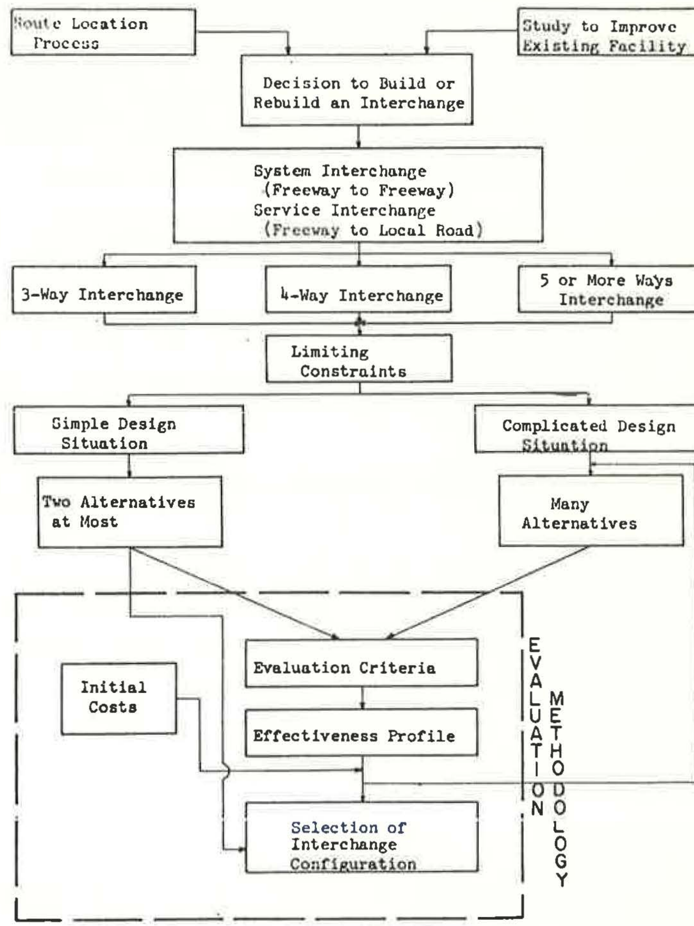


Figure 1. Interchange selection process.

neer at these stages will help minimize the situations where an adequate interchange cannot be built because of predetermined constraints.

Once the determination is made that an interchange is needed, the first step is to determine if a system interchange or a service interchange is required. A system interchange must have all free-flowing ramp terminals for the quick transfer of traffic from one freeway to another.

A service interchange, a freeway to local road connector, usually has stop-controlled or signal-controlled ramp terminals on the crossroad; but in certain areas, free-flowing ramp terminals may be desirable. This division into either a system interchange or a service interchange reduces the set of possible interchange configurations that can be used in any given location.

The number of possible interchange configurations is still further reduced by classifying the desired interchange by the number of approach legs or streets: three-way, four-way, and five or more ways. The interchange types that are applicable, based on the number of approach legs and the classification of the crossroad, follow:

1. Three-way interchanges (three approach roads)—A system interchange involves directional T or Y, trumpet A, and trumpet B. A service interchange involves directional T or Y, trumpet A, trumpet B, half diamond, and hybrids.

2. Four-way interchange (four approach roads)—A system interchange involves directional without loop ramps, directional with loop ramps, and cloverleaf with C-D roads. A service interchange involves directional with loop ramps, cloverleaf with

C-D roads, parclo A-4, parclo A, parclo B-4, parclo B, parclo A-B, diamond with its many variations, and hybrids.

3. Five-way or more interchange (five or more approach roads)—A system interchange involves directional without loop ramps, directional with loop ramps, and hybrids (local ramps within a system interchange). A service interchange involves directional with loop ramps, rotary, and hybrids.

Hybrids are interchange configurations that are modifications of the basic types of interchanges; the modifications are made to meet existing constraints. Rotary interchanges should not be used in this country because of the operational problems associated with their built-in weaving maneuvers.

After narrowing the number of possible interchange types by the functional classification of the interchanging facilities and the number of approach roads, the designer should then determine if the design location has any limiting constraints on the interchange configuration. The existing land use in one quadrant may force the designer to completely avoid that quadrant when he lays out the alternative interchange designs. For example, parks, schools, and other public land are bypassed, if possible. Frontage roads also limit the type of interchange. With a two-way frontage road system, partial interchanges are developed though the use of buttonhook ramps. There are, however, many disadvantages associated with buttonhook ramps. They are usually the second best solution, difficult to sign, induce wrong-way movements when ramps are isolated, and require low design speeds. Buttonhook ramps should be avoided if possible.

Likewise, slip ramps are appropriate for connecting the freeway to a one-way frontage road network, whereas interchanges with loop ramps are not readily adaptable. A natural or man-made obstruction greatly influences the type of interchange. A river or railroad paralleling the crossroad can force all of the ramps to be located in two quadrants on the same side of the crossroad.

The next step is to determine if the particular design problem under study is simple or complicated. A simple design situation would require only one or possibly two alternative interchange designs. Even with a simple or clear-cut design location, it is recommended that two alternatives be developed and compared. An example of a simple design situation is a service interchange between an Interstate route and a low-volume secondary state highway where access is needed because of the long distance between adjacent interchanges. In this case, a diamond interchange would probably be designed. Most interchange designers would find it difficult to justify the time and expense involved in developing another alternative interchange configuration and would consider it a waste of effort to use any detailed evaluation. The interchange design engineer is encouraged, however, to look over the list of evaluation criteria presented later to make sure the design situation is truly simple.

Several alternative interchange designs are developed when a complicated design situation is encountered. The number of alternatives usually varies from two to about ten, depending on the complexity of the design problem. The major obstacles involved in interchange design are in urban areas where development has already occurred and the impact on the environment (the surrounding land) is felt the most. It is also in the urban areas where some of the early freeways are becoming obsolete and are in need of rehabilitation. These highly congested routes have become corridors of high land development because of the accessibility afforded by these freeways. Serious trade-offs have to be made between the community impact factors and the traffic operational factors so that substandard acceleration and deceleration lanes, the closely spaced interchanges, and the congested ramp movements, can be corrected. The following evaluation methodology is proposed to compare these two dichotomous sets of factors.

EVALUATION METHODOLOGY

The evaluation methodology is made up of the following procedures for the interchange design engineer:

1. The list of evaluation criteria should be scrutinized to determine which are pertinent to the design situation under study and which factors should be added.

2. The initial cost for each alternative interchange design should be estimated. The initial cost should include construction costs, right-of-way costs, and relocation costs.

3. An effectiveness profile for each alternative interchange design should be developed.

4. The initial cost of each alternative design should be compared to its effectiveness profile, and the most cost-effective interchange configuration should be selected. If the interchange design engineer doing the work cannot make the final decision on the interchange type, then he should present the initial cost information and the effectiveness profile data to the decision-maker.

Scrutinize List of Evaluation Criteria

There are many criteria that should be considered to some degree in selecting an interchange type, and it is easy to overlook some. The following are some of the evaluation criteria that should be considered in the design of every interchange.

1. Operational and design factors include (a) level-of-service continuity between the main line and the ramps; (b) level-of-service continuity on the crossroad through the interchange area; (c) safety, i.e., uniformity of flow and accident potential; (d) uniformity, i.e., on- and off-ramp design, route continuity, and signing; (e) flexibility, i.e., basic number of lanes, lane balance, stage construction, and maintenance of traffic during construction; (f) number and length of weaving sections; and (g) other factors depending on the design situation and the designer's experience.

2. Community impact factors include (a) number of acres taken outside of the mainline right-of-way; (b) number of families relocated; (c) number of commercial establishments relocated; (d) number of tax dollars removed from the tax rolls; (e) number of local streets closed; (f) taking of a particular parcel of land, e.g., church, school, historical landmark, and public land; (g) lack of access to adjacent property; and (h) other factors depending on the design situation, designer's experience, and community feelings.

These basic criteria include measures of the traffic operational capabilities and design characteristics of an interchange. If certain minimum traffic operational constraints are not met, there is no reason to further consider that interchange configuration. For example, each of the alternative designs must be able to carry the forecast traffic volumes.

The individual designer may have a particular measure or measures that he has used in the past as operational and design criteria for the selection of an interchange configuration. The following are some of these additional criteria: (a) travel time; (b) travel distance; (c) radius of curvature; (d) ramp grades; (e) topography; (f) soil conditions; (g) drainage; (h) spacing of interchanges; (i) design speed; (j) composition of traffic; (k) operating costs—running costs (fuel, tires, oil, maintenance); and (l) level of service.

The community impact factors should be individualized for each interchange design; therefore, no set of criteria is recommended as a minimum measure of the impact on the community from the various alternative interchange configurations. The objective is to minimize the detrimental community impact while maximizing the traffic operational capabilities of the interchange. Trade-offs between these two dichotomous interchange consequences are always present.

There are several more prevalent community impact factors. Additional factors include noise and air pollution, local street connectors, landscaping opportunities, land development opportunities, local planning values, barrier effects, and aesthetics.

These operational and design factors and community impact factors are intended to be open-ended because it is impossible to include in this paper all of the factors that could influence the selection of an interchange configuration. The designer should anticipate the evaluation criteria considered important by the public and include these in the evaluation process. The important thing is to include the factors or evaluation criteria that affect the possible interchange type. Without a set of evaluation criteria as a foundation to measure the differences between the alternative interchange configurations, the proposed evaluation methodology is weak at best.

Develop Initial Cost for Each Alternative Design

The initial cost of each alternative interchange design is used in the evaluation methodology because it is easily obtainable and does not include some of the uncertainties associated with calculating road-user costs. Included in the initial cost are construction costs, right-of-way costs, and relocation costs, e.g., utilities and families and businesses.

Road-user costs are not included in the determination of the cost of each alternative design because of the problems associated with calculating dollar values. In arriving at a value for time, the accumulation of small increments of time and the uncertainty associated with the monetary value of a fatality are some of the questionable areas. It is also felt that the road-user costs would not be significantly different for alternative interchange configurations.

If the designer feels that some measure of road-user costs should be included in the evaluation process, he could always include it as an evaluation criterion. For example, the present worth of operating cost could be included in the analysis as a measure of the effectiveness of the alternative designs: The lower the operating cost is, then the more attractive will be that alternative design. The designer should make an honest attempt, however, to accurately determine the operating cost. He should not take the average of the existing annual traffic and the projected annual traffic as the yearly traffic over the life of the project and apply the fuel, oil, maintenance, etc., factors. Operating costs vary not only over the duration of the project and over the increase in traffic but also by the hour of the day. Maintenance costs are not included because again it is felt that it would be better to include them as an evaluation criterion.

Develop an Effectiveness Profile

A technique is needed to compare the impact of the alternative interchange designs based on qualifiable as well as quantifiable criteria. There are several approaches that this evaluation procedure could take. It can simply be a rote process, similar to the interchange design table found in one of state highway design manuals. This technique of interchange configuration selection leaves nothing to the design engineer's imagination or ingenuity. The designer simply goes to a predeveloped table or chart and selects an acceptable interchange configuration.

One form of evaluation methodology applies economic measures such as the benefit-cost ratio, rate of return, or net present worth. These techniques are primarily based on (a) first costs such as cost of construction and right-of-way costs, and (b) motor vehicle operating costs, such as those associated with accidents, delays, and travel time costs. The alternative with the best ratio or economic index is the selected interchange configuration.

Another technique uses a point weighting scheme (1) similar to the sufficiency rating method of evaluating highway pavements to determine the best interchange configuration. The alternative with the highest numerical score is accepted as the most appropriate solution. Figure 2 (1, p. 21) shows this numerical approach for the selection of the proper interchange type (alternative 2). One of the noteworthy aspects of Leisch's methodology (1) is that the costs only constitute 25 percent of the evaluation weight.

Oglesby, Bishop, and Willeke (2) clearly state the basic problem with most of these previously mentioned evaluation techniques.

> A general criticism of these approaches is that they have failed to recognize the two basic principles of decision making: (a) decisions must be based on the differences among alternatives; and (b) money consequences must be separated from the consequences that are not reducible to money terms, and then the "irreducibles" must be weighted against the money consequences as a part of the decision making process.

Figure 2. Comparison of alternative interchange solutions.

Output Variables (Comparison Items) (1)	Scale Value (2)	1 (3)	(4) 2x3	2 (5)	(6) 2x5	3 (7)	(8) 2x7
Operation [30]							
Speeds of operation	(5)	10	50	8	40	6	30
Travel distance	(5)	10	50	9	45	7	35
Safety - compr. & antic.	(5)	10	50	10	50	7	35
Safety aspects - other	(5)	8	40	10	50	7	35
Capacity	(10)	10	100	8	80	6	60
Costs [25]							
Capital	(15)	6	90	9	135	10	150
Operating	(10)	10	100	10	100	10	100
Implementation [15]							
Construction staging	(10)	6	60	10	100	8	80
Maintenance of traf.	(5)	8	40	10	50	10	50
Environmental [30]							
Traffic disturbances	(5)	6	30	10	50	10	50
Aesthetic qualities	(5)	6	30	9	45	8	40
Barrier Effect	(5)	5	25	10	50	7	35
Impact on develop.	(15)	5	75	9	135	10	150
Total (Index Value)	(100)		740		930*		850
(*Best Alternative)							

Grant and Oglesby (3) make the following statement about highways and freeways, but it also seems very pertinent to the design of an interchange.

> In many cases some consequences of decisions among highway alternatives (interchanges) cannot be expressed in terms of money. Furthermore, the "irreducibles" to whomever they may accrue are relevant to the decision. In these situations the "dollar" answers from the economy study do not dictate the final choice; but on the other hand they provide a money figure against which the irreducibles can be weighed and thereby narrow the area of uncertainty with which the decision maker is faced.

Wattleworth and Ingram (4) tried to overcome these problems by applying the cost-effectiveness methodology to the analysis of alternative interchange design configurations. They recognized the "need for a procedure that can be quickly used by a designer to compose alternative interchange design (or redesign) configurations and that considers the cost of each configuration as well as the effectiveness of the interchange." The effectiveness measure used in this research was the total interchange capacity, expressed in terms of equivalent average daily traffic entering the interchange. The cost measure was in terms of the initial costs of the project. Before this cost-effectiveness approach was developed Wattleworth and Ingram formulated a linear programming model to determine interchange capacity (5). This linear programming model, itself, would be a good tool to determine the proper interchange configuration, if capacity was the only measure of effectiveness that was used.

During field interviews with interchange designers it became apparent that there was no generally accepted evaluation methodology for the comparison of alternative interchange configurations. In most rural areas there is no problem; diamond interchanges are used most of the time without any comparison to other configurations or without any evaluation of traffic operations or of the effect on land use, etc. However, when a decision has to be made because of a complicated design situation, there is no accepted methodology that could be used in the selection of an interchange type.

An appropriate evaluation methodology for the comparison of alternative interchange configurations must include nonmarket variables as well as market variables. The best way to incorporate these nonmarket variables into an evaluation methodology is through the use of the cost-effectiveness technique.

The application of the cost-effectiveness approach in this paper results in an effectiveness profile that is a set of vertical scales; each vertical scale represents a different criterion. For each alternative design, its effectiveness rating for every evaluation criterion is plotted on the proper vertical scale. Straight lines are then drawn that connect the appropriate effectiveness ratings to form an effectiveness profile for each alternative configuration. The final effectiveness profile is a compilation of two or more cost-effectiveness curves into one graph. The effectiveness profile is an expansion of the community factors profile developed by Oglesby, Bishop, and Willeke (2) as a method for decisions among freeway location alternatives based on user and community consequences. Figure 3 is an example of an effectiveness profile used to evaluate three alternative interchange configurations.

The effectiveness ratings are measured objectively if possible (in terms of level of service, acres required, number of families relocated, etc.) or subjectively (poor, fair, good, excellent) based on the designer's experience and community attitudes. The bottom line of the effectiveness profile represents the lowest or worst possible effectiveness rating, and the top line the highest or best possible effectiveness rating for each criterion. Each vertical scale is subdivided into equal segments between these two extreme measures of effectiveness. If no predetermined maximum or minimum value can be set for a vertical scale, then the best effectiveness rating for the given alternative designs should be scaled on the top line and the worst effectiveness rating on the bottom line.

Some of the evaluation criteria may have a minimum acceptable effectiveness limitation that is more restrictive than the lowest possible effectiveness rating and that is represented by a horizontal line across the vertical scales representing those criteria.

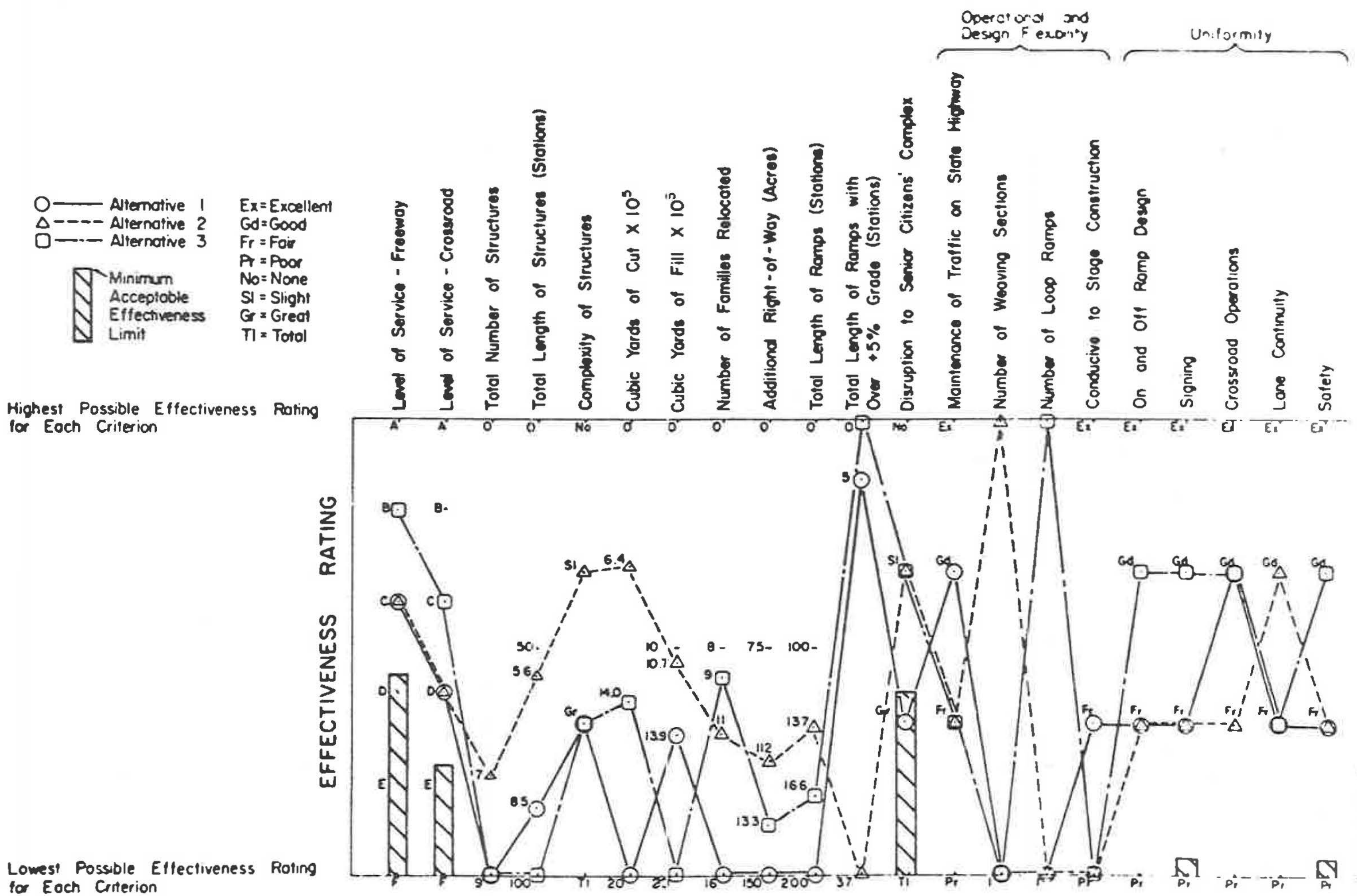
If a minimum acceptable effectiveness limit is assigned to an evaluation criterion, it should be done a priori and not after the effectiveness profile has been developed. The segment of the vertical scale below this minimum acceptable effectivenes limit is an area that indicates rejection of any alternative whose effectiveness rating falls in it. This rejection of the alternative design should be final unless conditions are changed that either alter the minimum acceptable effectiveness limit or improve the interchange design so that the alternative's effectiveness rating increases above this limiting constraint. For example, in Figure 3 the criteria, level of service on the freeway and on the crossroad and the disruption to the senior citizens' complex, have minimum acceptable effectiveness limits.

The changing of either the minimum acceptable effectiveness limit or the effectiveness rating because of some design alteration lends itself quite readily to a rough form of sensitivity analysis. By making either of these changes, alterations occur relative to the differences between the alternatives and possibly result in the selection of a different alternative design.

Evaluation criteria that indicate similar characteristics for the three alternative interchange designs are not included in the effectiveness profile; however, they are important for deciding whether an interchange should be constructed. If all three alternative configurations have a similar positive characteristic, then any of the three types could be built based solely on this factor. But if all three alternative configurations possess the same absolute negative characteristics, then the decision process becomes more complicated. For example, if all three alternatives require taking a certain parcel of land that is unattainable, then there is no feasible alternative among the three given, and either additional alternative designs must be developed or the total project abandoned.

It is also possible to place confidence limits on the effectiveness ratings for certain subjectively measured criteria. For example, the effectiveness rating for alternative 1 for the safety criterion might range from good on the high side to fair on the low side. As long as the confidence limits do not intersect a minimum acceptable effectiveness limit, they will show the possible ranges of acceptable effectiveness ratings. If they do go below the minimum level, then a judgment has to be made on the probability of attaining an unacceptable design.

Figure 3. Effectiveness profile.



Select an Interchange Configuration

In a simple design situation for which only one interchange configuration is developed, there is no need for an evaluation methodology because the interchange configuration is already selected. However, when a choice must be made between two or more alternative interchange types, the decision-maker, be he the interchange design engineer or his superior, should analyze the effectiveness profile of each alternative design. After eliminating those alternative designs that do not meet all of the minimum attractive effectiveness limits or that are dominated by another alternative design, the decision-maker is left with interchange configurations that meet minimum requirements. In the effectiveness profile (Fig. 3), one of the alternative designs could be quickly eliminated from further consideration. Alternative 1 causes too much disruption to the senior citizens' complex, and this is unacceptable to the community. The basic decision, then, is between alternatives 2 and 3. After comparing the initial cost of each of these remaining interchange types, the decision-maker should be able to make a decision on the type of interchange to design.

DISCUSSION

This graphical display of alternative consequences, the effectiveness profile, should be useful in many ways for the design engineer. It will provide him with an easily understood representation of the overall effects of each alternative design. The effectiveness profile (besides being an aid to the design engineer and his technical associates) should be a helpful visual aid at a public meeting because it clearly illustrates which criteria were used and their effectiveness ratings. The public may not agree with some of the effectiveness ratings, but at least they will be able to see how the designer arrived at his decision. The public will also be able to see the influence of any absolute criterion by seeing which alternatives were dropped from further consideration because they did not meet certain minimum acceptable effectiveness limits.

The effectiveness profile could be very useful as an indicator of the monetary value of qualifiable variables. After many years of interchange design evaluations, it may be possible to review the effectiveness profiles of past evaluations and quantify the monetary value of the qualifiable variables or at least recognize which qualifiable criterion carried weight in previous decisions. For example, if a certain evaluation criterion seems to be prevalent when the cheapest design alternative in terms of dollars is not chosen, then it should be possible to assign some dollar value to this criterion.

The effectiveness profile should encourage design variations after the initial alternatives have been developed. If an alternative meets all of the evaluation criteria except one or two, the decision-maker should feel compelled to see what would happen to the decision outcome if he were to make modifications to the rejected alternative design so that it would at least meet all of the minimum acceptable effectivness limits. This procedure will provide the decision-maker with a method of evaluating the results of placing certain constraints on the design.

The effectiveness profile (depending on the selection of evaluation criteria) should be sensitive enough to register any significant differences in alternative interchange configurations. The operational differences between a tapered off-ramp and a parallel off-ramp will not be noticed unless the designer makes this design element one of the evaluation criteria. Significant design variations, e.g., a loop ramp versus a diamond type ramp, will definitely register in the effectiveness profile.

The strength of the proposed evaluation methodology is contingent on the selection of the evaluation criteria and the development of the effectiveness profile. The evaluation methodology is simple to apply and should not require much time. These attributes are necessary for practicing interchange design engineers to use in the selection of an interchange configuration.

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