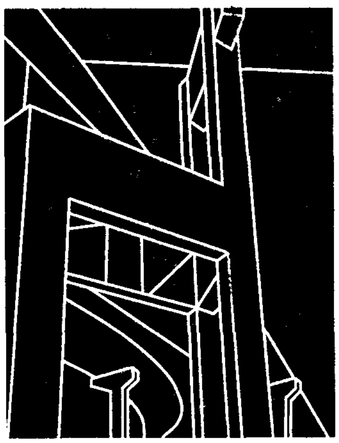
SYSTEM FOR EVALUATING BRIDGE CONSTRUCTION PLANS

Tamer El-Sayed El-Diraby and James T. O'Connor



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ABSTRACT

At present, there are no tools available for objectively evaluating the effectiveness of a bridge construction plan (BCP). As a result, bridge designers predominantly evaluate BCPs by considering only the short-term economics (i.e., construction costs). Other significant issues for project success, like safety, accessibility, and impact on local community, are evaluated based on *subjective* judgments, not on systematic analysis.

A BCP, as defined by this research, has a direct impact on the surrounding neighborhood and on overall project performance. Hence, it is desirable to optimize a BCP through rigorous evaluations during the design phase. A model developed for such evaluations would need to perform the following specific tasks: (1) define the exact construction concerns anticipated within project execution (the definition of BCP-specific objectives other than the traditional objectives of cost and schedules); and (2) provide a means for evaluating a BCP against a multitude of objectives (given that such objectives have been defined in the previous step).

Thus, the fundamental hypothesis of this research is that a beneficial BCP evaluation tool can be developed for use in the design phase. Of course, this suggests that there are a set of evaluation criteria that are common to all bridge construction projects that can be used as a base for BCP evaluation, and that the data available during the design phase are sufficient for performing the evaluation. This report, then, describes the development of a mechanism (model) for evaluating the effectiveness of bridge construction plans during the design phase.

1. INTRODUCTION AND BACKGROUND

Optimizing the performance of urban freeway bridge projects demands that more attention be placed on bridge construction planning. Construction sequencing and traffic control planning have to be coordinated to assure safe and adequate traffic flow and, at the same time, safe and efficient construction work. Furthermore, construction sequencing has to be planned to minimize the disruptions to the local community—especially its business activities.

Of the nation's 576,000 bridges, more than 30% were reported to be deficient in one or more ways (Ref 1). The average investment required to repair, reconstruct, or rehabilitate (RRR) these deficiencies over the next two decades is estimated at $8.2 billion annually. In addition, more and more bridges are being built to meet the ever increasing growth in travel demand. The US Department of Transportation (DOT) estimates an annual 2.5% growth rate in travel demand over the next two decades (Ref 2). On average, there were more than 1,600 new urban bridge projects every year over the last 3 years.

The lack of adequate balance in accommodating construction, traffic, and community needs within such projects can result in excessive project cost and time, traffic flow inefficiency, and, most importantly, safety hazards to both the traveling public and construction crews. Significant enhancements to all these parameters and to overall project output can be realized through careful project analysis and through the use of the vast construction experience gained through years of work in similar projects. Such expertise, if utilized at the appropriate time and in the appropriate way, can and does provide the design and construction teams with effective and practical techniques for balancing a project's sometimes conflicting challenges (Refs 3, 4).

This study presents one way of modeling field experience into a system for evaluating the effectiveness of bridge construction plans.

1.1 DEFINITIONS

Bridge Construction Plan

A bridge construction plan (BCP) is a comprehensive plan for the construction of a new bridge that satisfies project-defined objectives. It includes the following major items:

a. a detailed description of the bridge construction method,

b. general project specifications as regards safety and traffic handling,
c. a detailed sequence of bridge construction activities, and
d. a detailed plan for handling traffic during construction, or what is known as traffic control plan (TCP).

Construction Knowledge

Construction knowledge is the experience gained from executing and analyzing field projects that will teach us 'how to conduct business better' (i.e., how to manage the work process to produce the optimum design and project). Such knowledge spans three major dimensions:

1. Procedural: the development of a systematic design process that optimizes the procedures of developing a new bridge. This process—based on field experience—will define who is the most appropriate person to do what, at which stage of the design process, and with which specifications in order to achieve the optimal design.
2. Design audit and decision making: evaluating mechanisms, or decision support systems, driven from field experience. These techniques preserve the wisdom gained from field success and failures. They assist the designer in selecting the one design approach most likely to succeed.
3. Technical lessons learned: technical and engineering lessons learned are to be preserved in a data base for future usage.

1.2 PROBLEM STATEMENT

Currently, the design team of a new bridge lacks any objective tool for evaluating the effectiveness of a BCP. The evaluation of a BCP is now predominantly based on short-term economic considerations (i.e., construction costs) (Ref 5). Other significant issues for project success, like safety, accessibility, and impact on local community, are evaluated based on subjective judgments and not on systematic analysis.

Several research efforts have focused on learning from site experience by documenting technical lessons learned (see Chapter 2 for a detailed review of the literature regarding BCP). Less research effort has focused on transforming construction field knowledge into models and systematic procedures for guiding the design effort. Therefore, no previous research has developed a model to assess the effectiveness of a BCP based on the multitude of factors influenced by its design.

BCP, as defined by this study, has a direct impact on the surrounding neighborhood and the overall project performance (see Chapter 5 for detailed analysis of BCP impacts); hence, it is desirable to optimize a BCP. Designers need a model to evaluate a BCP during design phase that would perform the following specific tasks:

a. define the exact construction concerns anticipated within project execution (the definition of BCP-specific objectives other than the traditional objectives of cost and schedule), and
b. provide a means to evaluate a BCP against a multitude of objectives (given that such objectives have been defined in the previous step).

1.3 RESEARCH HYPOTHESIS

The fundamental hypothesis of this research is that a beneficial BCP evaluation tool can be developed for use in the design phase.

This suggests the following specific hypotheses:

a. There exists a set of evaluation criteria that are common to all bridge construction projects that can be used as a base for BCP evaluation.
b. The data available during the design phase is sufficient to perform the evaluation.

1.4 RESEARCH OBJECTIVES

The main objective of this research is to develop a mechanism (model) for evaluating the effectiveness of bridge construction plans during the design phase.

The specific objectives of the research are:

a. to develop a list of evaluation factors that are meaningful to BCP evaluation,
b. to develop specific BCP evaluation procedures, and
c. to suggest a framework for implementation of the proposed evaluation procedures within the bridge design process.

1.5 RESEARCH SCOPE

The evaluation model developed in this research effort is the first of its kind in this field and focuses on the unique challenges of urban bridge construction projects. The model includes only parameters that are common to a generic bridge project. An all-inclusive model addressing every possible BCP concern is not achievable because of the variable nature of every bridge project (see Chapter 5 for more details about the nature of BCP evaluation).

The major evaluation factors proposed by the model are safety, accessibility, carrying capacity, schedule performance, and budget performance. Additional project-specific factors are to be developed by each project's design team based on the particular project conditions. Designed for a generic urban bridge project, the model contains only those parameters that can be reasonably estimated during the design phase.

BCP, as defined by this research, does not include the design of bridge layout or the selection of bridge structural system. Hence, the model is intended for application after the following decisions have been made:

a. a definition of bridge configuration, including capacity, elevations, horizontal alignment, ramps, etc.,
b. bridge layout design,
c. selection of construction material (concrete, steel, composite),
d. selection of bridge structural system, and
e. selection of bridge macro construction technology (segmental, pre-cast, cast-in-place, etc.).

The model is designed in an ordinal format, involving the comparison of several schemes for constructing a single bridge. It is not intended for comparison of different bridge BCPs.

1.6 REPORT ORGANIZATION

Chapter 2 summarizes past research efforts relevant to this study. The details of the research methodology and a discussion of problems of research validity and the solutions generated for overcoming them are presented in Chapter 3. Chapter 4 presents the details of BCP development and its impacts on project performance and on the surrounding neighborhood. The initial data collection effort and the development of the preliminary model are described in Chapter 5.

Results of the first round of interviews, formally soliciting expert opinions about BCP evaluation factors, are presented in Chapter 6. Based on these interviews, a BCP evaluation model was developed. Chapter 7 presents the details of the final evaluation model. Chapter 8 then summarizes the results of the second round of interviews that focused on validating the proposed model. This chapter also presents the results of a model application demonstration case. Chapter 9 presents a proposal for changing the BCP development process and discusses some of the anticipated results of model application. Finally, Chapter 10 presents the research conclusions and recommendations.

2. LITERATURE REVIEW

Reported research relevant to this study can be found in the fields of construction engineering, transportation engineering, and decision-making. Figure 2-1 schematically shows the major research fields and data sources that were used to collect information relevant to this study. The major finding of this survey is categorized into the following sections.

2.1 ROADWAY ACCESSIBILITY AND CARRYING CAPACITY

Previous research investigated the design and management of highway access. Highway access is important for business activities and neighborhood quality of living, and impacts highway carrying capacity.

Koepke (Ref 6) reviewed the current practice in designing access to business areas around freeways. The study also developed a list of general guidelines for legal and institutional bases for controlling access, access permit procedures and traffic impact studies, access categories, and design concepts and strategies.

The research developed the following design criteria for business access: arterial traffic flow, driveway traffic flow, operating speed, capacity criteria, queuing length, vehicle turning path, driver perception-reaction time, median dimensions, lane width, and driveway radii.

Flora and Keitt (Ref 7) presented a summary of access management regulations in the U.S. In addition, they presented several techniques for access management, including limiting the number of conflict points, separating basic conflict areas, limiting deceleration requirements, and prevent vehicle-turning from through lanes.

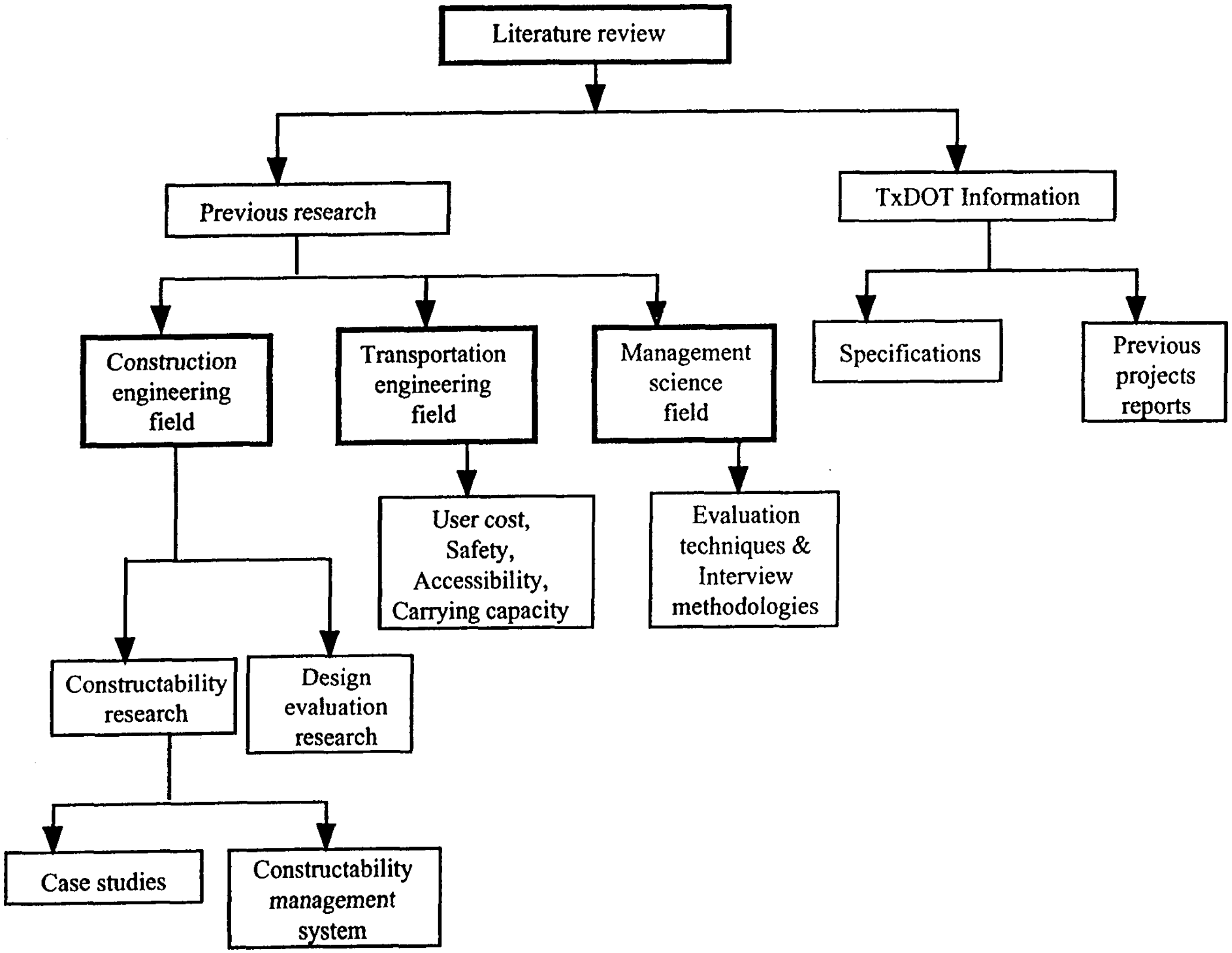

Figure 2-1. Literature Review

Factors defined by the research as influencing the access design process are available ROW, median width, frontage road width, driveway spacing, corner clearance, major intersection spacing, and spacing of median openings. The research also defined the access design effectiveness criteria as vehicle deceleration rate, drivers' perception-reaction time, speed deferential between vehicles, design vehicle dimensions, and vehicle turning path and speed.

In the 1970s, when cost-benefit analysis was the predominant evaluation methodology, Azzeh and others (Ref 8) developed a cost-benefit-based evaluation technique to judge the worth of direct access to commercial properties on two-lane and multi-lane highways. The model includes all direct and indirect construction costs and annual accident and delay benefits. Developed in 1975, the model used the following figures for annual accident benefits: cost of fatal accident ($200,700), cost of injury accident ($7,300), cost of property accident ($300), and average cost per accident ($2,800). Delay time cost was estimated to be $4.5 per hour per car. These numbers give an indication of the significance of costs other than construction in a bridge project.

Johnston and others (Ref 9) compared several techniques for reducing congestion in urban highways. These techniques included, among other things, allocation by passenger load, ramp metering, road and parking pricing, allocation by trip purpose, and mixed strategies. The evaluation criteria included effectiveness at reducing congestion, economic efficiency, income distribution effects, and flexibility of access for urgent trips. The evaluation was conducted on a qualitative basis. The research also reviewed literature regarding user cost estimates, concluding that "the full cost of freeway travel in an urban area is about $0.5-0.6 per vehicle-mile at peak hours." Assuming an average 20-30 mph at peak hours, user cost may be between $10 and $18 per hr per car. The research concluded that "the selection of a technique to optimize capacity on a freeway is not a simple decision. No one method was proven to be superior to others."

In summary, substantial highway user costs can occur due to access impedance or reduction in highway capacity. These costs are increased during construction projects. Nonetheless, there are no standard procedures for measuring the actual user cost.

2.2 SAFETY ON HIGHWAY CONSTRUCTION PROJECTS

Because highway accidents are more frequent within construction zones (Ref 10), much research has been conducted to assess, analyze, and enhance safety within these construction zones. Other studies examined the relationship between highway configurations and safety performance.

Glennon (Ref 11) investigated the effect of alignment on highway safety. This study included the effects of horizontal curves, cross sections, and vertical alignment. The study was designed to assess the impact of road design parameters on road safety. The results can also be used to evaluate construction detours.

Regarding horizontal alignment, the study found that:

a. the average accident rate for highway curves is "about three times the average accident rate for highway tangents,"
b. the average single-vehicle run-off-road accidents (ROR) rate for highway curves is "about four times the average ROR for highway tangent," and
c. the degree of curve, curve length, and shoulder and lane width are the major factors correlated to accident rate. However, the study concluded that all previous research that tried to develop a model to estimate the impact of these factors on the expected accidents rate were not successful. Most of these model results have very low correlation with the actual data measured. Moreover, the study found that these models usually contradict each other. The study concluded that there is no single model to objectively evaluate *a priori* the accident rates based on alignment design data.

Regarding vertical alignment, the study found that:

a. grade sections have higher accident rates than level section,
b. steep sections have higher accident rates than mild grades, and
c. downgrades have higher accident rates than upgrades.

Another noteworthy conclusion of the study is that "because of the high rate of single-vehicle accidents on highway curves, low cost roadside safety improvement on highway curves may be one of the most effective tools. This is particularly true for improvement of low-height fill slopes, and removal of trees to improve clear-zone width on the outside of curve." This gives a clear indication of the possible effects of construction cranes and other equipment on obscuring or reducing sight distance and of the possible effect of construction activities (beam setting for example) on driver attention levels, the diminution of which may cause higher accident rates.

Zeeger and others (Ref 12) investigated the effect of lane width, shoulder width, and shoulder type on highway safety. The study concluded the following:

a. Although more than fifty design features have been found to affect safety by the researchers and by previous research, the validity of the various safety relationships developed by these research efforts "had not been evaluated and noted that some of the relationships were contradictory."
a. Lane and shoulder conditions affect ROR and opposite-direction (OD) accidents.
a. Rates of ROR and OD decrease with the increase of lane width.
a. Rates of ROR and OD decrease with the increase of shoulder width.
a. Lane width has a greater effect on accident rates than shoulder width.
a. Non-stabilized shoulders exhibit larger accident rates than stabilized or paved shoulders.

The study attempted to produce a model to estimate the impact of various factors on the accident rate. However, the model was "not considered to be a precise representation" of the matter.

Mak (Ref 13) investigated the effect of bridge width on highway safety, reporting that "the number of bridge-related fatal accidents per 100 million vehicle miles of travel was significantly higher than average for all road types. The number of bridge-related nonfatal accidents per 100 million miles of travel was also higher than average for Interstate, rural arterial and collectors; but lower for urban arterial and collectors." The study also reported that the fatality rate for bridge-related accidents may be as much as twice the average accident rate.

Ivey and others (Ref 14) studied safety at narrow bridges. The study developed a bridge safety index (BSI) to assess the level of safety of a narrow bridge. The study used the following parameters to evaluate the index:

a. clear bridge width,
b. (bridge lane width) / (approach lane width),
c. guardrail and bridge rail structure,
d. (approach sight distance) / (85% approach speed),
e. (100 + tangent distance to curve) / curvature,
f. grade continuity,
g. shoulder reduction,

h. (volume) / (capacity),
i. traffic mix, and
j. distractions and roadside activities.

In summary, highway layout and alignment directly impact on traveler safety. These impacts have to be considered when planning work activities for any highway construction work.

2.3 BRIDGE CONSTRUCTABILITY STUDIES

The concept of constructablity has gained popularity in the last several years. The studies conducted under this topic can be categorized into two major areas: constructability lessons learned and constructability case studies.

Constructability Lessons Learned

Much research has been focused on developing a methodology for using knowledge gained during site execution in the design phase. Most of this research has focused on documenting technical lessons learned.

One of the studies undertaken in the field of bridge constructability was conducted by Rowings and others (Ref 15), where they examined "the way that information and knowledge could be collected, evaluated, stored, and retrieved for use in the design of bridges."

The research developed two systems: (1) the constructability issue review process, and (2) the bridge constructability knowledge base. The first system was developed as a "means to formalize the process of collecting constructability issues from the field, evaluating the ideas for merit, and determining if the issue warrants an addition to the current constructability data base." The process was designed to collect only technical lessons learned. The second system is a computer data base that includes numerous technical lessons learned that can be retrieved by the designers to enhance their design constructability.

Another knowledge base was created by McCullouch and others (Ref 4). Though this knowledge base is for highway projects, it includes a separate section for bridge constructability lessons learned. This computer package is equipped with several documentation media (hyper text, graphics, photos). However, the study did not develop a system to collect new lessons learned.

Of special concern in the interviews the researchers conducted with field personnel were the following:

a. There is a need for a "system to explain why we do what we do during design with an example plan and checklist for each step."

a. Field personnel need "assistance in the design and evaluation of traffic control planning."

Lee and Clover (Ref 16) developed another knowledge base of lessons learned for highway projects. The knowledge base includes a separate section for bridge lessons learned and allows designers to document and retrieve lessons learned from actual sites. In addition, the research investigated the issue of change orders in highway projects. They suggested a system to investigate change order so as to reduce the review time and to learn from each case.

Kartam (Ref 17) developed a data base system to store and retrieve construction lessons learned. The system's main focus was on concrete, masonry, and site work activities in building construction. The data base is object-oriented, giving the user more flexibility to sort and create new lessons. However, the study did not suggest a system to collect these lessons.

O'Connor and others (Ref 18) approached the issue from the specification point of view, investigating specification-related problems in the field of highway and bridge construction. The study developed a problem structure incorporating the most frequent problems encountered in the field. These problems were then analyzed with respect to classification frequencies and apparent casual factors. It also developed a "specification problem information base," using information from interviews with highway department and contractor personnel. The study concluded that pavement and bridge specifications deserve particular scrutiny, and common apparent casual factors that lead to problems include information, communication, and project scoping.

Bridge Constructability Case Studies

Several researchers have documented case studies about the constructability of various bridge construction projects. A typical case study was presented by Yasuhara (Ref 19), which defined a layout, design standards, and construction method for a bridge in Japan.

The procedures of such studies are tailored to the specific case. The results, hence, provide little guidance for future projects. Nonetheless, they show the significant benefits of constructability studies.

In summary, all bridge constructability studies focused on documenting technical lessons learned from field execution. None attempted to model these lessons into systems that guide decision-making in the design process.

2.4 DESIGN EVALUATION STUDIES

Very few studies exist in the area of evaluating design, but one leading study was conducted by Tucker and others (Ref 20). The major focus of the study was on the evaluation of the design process and its outcomes from a professional point of view (i.e., budget, schedule, quality of drawings, etc.).

The evaluation model used the following parameters to evaluate the design process:

a. accuracy of design documents,
a. usability of the design documents,
a. cost of the design effort,
a. constructability of the design,
a. economy of the design,
a. performance against schedule, and
a. ease of start-up.

The model was designed to be applied after the end of the design phase and used the objective matrix method, which is a modified version of SAW, to evaluate the parameters.

Though focused on the design as a process, the study included constructability as one of the evaluation parameters. However, the model took a contemporary point of view and left its evaluation to the subjective opinion of the evaluator. For example, the model suggested the following parameters to evaluate constructability in a piping project:

> "Subjective rating for the number of unrealistic tolerances in the piping design versus the quality expectations.
> Subjective rating for total number of different crafts required to install the piping.
> Subjective rating for optimum pre-assembly on the piping phase of the project.
> Subjective rating for amount of specialized equipment required to install the piping.
> Subjective rating for compatibility of the piping design with current materials and technology."

Based on interviews with field personnel and on the analysis of the design phase in several construction projects, the study recommended the following:

a. Because of company or project differences, an absolute or all-encompassing list of evaluation factors is not possible. Evaluation models should be flexible and allow for addition/changes to the evaluation factors by the design team.
a. "Weight assignment should be made by the evaluator. Optimal results occur when all design users have input into the weight assignment process, as the analysis of the relative merits of the criteria provides excellent insight into the importance of each criterion to the different design users."

In summary, no previous research has developed a model to evaluate BCP. Furthermore, design and field engineers expressed a need for such a model to assist in selecting the optimum BCP during the design phase.

2.5 DECISION MAKING AND EVALUATION METHODS

BCP evaluation is obviously a case of multi-attribute decision-making. Multiple attribute decision-making (MADM) refers to making preference decisions (evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes (Ref 21).

MADM has become one of the most powerful methodologies in optimization analysis for the following reasons (Ref 22):

a. the possibility of including intangible effects with conventional cost-benefit analysis,
a. the conflicting of modern decision making problems, and
a. the shift from conventional "one-shot" decision-making to institutional decision-making, where several aspects affect the decision.

MADM is a branch of multiple criteria decision-making (MCDM), which also includes multiple objective decision-making (MODM). The difference between MCDM and MODM is that MODM deals with an infinite number of alternatives. Typically, it is used in situations where the designer can generate endless designs that possess, or satisfy, several defined objectives. The objectives can then take any value within a given domain. In other words, MODM deals with a continuum of solutions that need to be compared against a set of objectives (Ref 22).

MADM deals with a discrete decision-making situation. In it, there are a finite number of solutions. The decision-maker (DM) has to select a solution (not design it) that will optimize several desired attributes. Some researchers do not distinguish between the two techniques.

Though the development of a BCP is part of a design process, it cannot be considered a case of MODM because of the simple fact that the DM has only a finite number (not a continuum) of solutions from which to select.

The first step of MADM is to define the goals (objectives) of the decision. These objectives are usually arranged in a hierarchy of objectives and sub-objectives (or what is known as the HOT diagram). The lowest members of these objectives are often called tactics.

Both theory and practice have shown that decision attributes should satisfy the following requirements (Ref 23):

a. Completeness: The set of attributes should characterize all the factors to be considered in the decision-making process.
a. Importance: Each attribute should present a significant criterion in the decision-making process, in the sense that it has the potential for affecting the preference ordering of the alternatives under consideration.
a. Measurability: Each attribute should be capable of being objectively or subjectively quantified.
a. Familiarity: Each attribute should be understandable to the decision maker in the sense that he/she should be able to identify preference for different states.
a. Nonredundancy: No two attributes should measure the same criterion.

The attributes are usually selected by the DM or obtained through interviewing experts in the field (or by both methods).

Then, three major issues need to be decided: (1) how to weight the attributes, (2) how to assess or give the attributes a score, and (3) how to aggregate these scores to select a final alternative. Several techniques are available to handle these issues. The next three sections review the most widely used methods in this regard. Table 2-1 summaries the methods discussed below.

Table 2-1. Summary of Decision-Making Literature Review

Issue	Method
Weighting	• Direct assessment • Weights from ranks • Pairwise comparison • Weights based on statistics • Rating method • Verbal assessment
Scoring	• Direct scoring • Verbal scoring • Objective matrix approach • Semantic difference
Aggregation techniques	• Simple additive weighting • The analytic hierarchy process • Lexicographic method • Maximin method • Maximax method • ELECTRE method

Weighting

Direct assessment

The simplest method of weighting the attributes is to give them a direct weight between 0 and 1.

Weights from ranks

In this method the attributes are arranged in a simple rank order, listing the most important attribute first and the least important last. If *1* is assigned to the most important attribute and n to the least important one, cardinal weights can be obtained from the following formula (Ref 21):

$$W_j = \frac{1/r_j}{\sum_{k}^{n} 1/r_k}$$

where rj is the rank of the jth attribute.

Pairwise comparison (Ratio weights)

This technique (Ref 24) compares two attributes at a time and asks the DM to give a preference ratio between them. All attributes are arranged in a matrix whose rows and columns are the attributes themselves. The elements of the matrix *ajk* represent the weight ratio *Wj/Wk* (how many times attribute *j* is preferred over attribute *k*). The next step is to compute the geometric mean of each row of the matrix and then normalize the resulting numbers (make all weights add up to one by dividing by their sum).

Weights based on statistics

If there are sufficient statistics on the impact of the attribute on previous decisions, these statistics can be used to evaluate the relative weights, but this is rarely the case (Ref 22).

Rating method

In this case the DM is asked to distribute a constant number of points among attributes such that the points given to each attribute reflect its relative importance. The final weight can then be calculated from one of the following formulas (Ref 22):

$$W_j = x_j / max(x_j)$$

$$W_j = x_j - min(x_j) / max(x_j) - min(x_j)$$

where *xj* is the relative importance of attribute *j*; *max(xj)* and *min(xj)* indicate the maximum and minimum value observed to attribute j among all alternatives.

Verbal assessment

Several methodologies have been suggested for assessing weights (and scores) based on the verbal statements of the DM. For example, Nijkamp and others (Ref 22) suggested a five-point scale that can adapt to various decision-making situations. This scale is shown in Table 2-2 and can be used to directly rank attributes or to compare them pair-wise.

Table 2-2. Five-Point Scale

Statement	Relative Weight
Very	1
Slightly	2
Neither or both equal	3
Slightly	4
Very	5

Scoring

Scoring refers to assessing a score (grade) for a plan (alternative) as to its performance (fulfillment) of a single decision attribute (objective) (Ref 25). There are several scoring techniques that are used in the decision-making field.

Direct scoring

Using experience as a guide, the DM is asked to give a score (between 1 and 10 or 100) of the attribute under consideration. This takes place most often when the attribute is too subjective.

Verbal scoring

As in weighting, the DM is asked to give an assessment verbally using a pre-defined scale of statements. One of the most famous scales is the nine-point scale of Saaty (Ref 24) (Table 2-3) and is used to compare the relative importance or superiority of one alternative over another, as regards an attribute.

Table 2-3. Nine-Point Scale

Intensity of Importance	Definition
1	Equal importance of both elements
3	Weak importance of one element over the other
5	Essential or strong importance of one element over the other
7	Demonstrated importance of one element over another
9	Absolute importance of one element over another
2, 4, 6	Intermediate values between two adjacent judgments

The objectives matrix approach

This approach was suggested by Riggs (Ref 26). The technique assesses a score for each attribute as follows (Refs 26, 20):

a. DM establishes a set of performance goals for each attribute. The optimum performance measure is set to have a score of 10 (e.g., a material storage plan with 15% or less material waste is the best and will have a score of 10).

b. In the same way, attribute values representing the minimum performance are inserted in the row corresponding to 0 (e.g., a plan with more then 31% material waste would have a score of 0).
c. Step-wise values for the increments between scores are determined and ratios between scores 0 and 10 are assigned values.
a. At the evaluation, the actual measured value for each criterion is calculated (in our example, the % waste) and placed in the appropriate row. The level that corresponds to this value is the plan's score.

Semantic difference

This simple technique puts two extremes of the scale (bad and good or unfair and fair) on the opposite ends of a line segment. Between these extremes, the line is divided into intervals (usually seven). The DM can visually assess the score at any interval (Ref 27).

Aggregation Techniques

After setting attribute weights and the plan (alternative) score against these attributes, these scores are combined to detect the best alternative.

Simple additive weighting (SAW)

The aggregate utility function is the weighted sum of all the individual attribute scores (Ref 28).

$$U_i = \sum_k w_k * X_k$$

where *Wk* is the relative weight of attribute *k*; *Ui* is the final utility of alternative *i*; and *Xik* is the score of alternative *i* as regard to attribute *k*.

The analytic hierarchy process (AHP)

This technique (Ref 24) involves the decomposition of any complex problem into several hierarchies with the last hierarchy constituting the alternatives (or attributes) to be compared. At each level of the hierarchy the DM assigns relative scores by comparing the elements pairwise. These scores reflect the relative importance of the elements using the nine-points scale. The technique then forms the largest eigenvalue problem and solve to find the unique normalized vector of scores.

Lexicographic method

The first action for the DM is to rank attributes in terms of relative importance. The selection rule is simple: select the alternative that shows the greatest aptitude against the top ranked attribute. If two or more alternatives are equally 'best' on aptitude, distinguish between them according to the second most important attribute (Ref 29).

Maximin

Under this procedure, an evaluation matrix is developed. In it, alternatives are the rows and attributes are the columns. The elements of the matrix are the scores of the alternatives, as regards each attribute. The selection procedure has two steps: determine the poorest attribute value for each alternative, then select that alternative with the best value on the poorest attribute. In mathematical notation an alternative A^* is selected such that (Ref 21):

$$A^* = \{ A_i \mid \max(\min(R_{ij})) \}$$

where Rij is the score of alternative i on the jth attribute.

Maximax

In contrast to maximin, this method first determines the best attribute value for each alternative, then it selects the alternative with the maximum value out of this set of best values. In mathematical notation A^* will be selected such that (Ref 21):

$$A^* = \{ A_i \mid \max(\max(R_{ij})) \}$$

ELECTRE

The method includes several mathematical steps (eight general steps with smaller intermediate steps). More details can be found in several decision-making references (Refs 22, 21).

In summary, several techniques are available for making a decision based on multiple criteria. However, none of them has been proven to be superior to the others. Researchers in the field always recommend the use of the simplest technique applicable to the situation in hand.

2.6 CONCLUSIONS

1. There is a need to develop a model to evaluate a BCP during design because designers lack any objective tool to evaluate a BCP, and no previous research has investigated the issue of BCP evaluation.
2. Research investigating bridge constructability showed that a BCP has a tremendous impact on the surrounding environment. Its optimization is desirable in order to balance the conflicting needs of the project. Hence, a BCP evaluation model will have a positive impact on bridge project performance.

3. RESEARCH METHODOLOGY

The development of a sound research methodology is critical to research validity. The need for such a sound methodology is more obvious in a field with less recorded data and a changing nature like the construction industry. This chapter discusses the potential threats to research validity, and the solutions developed to overcome them. It also provides a log of all research activities.

Two major tasks were conducted to ensure that research design addresses all possible validity concerns:

a. Defining logical fallacies that threaten research value and validity. The investigation of these threats resulted in identifying a list of major criteria that should be fulfilled by the selected methodology.
b. Selection of an appropriate research path (procedures). This task focused on selecting a research approach that has been tested and proven to be effective in meeting the previously defined criteria.

3.1 VALIDITY CONCERNS

Validity refers to "the best available approximation to the truth or falsity of a proposition (Ref 30)." There is no single definition of the ingredients or subsets of the concept of validity. In fact, "the discussion of validity in the literature is littered with controversy (Ref 31)." Nonetheless, Cook and Campbell presented a widely approved classification of the term (Refs 31, 32) and divided validity into four major types:

a. Statistical validity. This type refers to whether or not there is a relation (covariation) between two variables of an experiment or research. It requires proving such relation through sound statistical methods.
b. Internal validity. This type addresses whether an observed covariation between two variables is causal or not. In other words, is one variable causing the other, or are both variables caused by a third—or a multitude of—variable(s)?
c. Construct validity. This type considers whether or not the operational variables used to observe co-variation can be interpreted in terms of a theoretical construct (parameters). In other words, can the observed relation be transferred into a theory using more primitive or common parameters?

d. External validity. This type deals with the reliability of a proposition or theory. It examines whether or not an observed causal relationship should be generalized to and across different measures, persons, settings, and times. In addition, it deals with the applicability of the proposition (Ref 33).

Analysis of Validity Concerns

The objective of this study is not to develop a universal theory for evaluating a BCP—if such a theory exists or ever will exist. Rather, it aims at developing a general, yet simple, model for evaluating a BCP. With this objective in mind, the previous concerns about validity were analyzed as follows:

a. Statistical validity concerns. Since this study is the first of its kind, a considerable amount of data was needed to cover the lack of relevant data in the literature. The study, however, could not embark on a wide-scale survey of construction projects to collect such data. Therefore, the researcher decided to closely and frequently monitor the actual construction of some large urban bridges to collect required data. In addition, several experts in the field were interviewed to acquire additional data.
b. Internal validity concerns. Two techniques were identified to overcome concerns over the internal validity of the final model:
   i. The use of different data collection tools: Variety in data collection tools guarantees that the model covers the whole data domain. Furthermore, the results of one tool can correct/strengthen the outcome of another. In this way, irrelevant and project-specific evaluation factors can be spotted and eliminated.
   ii. Thorough analysis of evaluation factors: Stepwise analysis of data collected was conducted after each research step. Such analysis was the key to eliminating redundant parameters.
c. Construct validity concerns. Generic and familiar BCP ingredients were used, as much as possible, as evaluation parameters. Experts opinion was also solicited in this regard.
d. External validity concerns. The reliability and applicability of the model are very crucial. To assure these two concerns were accounted for, only general and objective evaluation factors were considered in the model. The opinion of field and design engineers (potential users of the model) regarding the contents of the model, availability of data, and ease of measuring the proposed factors was extensively solicited.

By the end of the aforementioned analysis, several solutions were developed to overcome any validity problems. Table 3-1 summarizes the possible validity concerns and the solutions developed to address them.

Table 3-1. Validity Concerns and Solutions

Concern	Solution
Statistical validity	• Observe site closely • Interview highly professional experts • Use interlocking data tools
Internal validity	• Use interlocking data tools • Analyze factors (redundancy, irrelevancy)
Construct validity	• Use generic and familiar evaluation factors
External validity	• Involve site personnel in model development • Emphasize ease of measurement, generality and objectivity

Four major techniques/attributes were identified as key to a sound research methodology. These criteria guided the selection of the general research path and were carefully observed throughout the model development and are as follows:

a. The use of interlocking data collection tools. This addresses concerns about the statistical and internal validity of the model. In the end, three major data collection tools were used: analysis of project documents, site observation, and interviews of domain experts.
b. Keen selection of data sources. Only those sources that could provide meaningful and general data were pursued. When observing construction sites, only those large sites that truly presented a challenge in their construction were visited. When interviewing experts, only those experts who were highly experienced in the field were selected (see Appendices B and D for the ranks and field of expertise of those interviewees). Such thorough data sources were vital for assuring both statistical and external validity.
c. Critical data analysis. A detailed data analysis was conducted after each major step of model development. The analysis assured the elimination of redundant and irrelevant data that could threaten statistical and internal validity. In addition, the analysis guaranteed that only general, objective, and easy to measure parameters were included in the model to ensure external validity.

d. Involvement of site and design personnel. In the interest of model reliability and applicability, site and design personnel were highly involved in the data collection and data analysis.

3.2 SELECTION OF RESEARCH PATH

The research approaches contained in the literature were reviewed so as to select a research path that could facilitate the implementation of the previously identified solutions. Generally, research paths (procedures) can be categorized as follows (Ref 34):

a. Experimental path: building a design and implementing it by using it on a set of substantive events.
b. Theoretical path: building a set of hypotheses and testing them by evaluating them with an appropriate set of methods.
c. Empirical path: building a set of observations and explaining them by constructing them in terms of a set of meaningful concepts.

The theoretical path is, obviously, the most suitable method for this research effort. This path usually includes four major steps: hypothesis formation, data collection, data modeling, and validation.

This path has been used extensively by several researchers in the field of construction management, especially those associated with the Construction Industry Institute (CII) of The University of Texas at Austin. Tucker (Ref 20) used it for developing a model to evaluate the design phase (see Chapter 3). O'Connor (Ref 3) used the same path, with some modification, to collect constructability ideas for industrial projects. Hinze (Ref 35), Tatum (Ref 36), and Gibson (Ref 37) also used this path for similar research projects.

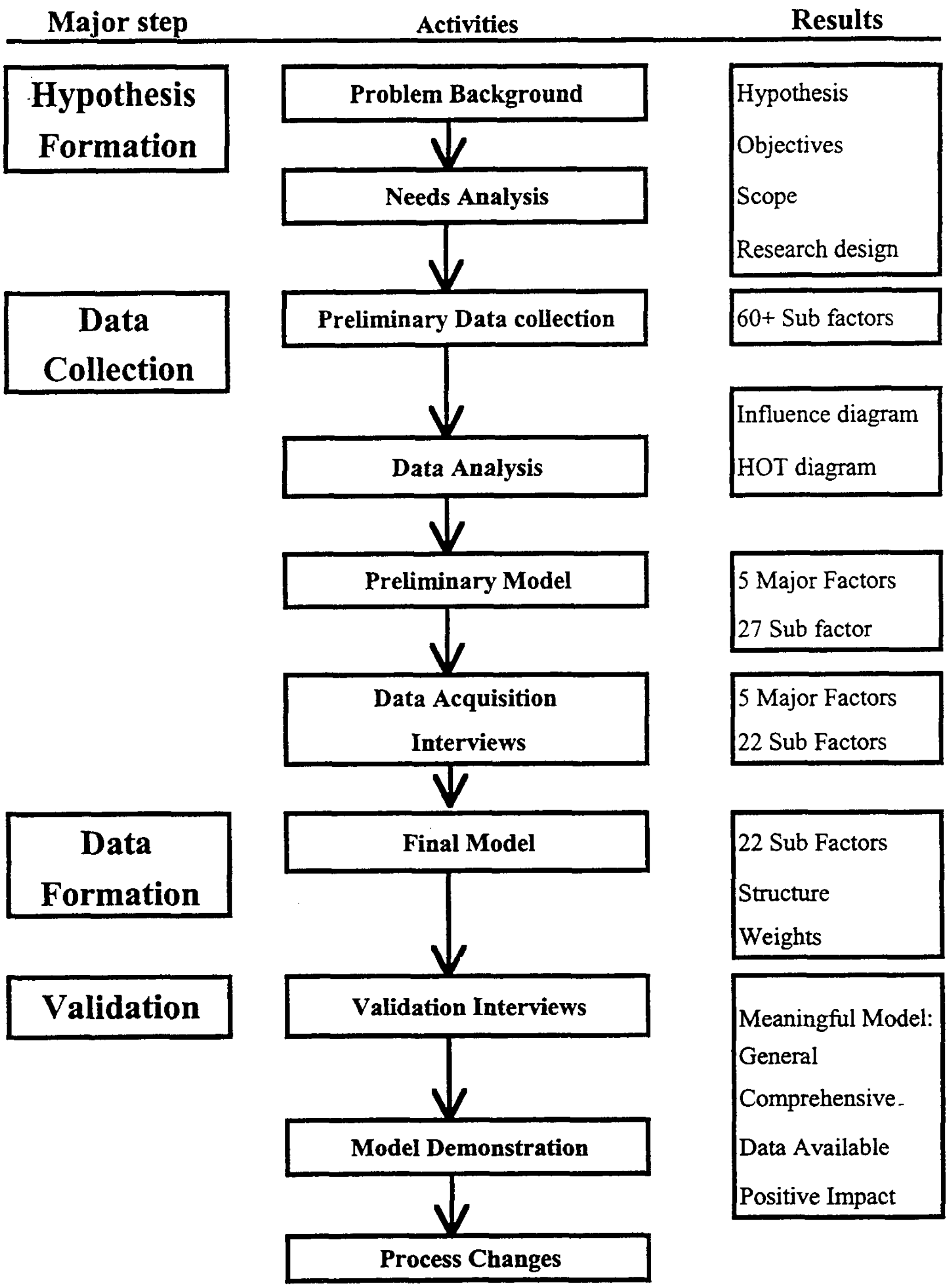

Figure 3-1. Research Methodology

The details of the research methodology are shown in Figure 3-1 and are described in the following sections.

3.3 PROBLEM BACKGROUND AND FORMATION

This stage of the research focused on developing a general understanding of the current situation both at the design and construction phases of the bridge:

a. Design phase: understanding the organizational structure of the Texas Department of Transportation (TxDOT) and the current bridge development process.
b. Construction phase: understanding current bridge construction techniques and procedures, recognizing problem areas in the construction field, and identifying the best construction practice based on field and design expertise.

Information about these issues was collected through a literature review and site visits. In reviewing previous research related to the study subject, it was found that none had developed an evaluation methodology for a BCP. However, several studies aided in developing some evaluation parameters.

Several site visits to bridge construction projects were conducted to observe current bridge construction practices. During these visits, informal interviews were conducted with field personnel to solicit their opinion about BCP impact and evaluation. Sites visited included the U.S. Highway 183 bridge projects and the Ben White bridge project in Austin, Texas, and the Mockingbird bridge project in Dallas, Texas. Results of this stage were acknowledgment of a need for a model to evaluate BCP effectiveness during the design phase, and determination of exact research hypothesis and objectives.

3.4 NEEDS ANALYSIS

This stage of the research focused on identifying research needs and included two major tasks: (1) identification of needs for data, and (2) the development of data collection tools.

Identification of Needs for Data

Based on the initial information gathered in the previous stage, it was determined that to accomplish research objectives, data would be collected regarding the BCP impact on the project and the surrounding community, including user cost, highway construction zone safety, business impacts, and community and environmental impacts.

Project and site factors influencing BCP development were considered, which represent the input variables that limit the effectiveness of a BCP. Techniques and methodologies to enhance the BCP performance, which represent the solution to the restrictions implied by the input variables, were also considered. Such techniques are the key to defining and achieving an effective BCP. And finally, evaluation parameters that can be used to assess the effectiveness of a BCP were investigated.

Development of Data Collection Tools

The data needed for model development, as defined in the previous step, span a relatively wide spectrum. The breadth of the data requires the development of sound data collection tools. A list of barriers to data thoroughness and some barrier breakers are defined in Table 3-2.

Three major data collection tools were developed, including analysis of project documents, field observation, and interviews with domain experts. Combining three different tools helped minimize concerns for the statistical and internal validity of the final model.

3.5 PRELIMINARY DATA COLLECTION

Before formally interviewing experts, an initial list of evaluation factors had to be developed as the basis for the interviews. Given that no other research has developed a similar model, relevant data had to be collected from actual sites, field staff, and from previous project documents. Sources of the initial data are explained in the following sections.

Table 3-2. Barriers to Effective Data Collection

Barrier	Barrier Breakers
Projects span over a long period of time	• Study past projects documents • Interview design staff • Observe bridge projects that are at different stages of completion
Less data are recorded about current and previous projects	• Observe site construction • Solicit information from field staff
Different parties are included in the evaluation, Most of them have different interests	• Interview all concerned parties • Observe site directly
Different sites have different needs	• Interview people who have vast expertise (especially managers) • Visit large/challenging projects • Look only for general evaluation factors
Construction personnel usually do not keep good data records of past experience	• Prepare a thorough interview guide • Interview people who are currently in charge of bridge projects

North Central Expressway Reconstruction Project

The North Central Expressway (NCE) reconstruction project is a $550 million project underway in Dallas, Texas. It includes the reconstruction of a 10-mile stretch of the highway (with 23 overpasses). Appendix A provides more data about the project and the constructability study that was conducted for it. Within this project, data were collected through the following techniques:

a. Field observation. Over 20 visits were conducted over two years to monitor current bridge construction technology, site problems, the impact of design options on construction effectiveness, factors influencing BCP, and enhancement opportunities.

b. Actual involvement in the project (CTR research project). TxDOT asked the Center for Transportation Research (CTR) of The University of Texas at Austin (UT) to conduct a research project to enhance the constructability of several bridges in the NCE project. This project included a review of the original plans and development of new, more constructable plans. The procedures and results of the UT research project presented a unique opportunity for collecting data. The researcher was able to collect a substantial amount of information about construction problems and opportunities for solutions. The UT research project also provided valuable insights into TxDOT's work culture. Such information was valuable for model development and the suggested changes in the process.

c. Actual reports of the NCE project. Reviews of the actual reports of the NCE project were periodically conducted and their contents discussed with key members of the project. These reports included the following: accident reports, change order reports, accessibility and business complaint reports, and other community and environmental reports.

Informal Interviews

Several of these interviews were held during visits to the NCE site. The purpose of these interviews was to obtain the input of different personnel at different managerial levels regarding the following issues:

a. current structure of the design process,
b. impact of design options on the construction effectiveness,
c. current evaluation methodology,
d. required level of details in the model, and
a. major evaluation factors that should be included in the model.

Analysis of Project Documents

In addition to the NCE reports, the documents of some of the major bridges completed in the last five years by TxDOT were reviewed to determine problem areas and the techniques developed to solve them. Such analysis allowed the generation of broad categories of evaluation factors that were used in the final model. The documents included historical records about previous construction plans, change order reports, final project reports, design/construction standards, and design process procedures.

3.6 PRELIMINARY DATA ANALYSIS

The data collected in the previous stage was analyzed and then presented in the following format:

a. BCP impact chart. This chart included the major entities affected by the BCP. It also presents an objective chart for the BCP. An effective BCP will optimize the impact on all items included in this chart (see Chapter 4 for more details regarding these charts).

b. BCP influence diagram. This diagram defines the input variables that impact the effectiveness of BCP. These variables limit designers' ability to develop an optimum the BCP. An effective BCP would create means to balance the conflicting demands of these input variables.

c. BCP hierarchy of objectives (HOT) diagram. This diagram, formulated based on the application of the hierarchy of objectives technique, defines the BCP hierarchy of objectives and the means to achieve them. Such a diagram is the basis for developing a set of parameters that characterize an effective plan.

Based on these diagrams, a comprehensive list of parameters to evaluate a BCP was developed. As expected, they did not present a final set of evaluation factors and needed more refinement to meet the model objectives. As a result, a set of analysis criteria was developed to judge these parameters. The initial parameter list was then tested against these analysis criteria, eliminating several redundant and excessively subjective parameters (see Chapter 5 for more details).

3.7 PRELIMINARY EVALUATION MODEL

This stage focused on developing a preliminary model to evaluate BCP effectiveness. This model was meant to incorporate all relevant and objective evaluation parameters developed in the previous steps into one structured evaluation format. Irrelevant, subjective, or redundant parameters were excluded from the parameter list generated in the previous stage and the remaining parameters were then categorized into evaluation factors and sub-factors. This model was the basis of the formal data acquisition interviews conducted with key experts in the field.

3.8 DATA ACQUISITION INTERVIEWS

Specific and detailed data from domain experts regarding relevant evaluation parameters were acquired during this stage. Twelve high level executives in owner, contractor, and consulting organizations were interviewed in this stage.

Interview Objectives

The interviews solicited expert opinions regarding factors and sub-factors that can be used for evaluating a BCP, relative significance of the factors and sub-factors, and ease of measuring factors and sub-factors in the design phases.

Interviewee Sampling

Two major sampling techniques, random and non-random, are widely known and used in expert polls (Ref 31). Random sampling selects interviewees from a target (study) group randomly. By contrast, non-random sampling selects interviewees based on a pre-defined set of criteria.

After analyzing the merits of each technique, Calder and others (Ref 32) found that "random sampling is not only unnecessary in theoretical research, but it may actually interfere with achieving a sever theory test." According to their definition, this research falls under the category of theoretical research. Therefore, the non-random sampling technique was adopted for selecting the interviewees.

Based on the nature of the research effort and the target population of experts, Black (Ref 31) defined the following four different techniques for non-random sampling: (1) purposive, (2) quota, (3) convenience or volunteer, and (4) snowball sampling. Among these techniques, purposive and snowball were most suited for the nature of this research.

In purposive sampling, a set of highly qualified experts is selected for interviewing. This technique was used because it "guarantees that the sample presents a realistic cross-section of the population (Ref 31)." Initially, eight interviewees were selected based on this technique. However, several interviewees suggested including more experts who were experienced in the field and met the selection criteria. Four additional experts were interviewed based on these suggestions (which is a typical case of snowball sampling). In the end, a total of twelve experts were interviewed—150% of the original target.

Field and design personnel were the major interview targets because they face and solve the problems of a BCP in every project they conduct, and have acquired a vast amount of knowledge that is not available through any other source. As well, all of them have a legal and moral responsibility to deliver the optimum BCP to the public.

However, the most important reason for targeting this group of experts is the concern for the applicability (external validity) of the proposed model. The less the model reflects the concerns and needs of design and field personnel, the less chances it has for application.

Experts from owner (in this case, TxDOT), contractor, and consulting organizations were targeted for interviews. However, more emphasis was devoted to the owner organization because:

a. TxDOT personnel (especially managers) are responsible to the public (legally and morally) for delivering optimum BCP,
b. TxDOT managers are the final decision-makers,
c. while contracting and consulting personnel work in general civil engineering works, TxDOT has a separate branch devoted to bridge operations,
d. TxDOT traditionally has staff who work across the design, construction and management disciplines of bridge development.

The criteria used for selecting the interviewees were that they should have at least fifteen years field/design experience and strong involvement in previous urban bridge construction projects, and be currently involved in/supervising a bridge project.

Out of the twelve interviewees, eight were TxDOT personnel, two were from contracting firms, and two were from consulting firms (Table 3-3). Among the twelve interviewees, five were top managers in TxDOT or their respective organization, four were senior design engineers, and three were senior construction engineers (Table 3-4). The combined experience of all interviewees total 308 years. Of this total, 137 years are in design, 67 years construction, and 104 years management (Table 3-5). Appendix B lists the names and ranks of all interviewees.

Table 3-3. Interviewees' Organizations

Organization	Number	%
TXDOT	8	66%
Contractors	2	17%
Consultants	2	17%

Table 3-4. Interviewees' Discipline

Discipline	Number	%
Designers	4	33%
Construction Engineers	3	25%
Managers	5	42%
Total	12	100%

Table 3-5. Interviewee Years of Experience

Interviewee	Years of experience			
	Design	Construction	Management	Total
1	4	6	3	13
2	10	7	7	24
3	10	0	3	13
4	0	10	10	20
5	20	9	11	40
6	18	0	10	28
7	31	0	12	43
8	8	3	14	25
9	15	0	10	25
10	15	4	10	29
11	0	19	10	29
12	6	9	4	19
Total	137	67	104	308

Interview Format and Process

Several interviewing formats are described in the literature (Ref 38) and are categorized into two major types, structured and non-structured. In the structured type, the interviewers use a schedule to which they must strictly adhere for all respondents. The same questions in the same order would be administered to all interviewees. In the second type, interviewers are free to ask questions in whatever way they think appropriate, and in whatever order is felt to be most effective.

> "Between the two extremes of standardized and non-standardized interviews is the large category of semi-structured interviews. As their name suggests they combine, or attempt to do so, the advantages of both of the two polar

types. The interviewer is normally required to ask specific questions but is free to probe beyond them if necessary. The relative weight of standardized and non-standardized sub-factors can vary from research to research" (Ref 38).

The purpose of data acquisition interviews is twofold: to solicit experts' input about any additional factors, and to specifically assess the significance and ease of measuring all factors. The first purpose is best served by non-structured interviews, while the second is best served by structured interviews. Therefore, the semi-structured approach was best suited for research needs.

The first part of the interview was designed in the form of a structured list of questions about the significance and ease of measuring the proposed evaluation factors. The second part was an open-ended session designed to let the interviewees speak for themselves. They were encouraged to add any additional factors that were not already included in the previous list. The full form of the interview is presented in Appendix B.

In assessing the significance and ease of measuring factors, the research used a scale from 0 to 6, with 6 being the most significant and easiest in both cases. Table 3-6 shows the scale used.

Table 3-6. Data Acquisition Interviews Scoring Scale

	0	2	4	6
Significance	No	low	considerable	major
Ease of estimate	Very hard	hard	easy	very easy

Note: Use numbers, 1, 3, 5 as intermediate scores between these options.

Though on-site interviews are difficult to arrange and can be time consuming (Ref 35), it was felt to be the best way for ensuring that the interviewee understood the exact scope and needs of the interview. All interviews were set up in a field office of the respective organization involved. The private rooms allowed free one-on-one conversation with each of the participants.

Interviews averaged 40 to 60 minutes each, depending on the interviewee's available time and enthusiasm. At the start of each interview, the researcher introduced himself, the research organization, and the interview purpose and expected length. This introduction was followed with an outline of the specific scope of the research, emphasizing that the research (1) seeks to determine factors to "evaluate," not "enhance," a BCP, (2) looks only at urban bridges, and (3) evaluates only BCP, not bridge layout or structural system. This was followed with a brief summary of the interview contents and steps. Interviewees were asked to fill out the first section of the interview form relating to significance and ease of measurement, and add any additional sub-factors to the list.

Whenever an interviewee suggested a new factor or sub-factor, he was asked to describe its causes and impacts and to provide a formal definition and title for it. Because the majority of these new sub-factors were not discriminatory (most were a function of site conditions or contract provisions) they could not be used to evaluate a BCP. However, the interviewer did not question their inclusion until the end of the interview. At that point, the researcher discussed the applicability and discriminating nature of the suggested factor with the interviewees. They agreed that most suggested sub-factors are "important but not discriminating" because they are either a site or contract mandate, or can be installed in all plans.

In completing the first section of the interview (significance and ease of measurement), some interviewees preferred to fill both at the same time for each sub-factor, while others preferred to complete one at a time. The researcher did not interfere in their selection. The interview time was roughly divided between completing these two columns and suggesting and developing new factors.

The coding of the first section was done by the interviewees themselves. For the second section, the interviewee wrote his own titles and factor definitions after discussion of a new sub-factor. The interviewer took notes of their comments and suggestions in both sections of the interview.

The interviewees were focused and consistent and their input was generally based on long-term experience. This professional conduct may be due to the fact that all of them were at a high level in their organization.

The interviewees also expressed interest in formalizing the process of BCP development. They expressed concerns about the need to build similar tools to capture knowledge in this format and to transfer it throughout the organization. Finally, they showed great appreciation and sensitivity to public and highway users' safety and satisfaction.

3.9 FINAL EVALUATION MODEL

The data acquisition interviewees showed high interest in the model. After analyzing the results of the interviews, a detailed version of the model was developed. This version included the following components:

a. a list of major evaluation factors,
b. a list of all sub evaluation factors,
c. the model's general structure,
d. evaluation procedures for each sub-factor, and
e. suggested factor/sub-factor weights.

3.10 MODEL VALIDATION

This stage sought to validate the proposed model and test its applicability. With the design process of urban bridge projects usually extending to more than two years, it was not feasible to validate the proposed evaluation procedures through actual projects. Therefore, interviews were conducted with another set of domain experts to validate the proposed evaluation procedures and parameters. In addition, the model was applied to a real bridge construction case to demonstrate its application.

Interview Objectives

These interviews were conducted for the following purposes:

a. testing the applicability of the proposed factors to a generic bridge project,
b. testing the availability of evaluation data during the design phase,
c. validating the relative significance of the proposed evaluation factors,
d. assessing the comprehensiveness of the proposed factors in covering the major concerns of an average bridge project, and
e. projecting the impact of utilizing the model on BCP effectiveness.

The Interviewees

As in the data acquisition interviews, purposive sampling technique was used to select the interviewees. This technique assures that interviewees have sound BCP design experience and are currently involved in the process of BCP evaluation or supervision

Eleven interviews were conducted during this phase, six with design engineers and five with managers. Five of the interviewees were TxDOT personnel, two were with FHWA, and four were with consulting companies. Tables 3-7 through 3-9 show the interviewees' organizations, fields of expertise, and years of experience. Appendix D gives a complete list of their names and occupations.

As seen in Table 3-7, this round of interviews included experts from the FHWA; however, they were only included in the second round to ensure that the second group of interviewees was as varied as possible from the first group. Furthermore, FHWA and consulting engineers constituted the majority of interviewees in the second round to ensure that the model was not colored by the engineering trends of one organization (in this case, TxDOT).

In addition, when selecting experts from TxDOT and consulting firms, 55% of all interviewees from these two organizations were from the Houston area; an area not included in the first round to ensure that the second group was, as much as possible, distinct from the first group.

Table 3-7. Interviewee Organization

Organization	Number	%
TxDOT	5	45%
FHWA	2	18%
Consultants	4	37%

Table 3-8. Interviewee Discipline

Discipline	Number	%
Designers	6	55%
Managers	5	45%
Total	11	100%

Table 3-9. Interviewees' Experience

Interviewee	Years of Experience			
	Design	Construction	Management	Total
1	7	5	5	17
2	4	7	3	14
3	20	1	9	30
4	12	0	0	12
5	10	3	10	23
6	8	0	4	12
7	16	13	9	38
8	10	3	11	24
9	11	2	1	14
10	3	3	0	6
11	14	10	8	32
Total	115	47	60	222

Interview Design

Because of its specific scope, this interview was designed in a strictly structured format and consisted of the following five questions:

1. Assess the relative significance (importance) of the proposed parameters for the success of a BCP.
2. Can each of these parameters be applicable to any bridge? More specifically, can they be meaningful to a generic bridge project?
3. Is the data required for evaluating these parameters available or can they be estimated during the design phase?
4. How well did the proposed factors cover the major concerns regarding BCP effectiveness?
5. Based on your experience, would the consideration of these factors be of benefit to BCP effectiveness?

During the first round of interviews, the researcher noted that the first question always induced experts to think about the sub-factor's relevance and meaning. Therefore, this question was included in the second round to guide experts into the research domain quickly. As in the first round, the second group of experts asked several questions about the definition of the sub-factors and their scope while they were assessing the significance of each parameter.

Significantly, including a common question in both interview rounds allowed comparison of the opinions of the two groups of experts and provided interesting results (see section 8.3.1).

In addition, the significance score was intended to be the basis for recommending the sub-factors' relative weights in the objective matrix. Including the same question in the second group expanded the pool of experts participating in such an assessment.

The other four questions were directly related to the interview objectives and were asked of all interviewees in the same sequence. Additionally, a description of each question was read to all interviewees.

The interviews were held at the relevant organization's office, with each interview averaging interview around 30 minutes in length. The interviewees did the coding themselves. For questions 1, 4, and 5, the interviewees were asked to report their answers on a scale of 1 to 6. Table 3-10 shows the corresponding meaning of each score. Please note that questions 2 and 3 required "Yes-No" type answers. The exact format of the interview is presented in Appendix D.

Table 3-10. Scoring Scales

A: Significance

Score	0	2	4	6
Significance	No	low	considerable	major

B: Generality & data availability
YES OR NO.

C: Comprehensiveness

Score	0	2	4	6
Comprehensiveness	Not at all	Minimal	Good	Very good

D: Impact

Score	0	2	4	6
Impact	No	Low	Considerable	Major

Note: Use odd numbers as intermediate scores

Model Application Demonstration

Next, the application of the model was demonstrated by evaluating two different BCP's for the Mockingbird Bridge in Dallas, Texas. The demonstration included a detailed evaluation of the factors/sub-factors, a selection of the optimum BCP, and an assessment of the required time to perform the evaluation.

3.11 SUGGESTED CHANGES FOR THE DESIGN PROCESS

General procedures for developing a new bridge were documented and studied. Based on the new model and on comments from several interviewees, a set of suggested modifications to the current process was developed to put the model into action. Figure 3-2 shows the steps taken and includes the following:

a. definition of change guidelines,
b. development of the new process general structure,
c. definition of new activities, and
d. definition of new/modified roles and responsibilities.

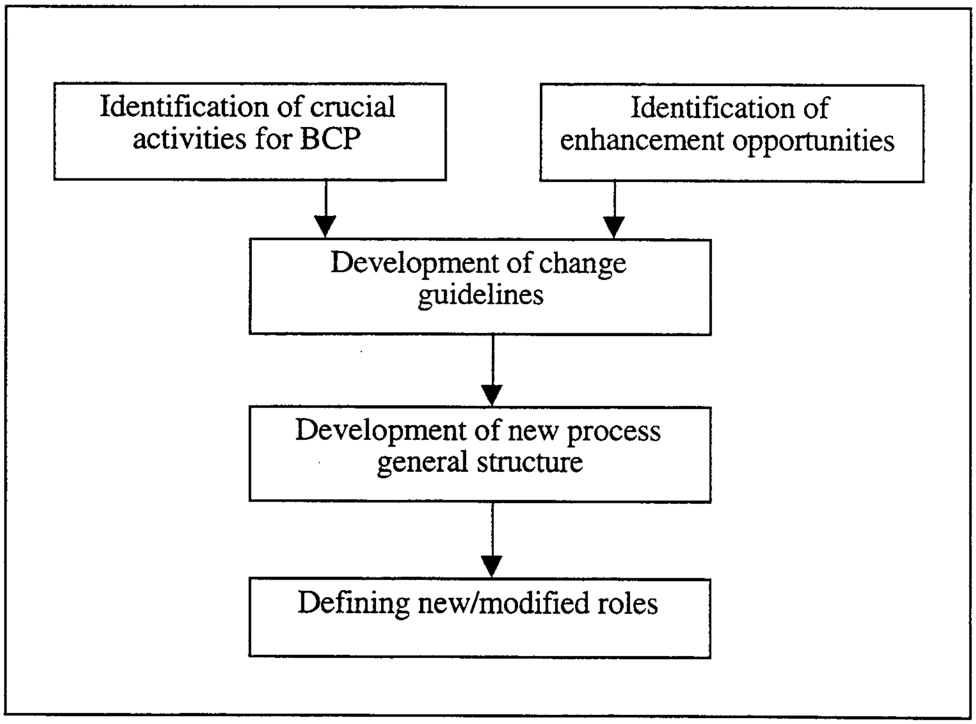

Figure 3-2. Research Methodology—Changes to the Design Process

4. BRIDGE CONSTRUCTION PLANNING

The development of a BCP is a complex process, controlled by a multitude of input variables. In addition, several project concerns have to be balanced. A BCP that overcomes the limitations imposed by the input variables and balances project objectives is considered optimum.

Four major steps required to evaluate the optimality of BCP are:

a. identify factors influencing BCP effectiveness (input variables),
b. define a complete set of objectives for the BCP,
c. develop a set of sub-objectives for each of the major objectives, and
d. develop a set of evaluation parameters to test the satisfaction of all objectives

This chapter presents general background about the BCP development process. It describes the major challenges facing BCP development and presents a summary of the major factors influencing BCP effectiveness. A collection of HOT diagrams for enhancing BCP effectiveness are also presented. Finally, the chapter establishes the need for developing a model to evaluate BCP effectiveness during the design phase.

4.1 BRIDGE PROJECT SPECIAL CHALLENGES

Bridge projects face special challenges due to the nature of their site. Among the most important challenges are:

a. limited work space due to limited right of way (ROW),
b. high level of interaction between traffic and construction activities,
c. many entities sharing the decision authority (FHWA, TxDOT, city representatives, local community representatives),
d. bridge construction technology issues (selection, sophistication, site problems, etc.), and
e. the usually compressed schedule.

4.2 PROJECT IMPACT ON SURROUNDING ENVIRONMENT

Unlike other projects, urban infrastructure projects have tremendous impact on the surrounding community. In the case of urban bridges, these impacts affect businesses, residents, the environment, construction zone accident rates, and traffic flow (Fig 4-1):

Businesses around the project are directly affected by construction activities. Commercial businesses are affected much more than non-commercial ones. BCP impacts on business activity are mainly attributed to the reduction of highway traffic volume and to customer access impedance.

A project can have a negative impact on the quality of life of the surrounding neighborhood. This includes increased noise level; impeding access to homes, recreational areas and parks; the effects on historical areas (if any); and reduction in area aesthetics.

The intense level of interaction between traffic and construction usually results in a higher accident rate (Ref 10). The effectiveness of construction sequencing and detour quality and location are directly related to the safety of both travelers and construction crews (Ref 11). Road users often face excessive delays in construction zones during lane drops or diversions, impeded access to desires destinations due to street or exit ramp closures, and limited sight distance due to construction equipment or traffic detouring. On a wider scale, construction around major thoroughfares often causes increases in traffic volumes on other highways and in user costs due to traffic delays, and causes delays to emergency trips (ambulance, police, fire-fighting).

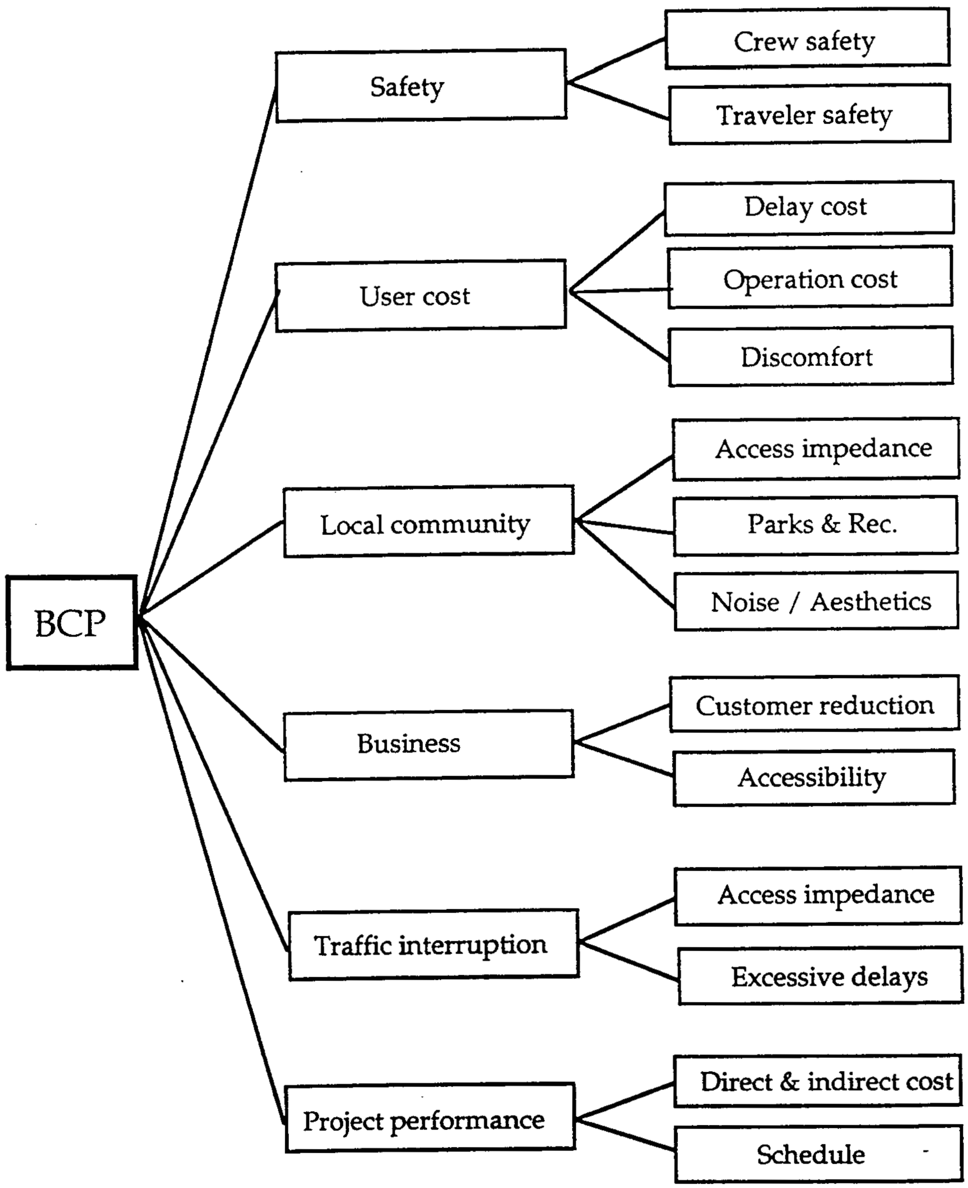

Figure 4-1. BCP Impact

4.3 CURRENT BRIDGE DEVELOPMENT PROCESS

The bridge development process consists of four major phases: planning, design, procurement, and construction. A brief summary of the components of each phase follows.

Planning Phase

As shown in Figure 4.2, the planning phase involves traffic evaluation and projection, environmental impact assessment, project affordability/feasibility study, and project scope development. Project scope development involves planning for bridge capacity, design criteria, and project objectives including schedule and budget.

Design Phase

This phase includes the development of the following (see Figure 4-3):

a. Bridge layout: number of lanes, lane width, lane assignment, horizontal and vertical curves, ramps, and clearances.
b. Bridge structural design: super structure system selection, sub-structure system selection, bridge design (building materials, span type and length, elevations, design specifications, foundation design), drainage design, signing, signals, and illumination.
c. Bridge construction plan: safety standards, construction sequence, and traffic control plan.
d. Project budget.

Procurement Phase

The procurement phase involves definition of material specifications, vendor/sub-contractor selection, and development of delivery schedules.

Construction Phase

The construction phase involves site preparation (right-of-way acquisition, general site work, detour construction), demolition of any existing structures, sub-structure and super structure construction, and traffic handling.

4.4 CURRENT BRIDGE DESIGN PROCESS

The bridge design division, with the help of the area engineer, is responsible for the development of bridge designs.

The final outputs of the process are bridge layout, bridge structural design, and bridge construction sequence.

The current design approach can be summarized as follows:

a. development of several alternatives for the bridge layout,
b. selection of the most appropriate layout,
c. development of several suggestions for the structural system,
d. selection of the optimum structural system,
e. consultation with the other departments to design the foundations and the pavement,
f. development of the complete bridge structural designs, and
g. development of the construction sequence.

The bridge design process is detailed below (Ref 5), with Figure 4-4 illustrating a schematic of the major steps of the process.

Conceptual Stage

Consultation between the bridge design section, bridge planning engineer, and district design engineer and/or resident engineer usually precedes determination of structure types and timing of the work. Bridge layouts are prepared by the resident engineer. These layouts are usually complete with geometric controls, type, size, and length of spans, hydraulic data, required clearance, and soil test boring data. The layouts are sent to the bridge planning engineer. The required number of prints are then forwarded to the highway design division and often to the Federal Highway Administration or other agencies that may exercise review authority.

Initial Design Stage

After securing all necessary approvals, timing for the plan work is negotiated with the district and the job is given to the bridge design engineer. The geotechnical group should be consulted early to verify the type of foundation. When foundation loads have been determined, the geotechnical group will be asked to establish founding elevations.

Detailed Design Stage

Monthly progress meetings are held with all design groups and the bridge design engineer. A progress report is given to all bridge planning engineers and the bridge engineer.

Delivery Stage

When plans are complete, prints are sent to the district for review. Following this review, prints are returned to the design group for any requested revisions. Originals, including all reproducible standards, are sent to the district. Project plans, specifications and estimates are sent to Austin. Revisions of structural details required by the pre-letting review are made by the design group.

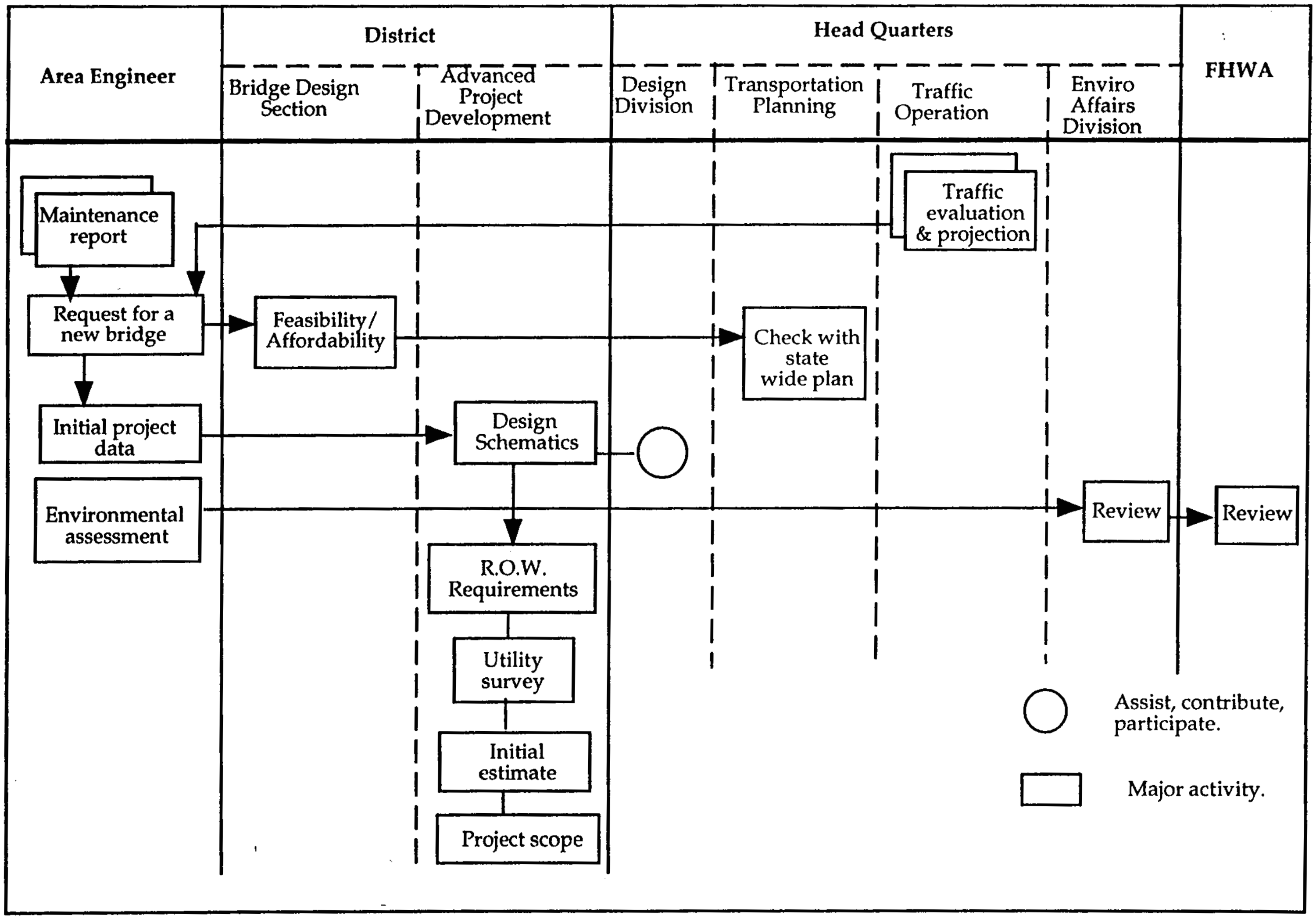

Figure 4-2. General Steps of the Planning Phase

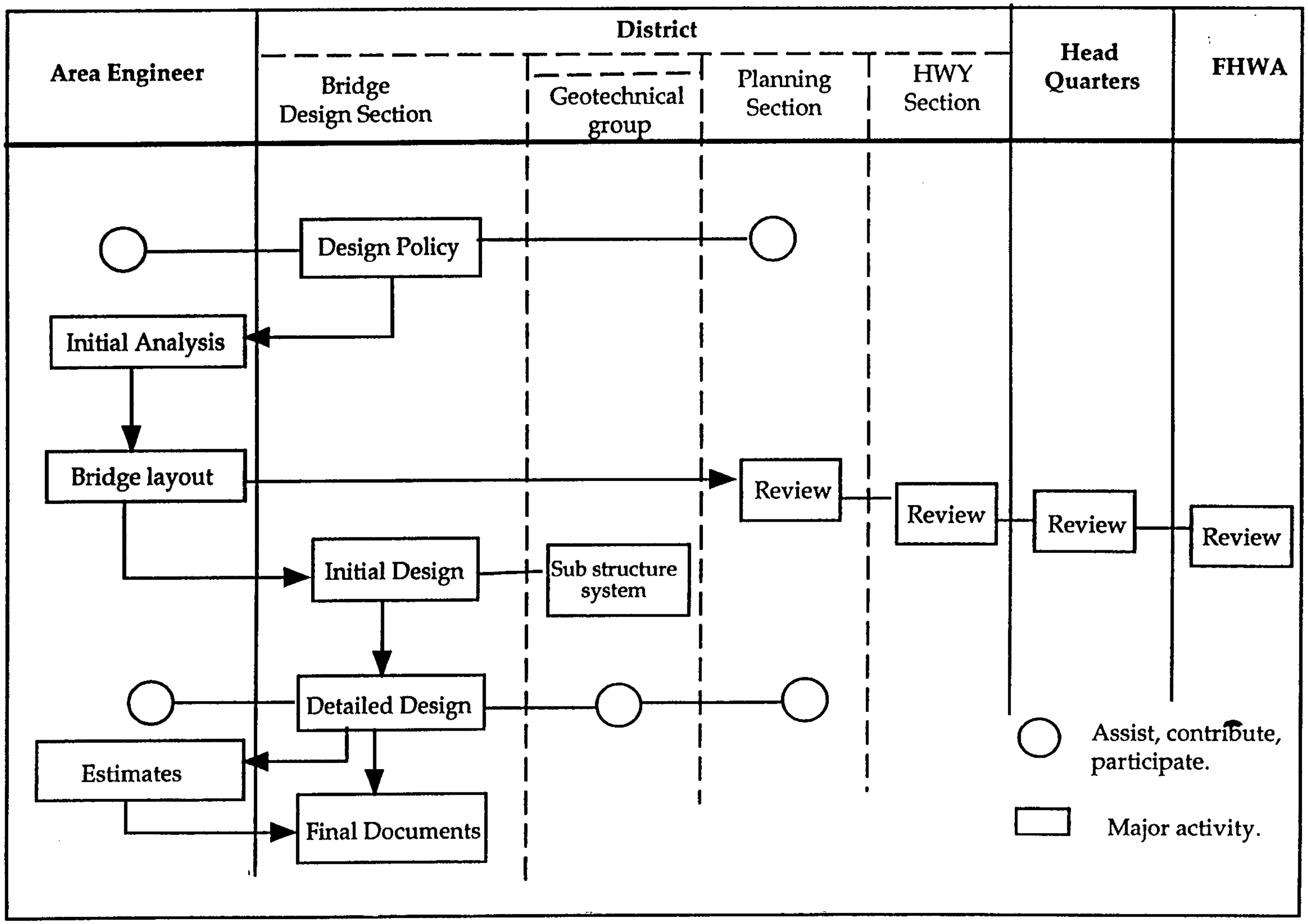

Figure 4-3. General Steps of the Bridge Design Phase

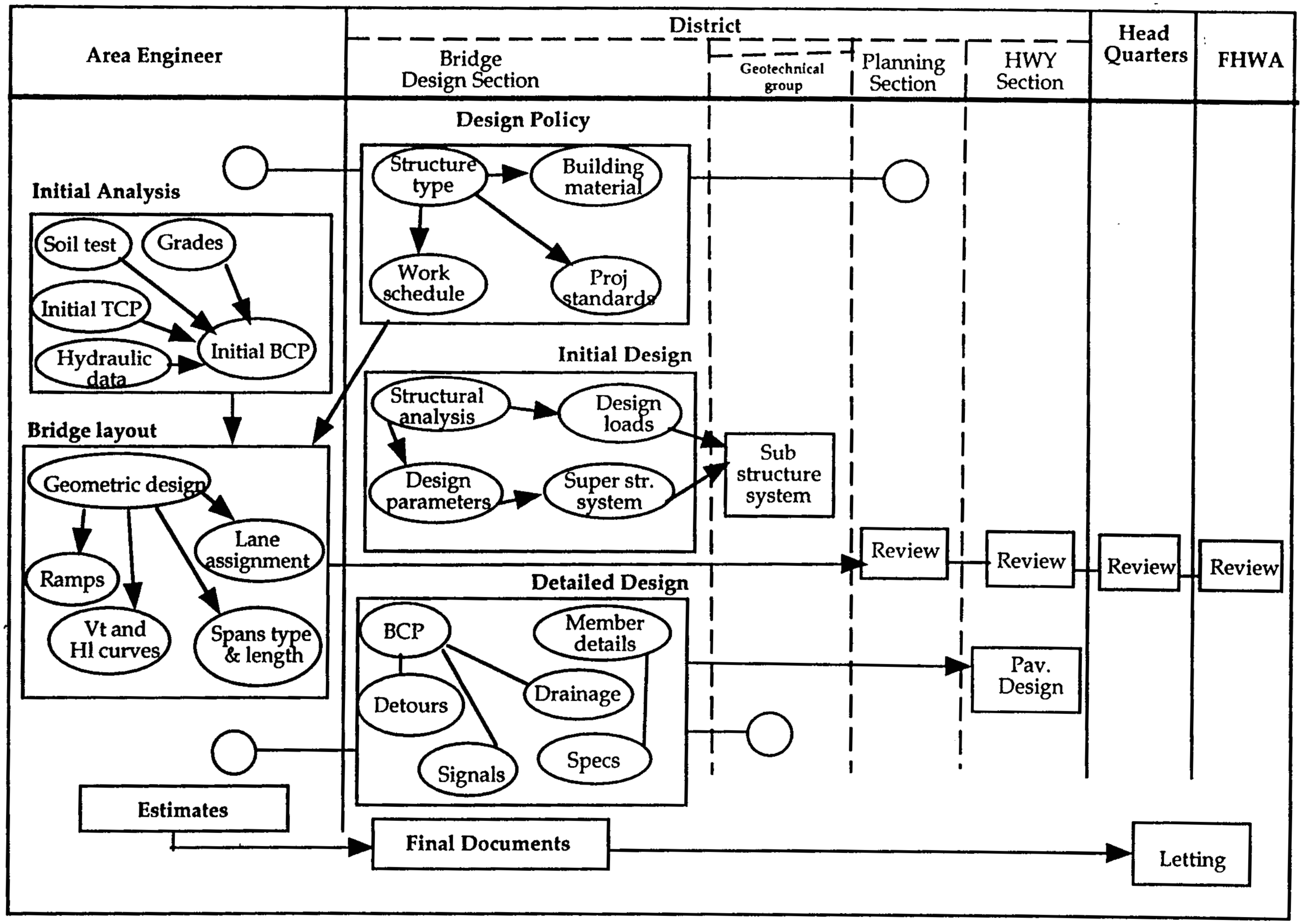

Figure 4.4. The Current Bridge Design Process

4.5 FACTORS INFLUENCING EFFECTIVENESS OF BRIDGE CONSTRUCTION PLANNING

A BCP is influenced by a multitude of input variables. The most important factors, shown in Figures 4-5 and 4-6, are discussed below.

Right of Way (ROW)

Almost all urban bridges face the problem of restricted ROW. Limited ROW controls planning options in regard to construction sequencing and equipment mobility. This usually leads to a serial construction sequence, small work zones, and too many traffic shifts.

Bridge Configuration

Bridge layout and structural system influence the development of an effective BCP. Complex bridges with sharp curves or many ramps require additional space for work in the already limited ROW. This may mandate several traffic shifts and detours, significantly impacting project duration and traffic flow.

Site Conditions

The actual site topology imposes many restrictions on the BCP. Existing horizontal and vertical curves have an impact on travelers' sight distance and, hence, their safety. A BCP planner has to consider these parameters when designing detours and construction activities.

In addition, clearances for traffic must be secured in each step. Work on bridge decks often reduces the actual bridge clearance, and planners must accommodate traffic beneath a bridge in all construction phases. This can mandate additional work activities or detours.

Traffic Conditions

Freeway traffic volume has a considerable effect on the BCP. Less traffic volume would make it easier to shift traffic back and forth.

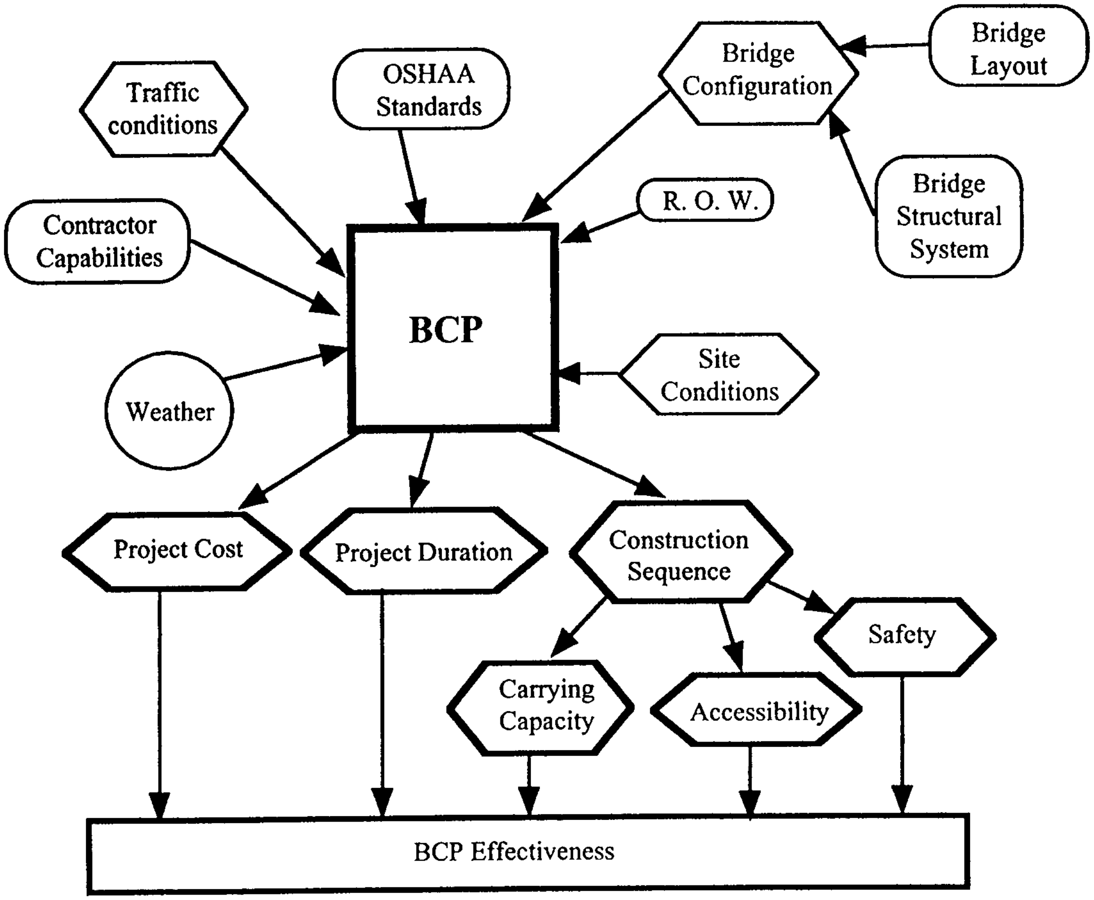

Figure 4-5. Simplified BCP Influence Diagram

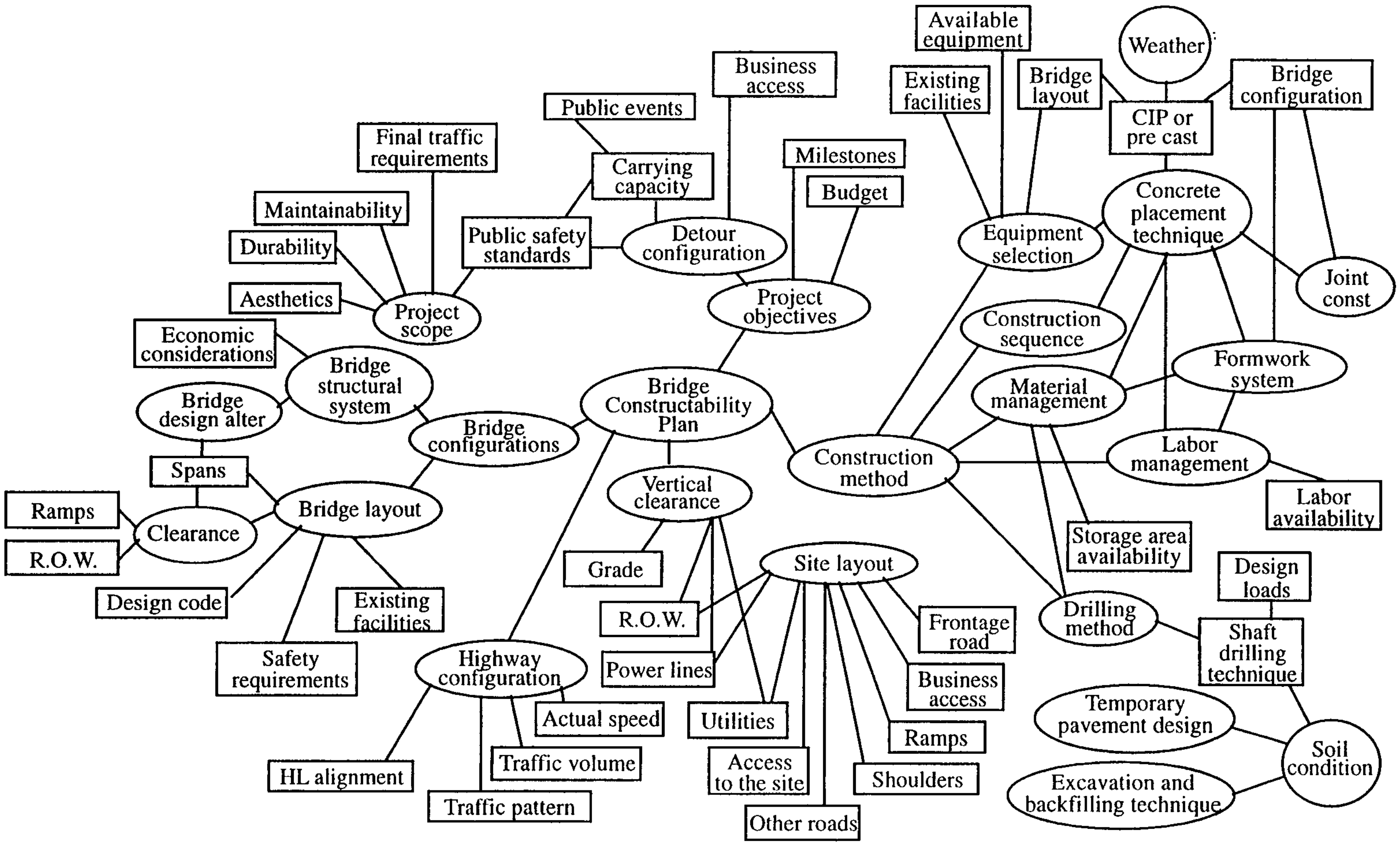

Figure 4-6. Detailed BCP Effectiveness Influence Diagram

4.6 BCP OBJECTIVES

Objectives of a BCP were identified based on the analysis of BCP impacts and input variables, and included recognition of the need to maximize safety, minimize overall cost (user, business, construction), enhance accessibility, and reduce impacts on the community and on citywide traffic flow.

An optimum BCP is, then, defined as one that satisfies the highest standards in each of the previous objectives without affecting any of the others. That is, to collectively optimize all the objectives.

4.7 BCP EFFECTIVENESS HOT DIAGRAMS

Based on previous project experience, several techniques and criteria were developed to overcome the limitations of the input variables on the BCP. The HOT diagrams in Figures 4-7 through 4-11 present simple categorizations of some techniques for enhancing BCP effectiveness. Most of these techniques were available through owner documents and a literature review. Additional techniques were developed through input from site and design engineers.

These HOT diagrams present a basis for developing parameters to evaluate the effectiveness of a BCP.

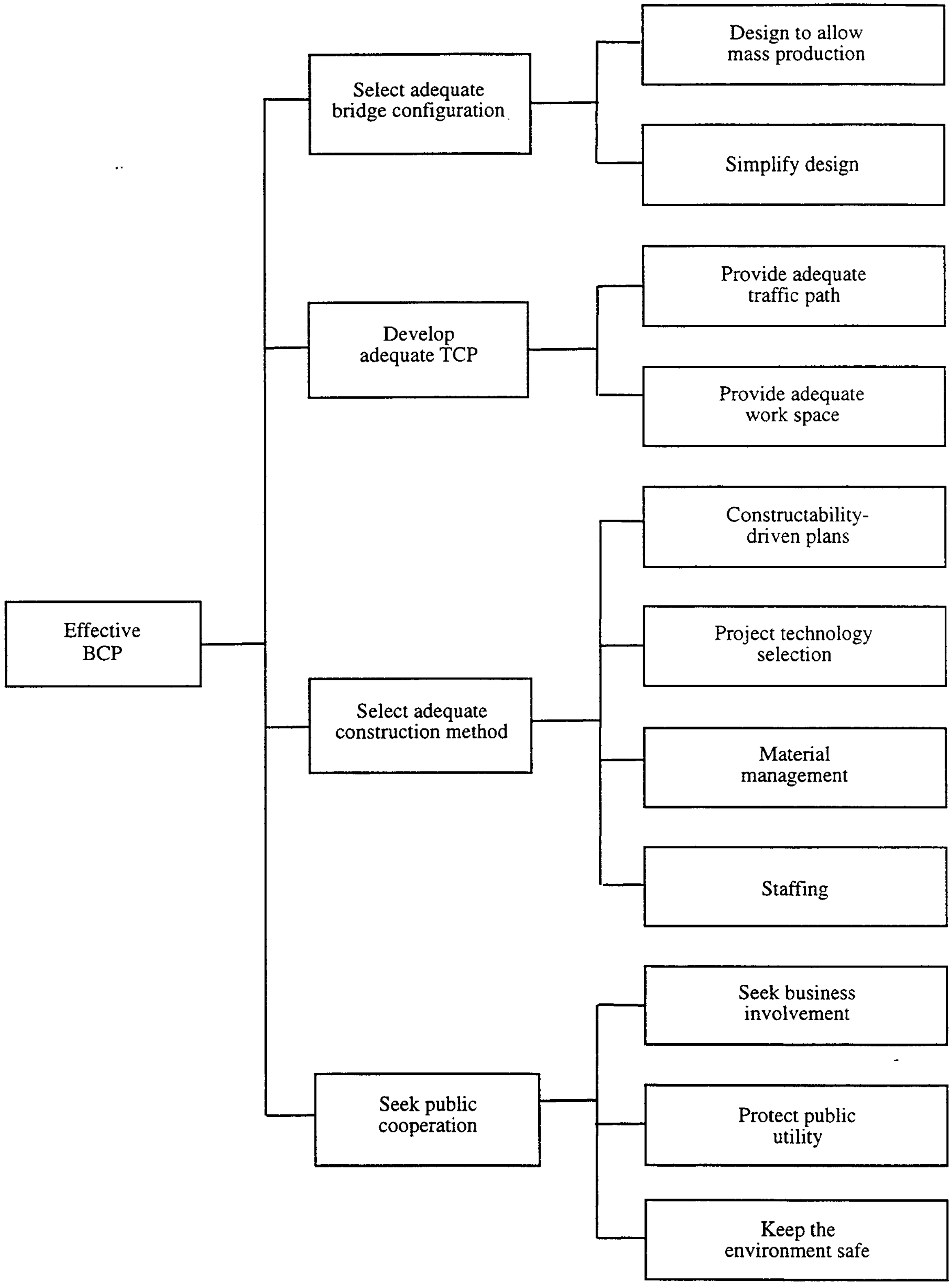

Figure 4-7. BCP Effectiveness HOT Diagram

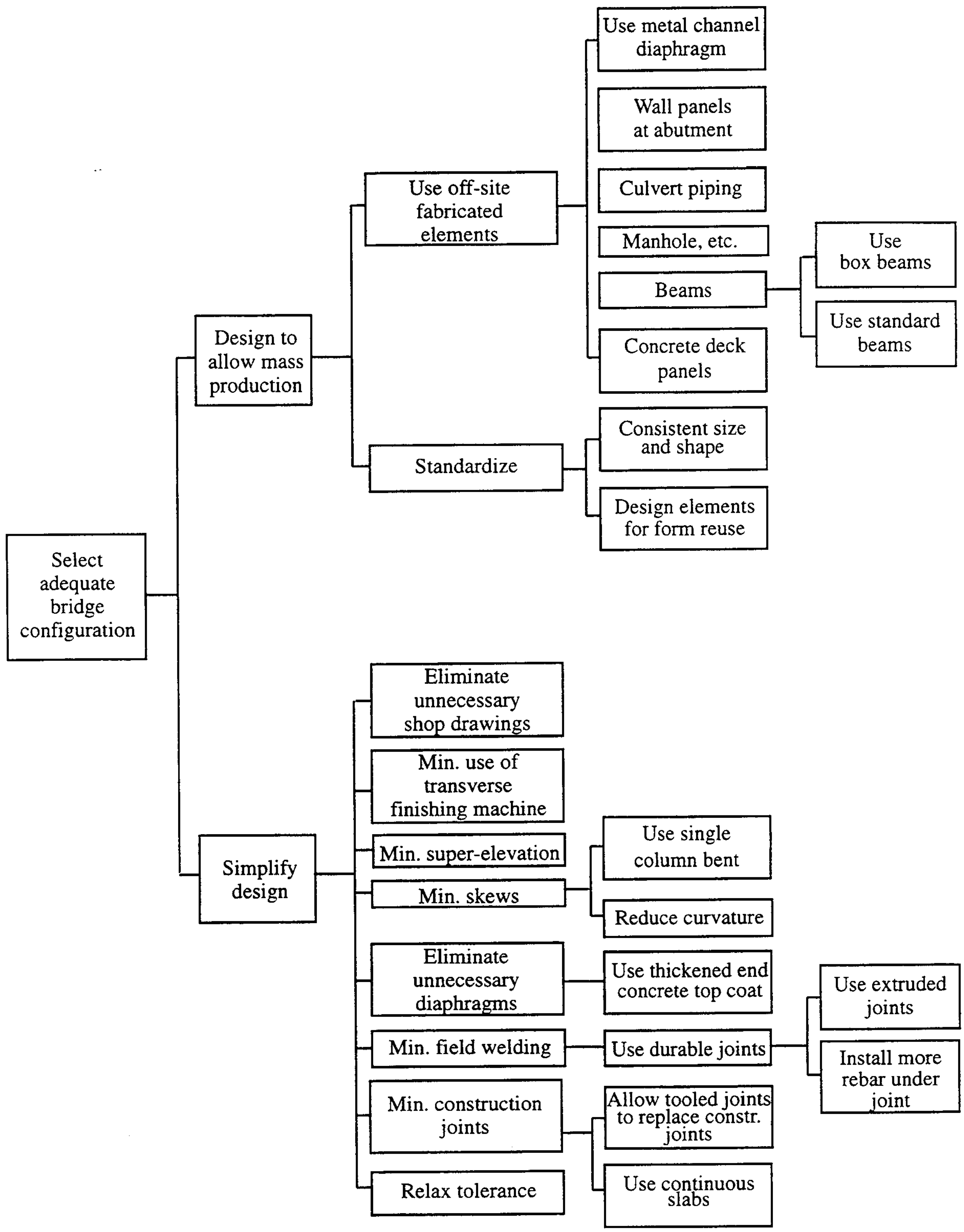

Figure 4-8. Bridge Configuration HOT Diagram

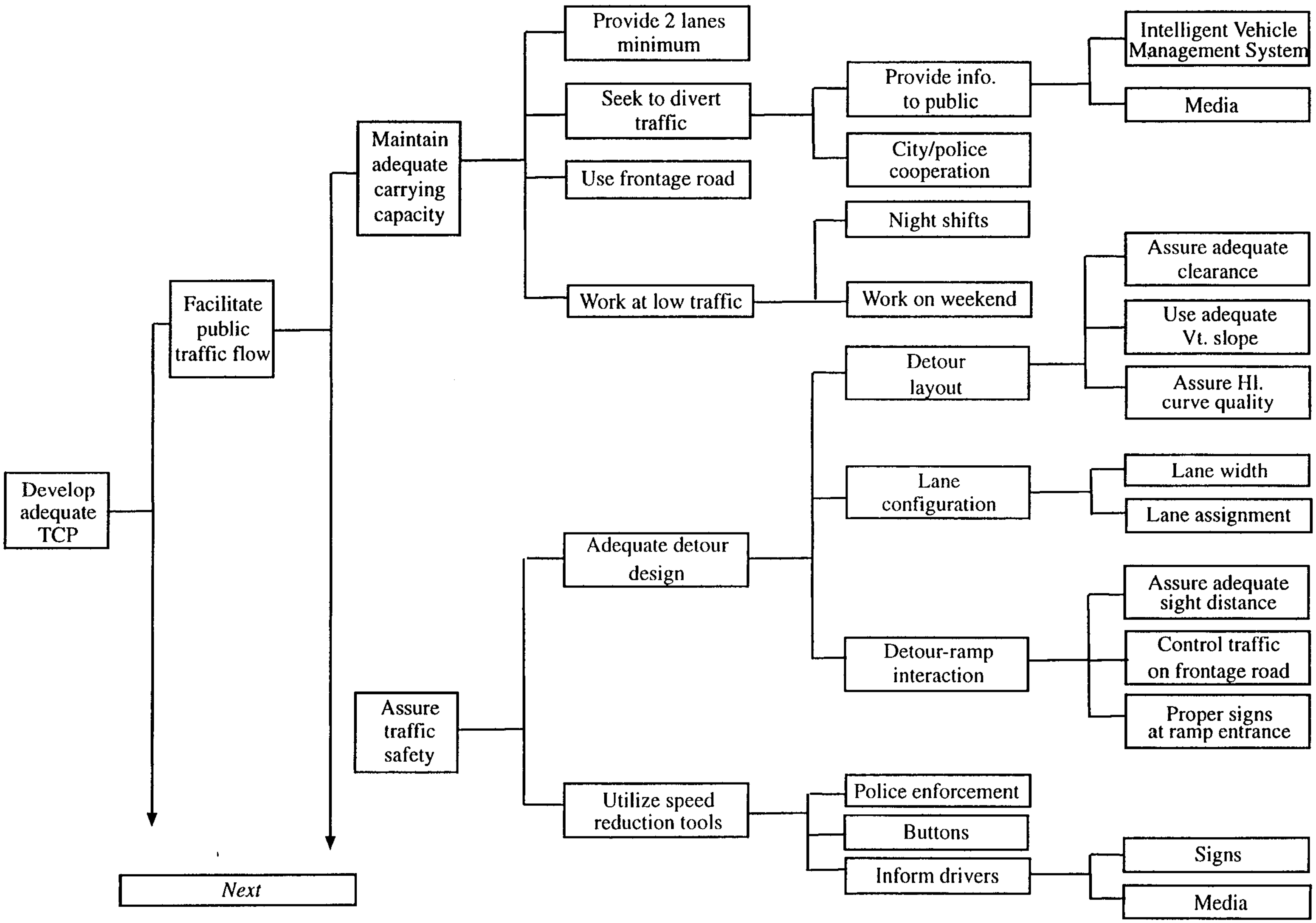

Figure 4-9. TCP Effectiveness HOT Diagram

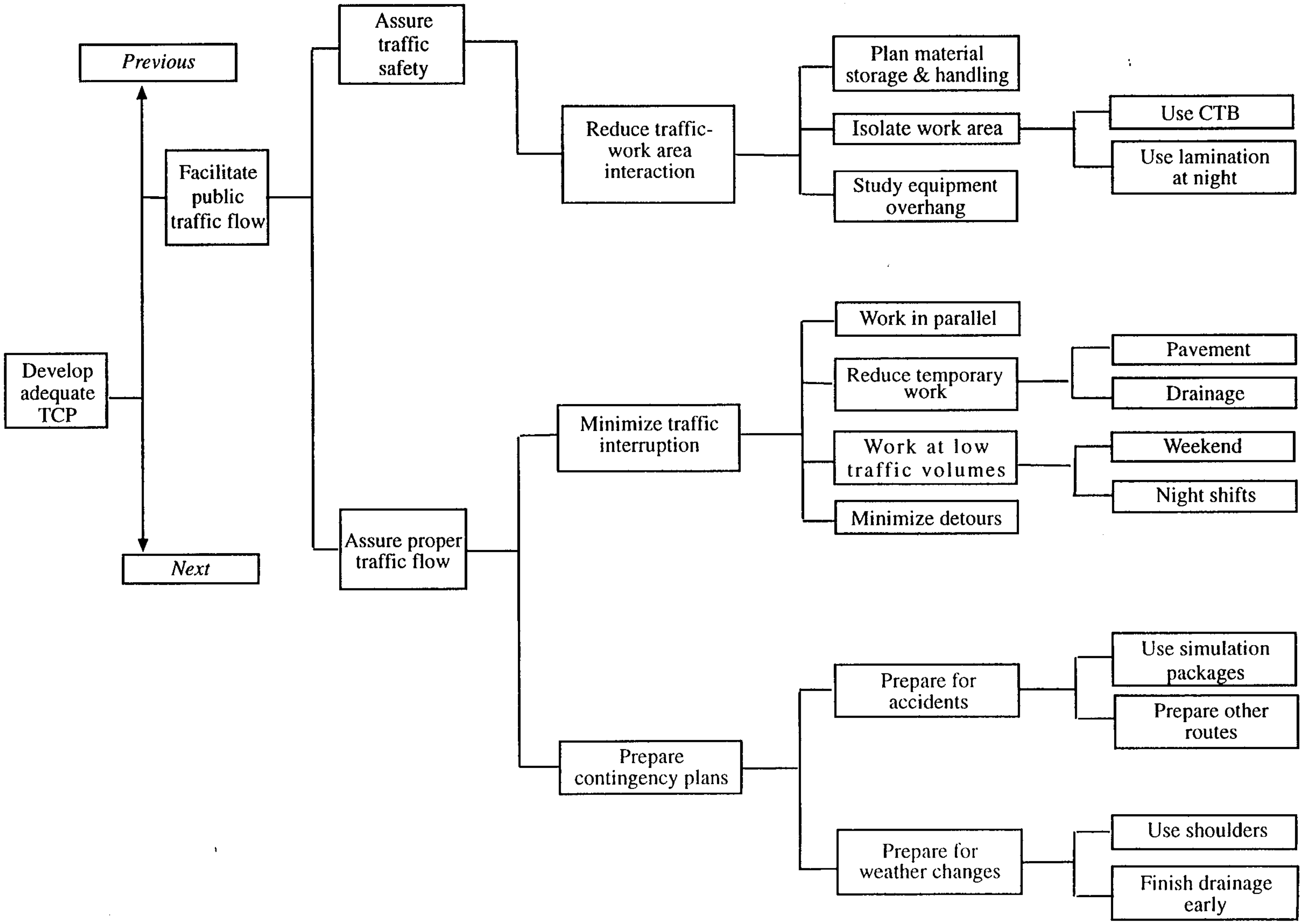

Figure 4-9. TCP Effectiveness HOT Diagram (Cont.)

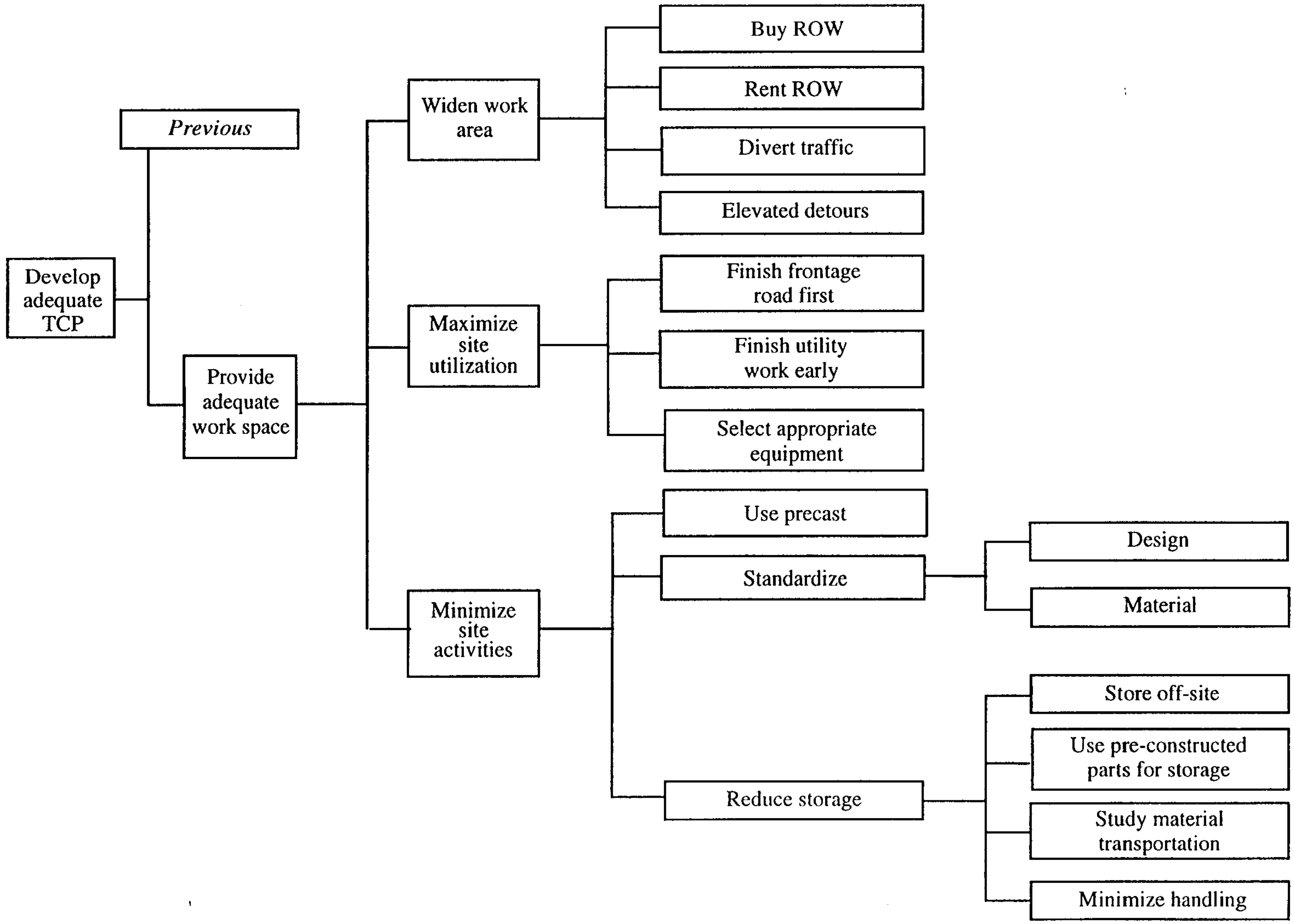

Figure 4-9. TCP Effectiveness HOT Diagram (Cont.)

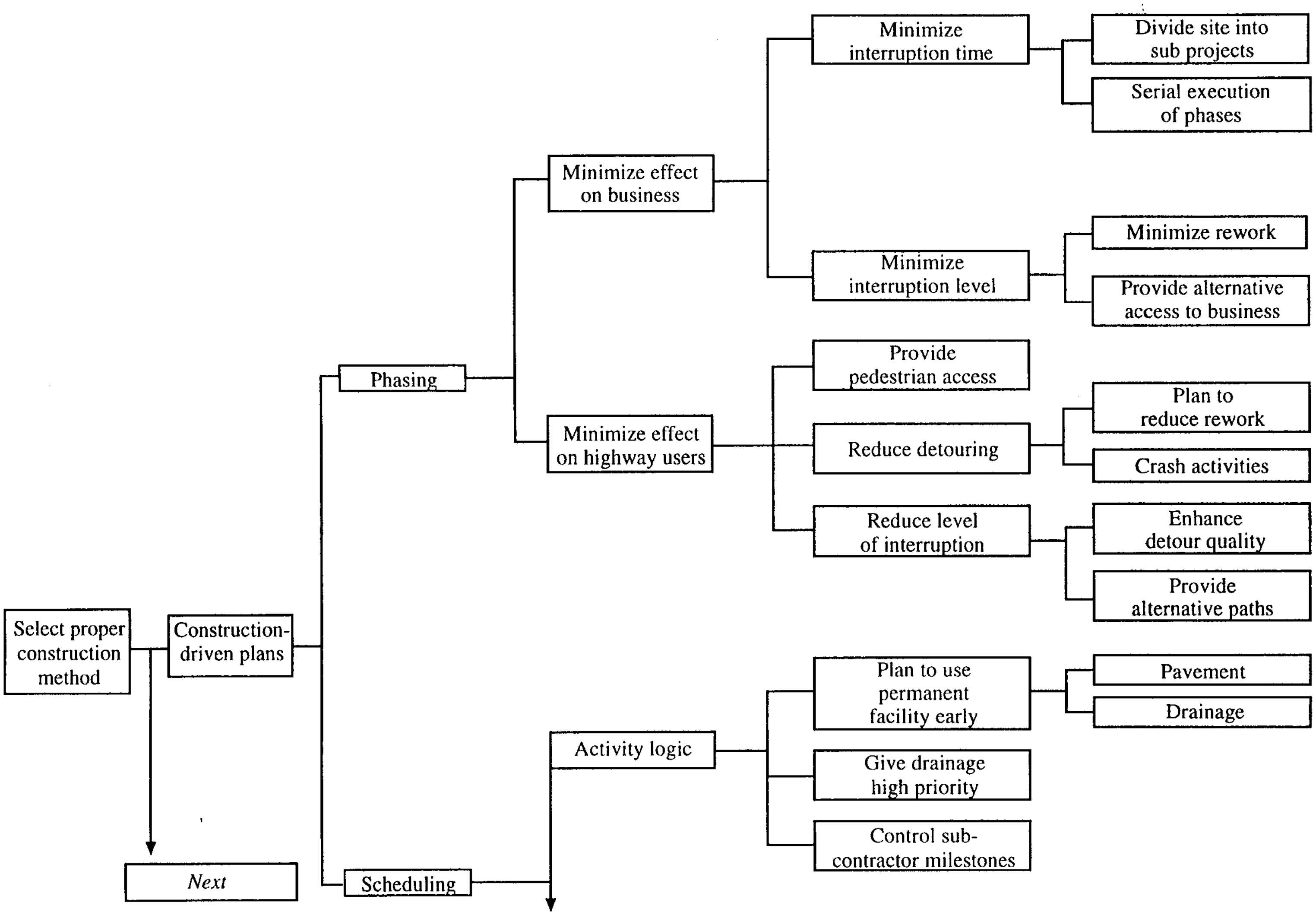

Figure 4-10. Construction Method Effectiveness HOT Diagram

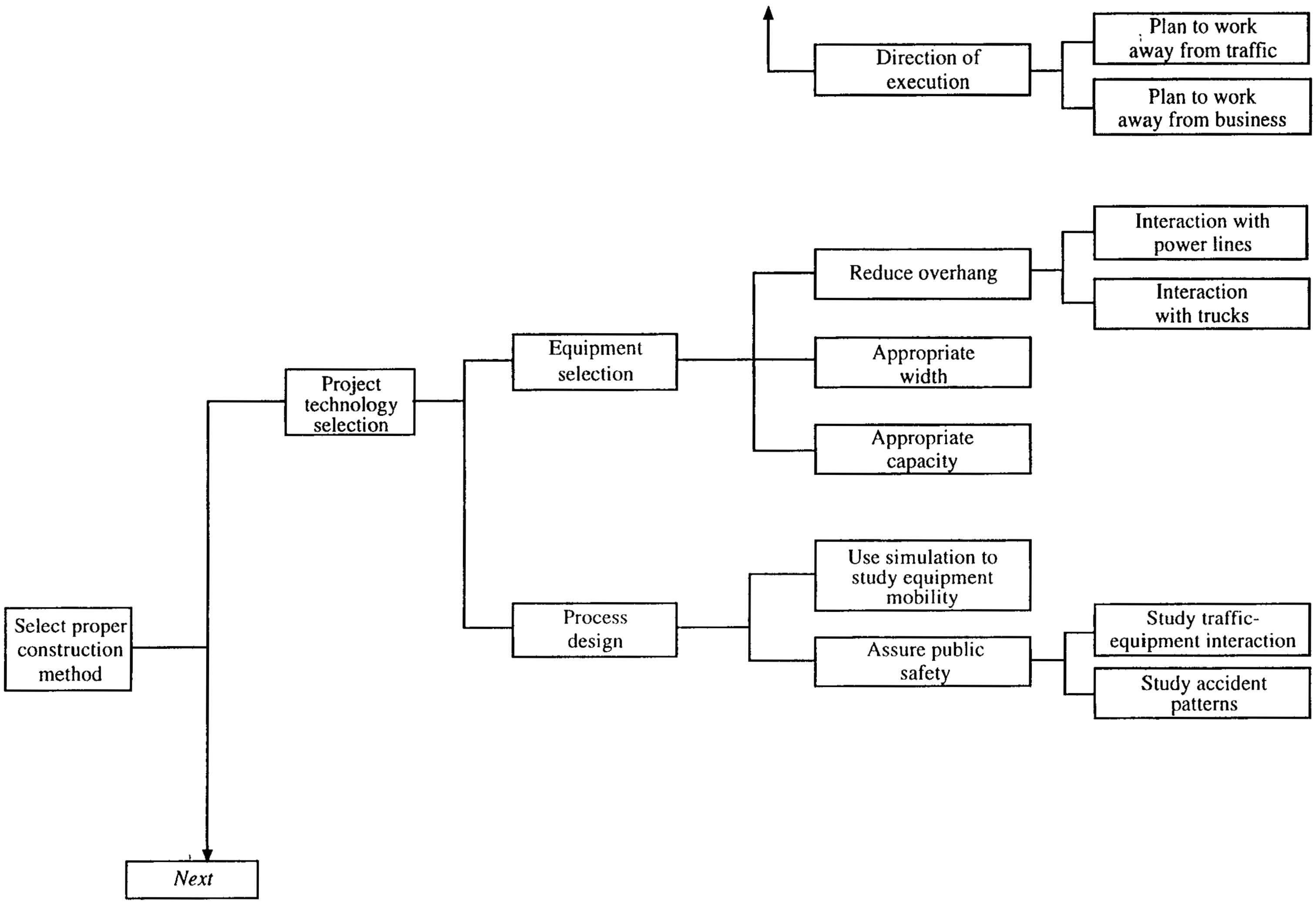

Figure 4-10. Construction Method Effectiveness HOT Diagram (Cont.)

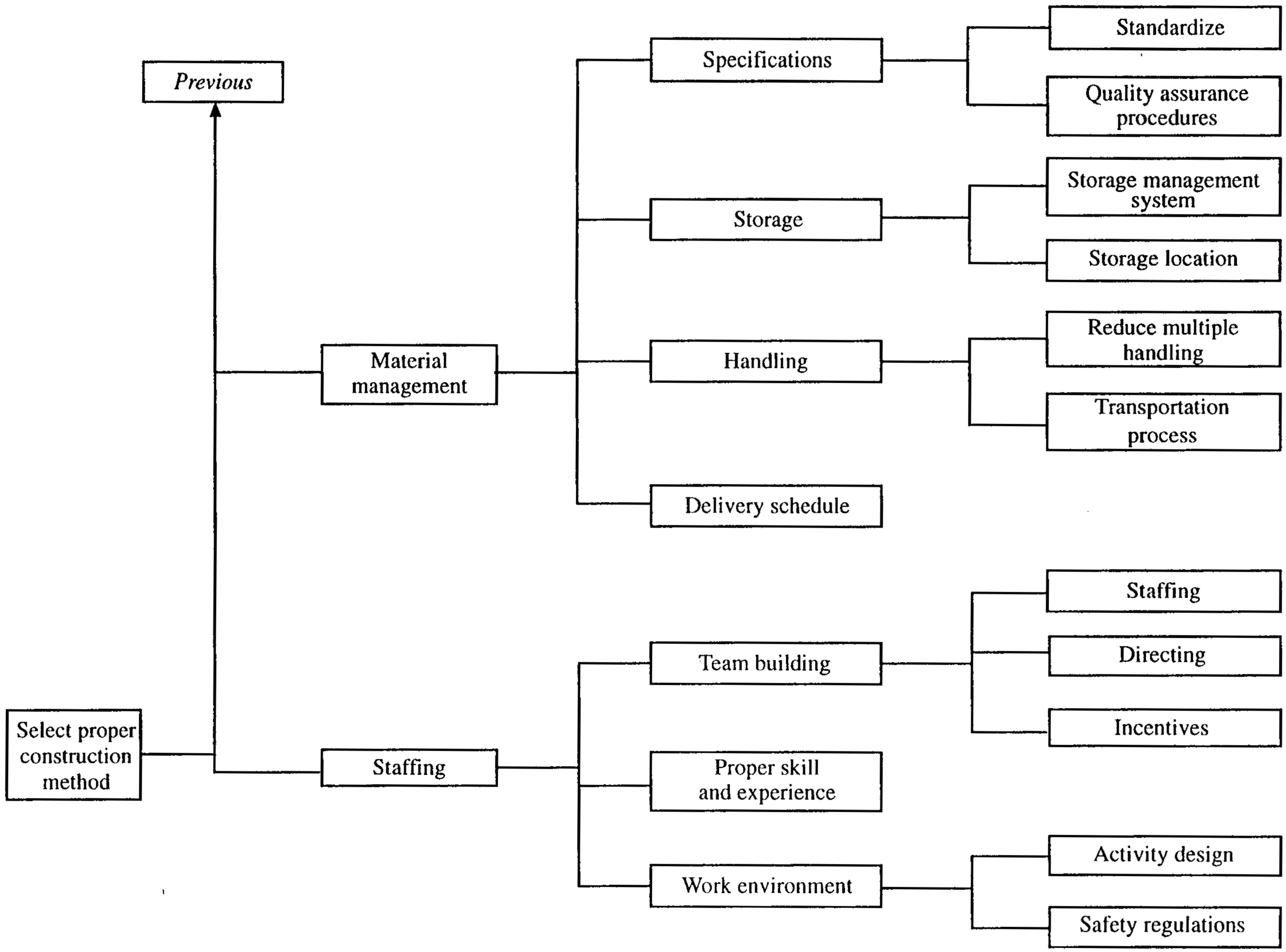

Figure 4-10. Construction Method Effectiveness HOT Diagram (Cont.)

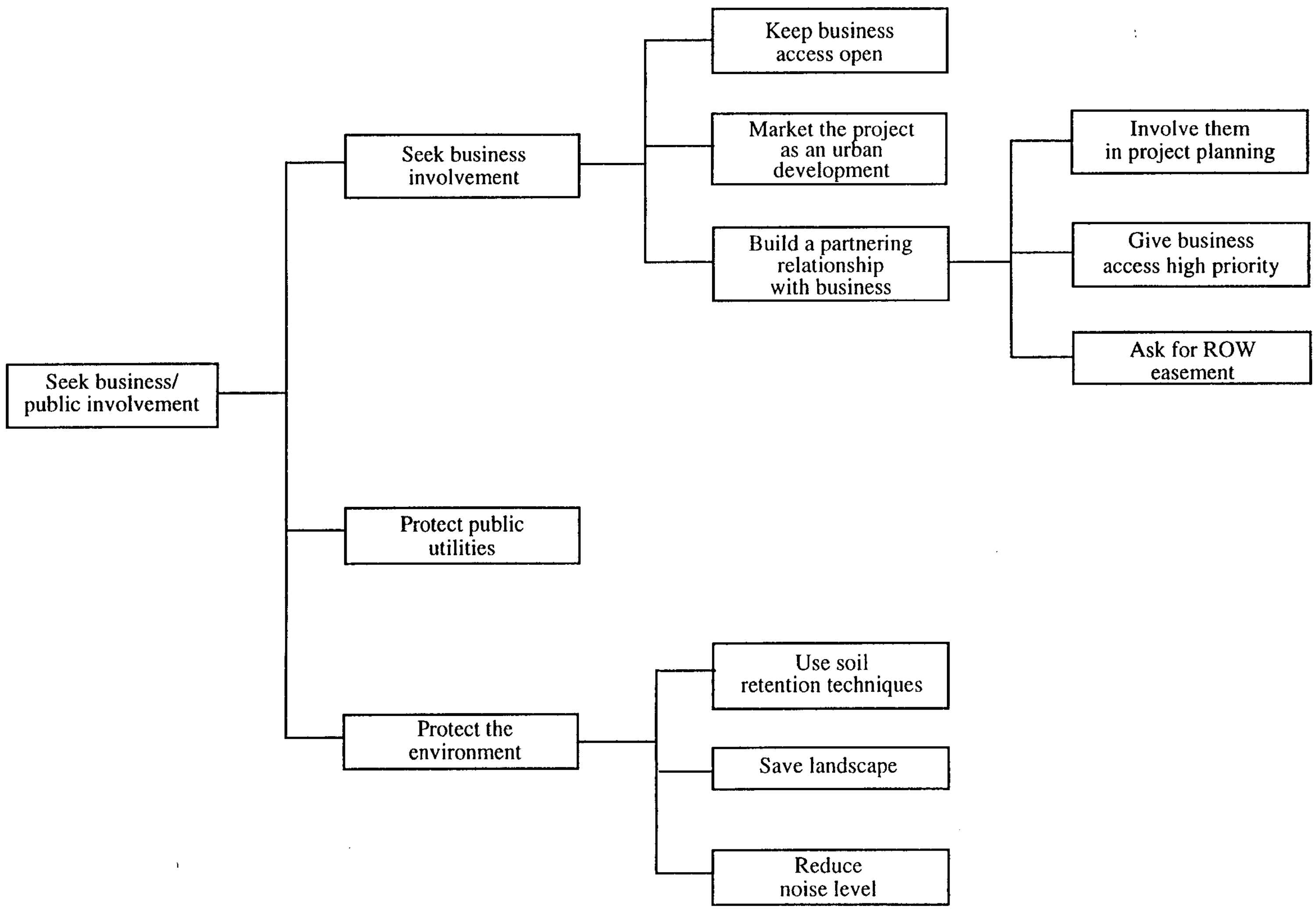

Figure 4-11. Public Cooperation HOT Diagram

4.8 NEED FOR EVALUATION MODEL

There is a need for developing a model to evaluate BCP effectiveness during the design phase. This model is needed because BCP has to optimize several—and in many cases, conflicting—objectives. The design team lacks the tools to evaluate these objectives.

The utilization of such a model will ensure that the BCP impact on the surrounding environment is optimized. Designers are the major users of this model during the design phase. The project team uses the model during a change order feasibility study.

5. PRELIMINARY EVALUATION MODEL

This chapter presents the procedures for collecting and analyzing relevant BCP evaluation parameters. The process began by identifying major obstacles for modeling a BCP evaluation. Based on the results, a specific model scope was developed to overcome these obstacles. Before collecting evaluation parameters, a list of criteria for the selection of final parameters was developed.

A preliminary list of evaluation parameters, composed over a period of 18 months, was based on site observations, reviews of TxDOT documentation on previous projects, literature reviews, and informal interviews with design and construction engineers. The preliminary parameters were analyzed against the pre-set criteria. The parameters were reduced to five major evaluation factors and 27 sub-factors. The reduced factor list was the basis for conducting a set of data acquisition interviews to formally solicit experts' input regarding BCP evaluation parameters (see Chapter 6).

5.1 OBSTACLES TO MODELING BCP EVALUATION

The obstacles to the development of a BCP evaluation model were identified as follows:

a. each project has its unique characteristics,
b. a large number of evaluation parameters must be considered,
c. conflicts and/or dependencies between parameters always exists, and
d. excessive subjectivity for many parameters.

5.2 EVALUATION MODEL SCOPE

An analysis of the model was conducted to define a specific scope to meet users' needs and to overcome the previous obstacles. This scope was defined as follows.

a. Evaluation procedures should be simple. Because there is limited time available during the design phase, the model should be easy to apply so as to encourage its application.
b. The model should be applicable to a generic bridge project. An all-encompassing model covering all details of a BCP is not possible due to varying bridge project conditions (site, topology, project objectives, traffic conditions, project volume,

project team mix), and policy changes during the project. Therefore, the model should include only parameters common to all bridge projects. Project-specific parameters are to be developed by the design team. Hence, the proposed evaluation factors are not necessarily all-inclusive. Additional factors may still be needed to meet project-specific needs. Also, the suggested factors' weights are not universal; they only help the designer in setting the appropriate weights to the project under study.

c. The evaluation should be ordinal. The model is to evaluate different approaches to build one bridge only. It should not compare the BCP's for different bridges. Such a comparison is not possible because there is no common basis for evaluation across different bridges.
d. The model should evaluate BCP effectiveness only. The model will not evaluate the process of BCP development (size of drawing, design budget and schedule, number of revisions, number of changes, etc.). Rather, the main objective of the model is to test the quality and effectiveness of the BCP. It should evaluate whether or not a particular BCP optimizes the pre-defined objectives.
e. The model will cover urban bridges only. The model will not cover rural bridges; such projects do not face comparable planning challenges.
f. The model should be applicable at the design phase. Evaluation data have to be available during the design phase.

5.3 CRITERIA FOR SELECTING EVALUATION PARAMETERS

Several parameters can be developed to evaluate a BCP. However, not all of them conform to the previous scope. The following set of criteria were developed to judge the parameters that merit inclusion in the model.

a. Relevance to a BCP. The model will only include parameters that are controlled by the BCP. Parameters that are not influenced by the BCP cannot be used to evaluate its effectiveness. For example, a BCP, as defined in this research, has no control over the selection of bridge construction technology. The selection of such technology is made before BCP development. A BCP cannot change the construction technology, say, from segmental to cast-in-place girders. This kind of parameter is an input variable to the BCP.

b. Discrimination. Only parameters that can discriminate between two BCP's performances are to be included. Some parameters have to conform to specific law. For example, BCP impact on air quality levels during construction cannot be used as an evaluation parameter. This is because every BCP has to satisfy certain standards in this regard. The satisfaction of these standards qualify a BCP to be an alternative. Nonetheless, it does not give one plan an edge over another. Another group of parameters cannot discriminate between BCP's simply because they can be applicable to all plans (staffing, or equipment selection).
c. Objectivity. Excessively subjective parameters will not be included in the model. This does not mean that the model will eliminate the evaluator's subjective judgment in assessing some parameters. Such judgment is valuable because several items in the evaluation are subjective by nature (Ref 20). A decision-maker's subjective assessment is indispensable in these situations (Refs 20, 22). Nonetheless, parameters that cannot be evaluated through systematic procedures or by extracting supporting data from the BCP will be excluded.
d. Generality. Only parameters applicable to a generic bridge project will be included in the model.
e. Ease of measurement. Hard-to-quantify parameters will be excluded.
f. Non-redundancy/independence. If the domains of two parameters overlap, they will be re-defined or one of them will be eliminated.

5.4 PRELIMINARY EVALUATION PARAMETERS

The following major parameters were identified as possible evaluation factors (detailed evaluation sub-parameters are shown in Table 5-1):

a. safety—to both travelers and crew, including traffic interaction with construction activities (especially equipment), crew interaction with running traffic, traffic changes, detour configuration, and proximity to probable accident location.
b. user cost—based on increased travel time and discomfort of highway users.
c. technology—the selection of proper construction technology including macro construction technology (segmental vs. girders, pre-cast vs. cast in place, steel vs. concrete), and micro construction technology (excavation technique, cast in place shafts vs. pre-cast, shoring technique, curing, etc.).

d. productivity—the probable impact a BCP may have on the productivity of a crew during construction.
e. work zoning efficiency—dividing a site into smaller zones in order to decrease business and community impacts and traffic interruption. Zoning is important because it affects total project duration, business and traffic interruptions, and equipment mobility.
f. business impact—reduction of business activity during construction, usually attributed to the reduction of traffic volume on the highway and access impedance.
g. community impact—BCP impact on local community activities.
h. environmental impact—effect on the surrounding environment.
i. material management—impact on the effectiveness of material storage and handling at the site.
j. site drainage—BCP effect on site drainage during construction.
k. project cost—BCP impact on project direct cost. A BCP with fewer steps will result in cost savings.
l. project duration—BCP impact on project duration. A simpler BCP will consume less time.

Table 5-1. Preliminary Parameter List

Major Parameter	Sub Parameters	Unit of Measurement
Safety	**Traffic interaction w. construction activities**	
	Distance from work area	Ft
	Interaction frequency	#
	Level of interaction	Scale
	Overhanging equipment	Scale
	Sight distance	Ft
	Interaction duration	Hours
	Crew interaction w. traffic	
	Level of involvement	Scale
	Distance from traffic	Ft
	Type of barrier	Scale
	Interaction length	Ft
	Level of activity sophistication	Scale
	Interaction duration	Hours
	Traffic changes	
	Change type	Scale
	Frequency of change	#
	Detour configuration	
	Degree of horizontal curve	Curve degree
	Lane width	Ft
	Shoulder width	Ft
	Shoulder type	Scale
	Sight distance	Ft
	Skid resistance	Scale
	Vertical alignment	% slope
	Fixed objects	Scale
	Proximity to accidents	
	Duration to reach accident	Hours
	Ease of access to accident	Scale

Table 5-1. Preliminary Parameter List (cont.)

Major Parameter	Sub Parameter	Units of Measurement
User cost	Blockage duration	Hours
	Level of blockage	Scale
	Blockage time	Scale
	Frequency of delays	#
	Average queue length	Ft
Technology	Level of technology maturity	Scale
	Number of crafts	#
	Number of equipment	#
	Level of sophistication	Scale
	Probability of failure	Scale
	Seriousness of problems	Scale
	Frequency of problems	#
	Impact on cost	% Savings
	Impact on schedule	% Savings
	Changes to TCP	Scale
Productivity	Access to task	Scale
	Level of fabrication	Scale
	Activity details	Scale
Business Impact	No. traffic interruptions	#
	Volume reduction	% reduction
	Ease of access	Scale
	Entrance clarity	Scale
	Different accesses	#
	Distance from construction	Ft
	Type of barrier	Scale
Major Parameter	Sub Parameter	Units of Measurement
Environmental Impact	Noise level	Scale
	Ease of access	Scale
	Access to recreational areas	Scale
	Effect on historical areas	Scale
	Aesthetics	Scale

Table 5-1. Preliminary Parameter List (cont.)

Material	Storage area	Square Ft
Management	Proximity to construction	Ft
	Ease of handling	Scale
	Accessibility	Scale
Work zoning efficiency		Scale
Work sequence efficiency		Scale
Project duration		Days
Project budget		$

5.5 PARAMETER ANALYSIS

The analysis of the previously discussed parameters against the pre-set criteria is shown in Tables 5-2 through 5-10. In addition to these criteria, the analysis included investigating redundancy between parameters. As seen in the tables, a majority of the proposed parameters were rejected because of the lack of objectivity or because the parameter is not easy to evaluate.

The objectivity of the proposed parameters was analyzed by answering the question "Is there a measure or BCP element that can be used to score this parameter?" Neither objective procedures nor a specific measurement element could be identified for the rejected parameters.

The ease of measurement criterion was analyzed by determining if there were sufficient data to perform the evaluation at the design stage, and the amount of time needed for the evaluation. Several parameters were eliminated because they did not meet these two criteria.

Table 5-2. Safety Parameter Analysis

Parameter	Analysis Criteria (lack of)					Decision
	Relevance	Discrimination	Objectivity	Ease of measure.	Generality	
Traffic interaction w. constr.						
Distance from work area						**Accept**
Interaction frequency				X		Reject
Level of interaction			X	X		Reject
Overhanging equipment						**Accept**
Sight distance				X		Reject
Interaction duration				X		Reject
Crew interaction w. traffic						
Level of involvement			X			Reject
Type of barrier						**Accept**
Interaction length						**Accept**
Level of activity sophistication	X		X			Reject
Interaction duration				X		Reject
Traffic changes						
Change type						**Accept**
Frequency of change						**Accept**
Detour configuration						
Degree of horizontal curve						**Accept**
Lane width						**Accept**
Shoulder width		X				Reject
Shoulder type		X				Reject
Skid resistance	X	X				Reject
Vertical alignment						**Accept**
Fixed objects	X				X	Reject
Proximity to accidents						
Duration to reach accident						**Accept**
Ease of access to accident			X			Reject

Table 5-3. User Cost Parameter Analysis

Parameter	Analysis Criteria (lack of): Relevancc	Discrimination	Objectivity	Ease of measure	Generality	Decision
Blockage duration						**Accept**
Level of blockage				X		Reject
Blockage time					X	Reject
Frequency of delays			X			Reject
Average queue length				X		Reject

Table 5-4. Technology Parameter Analysis

Parameter	Relevance	Discrimination	Objectivity	Ease of measure	Generality	Decision
Level of technology maturity	X					Reject
Number of crafts		X				Reject
Number of equipment		X				Reject
Level of sophistication			X			Reject
Probability of failure			X	X		Reject
Seriousness of problems			X			Reject
Frequency of problems				X	X	Reject
Impact on cost				X		Reject
Impact on schedule				X		Reject
Changes to TCP	X				X	Reject

Table 5-5. Productivity Parameter Analysis

Parameter	Relevance	Discrimination	Objectivity	Ease of measure	Generality	Decision
Access to task	X	X				Reject
Level of fabrication	X					Reject
Activity details	X					Reject

Table 5-6. Business Impact Parameter Analysis

Parameter	Analysis Criteria (lack of)					Decision
	Relevance	Discrimination	Objectivity	Ease of measure.	Generality	
No. traffic interruptions						Reject
Volume reduction						Reject
Ease of access			X			Reject
Entrance clarity	X					Reject
Reduction in parking space						**Accept**
Additional distance from ramp						**Accept**
Distance from constr.						Reject
Type of barrier						Reject

* Redundant parameter

Table 5-7. Community Impact Parameter Analysis

Parameter						
Noise level				X		Reject
Ease of access	X		X			Reject
Access to recreational areas					X	Reject
Effect on historical areas					X	Reject
Aesthetics			X			Reject

Table 5-8. Environmental Impact Parameter Analysis

Parameter						
Air quality		X				Reject
Water quality		X				Reject
Land use		X				Reject

Table 5-9. Material Management Parameter Analysis

Parameter	Analysis Criteria (lack of)					Decision
	Relevance	Discrimination	Objectivity	Ease of measure.	Generality	
Storage area		X				Reject
Proximity to construction			X	X		Reject
Ease of handling			X			Reject
Accessibility				X		Reject

Table 5-10. Other Parameter Analysis

Parameter						
Work zoning		X				Reject
Work sequence		X				Reject
Duration						**Accept**
Cost						**Accept**

5.6 EVALUATION PARAMETERS

The analysis process resulted in the formation of five major factors that are believed to cover the pre-defined objectives of a BCP: safety, accessibility, carrying capacity, schedule performance, and budget performance.

The HOT diagram in Figure 5-1 presents a collection of sub-objectives to the five major factors. It shows how these factors, if evaluated, measure BCP effectiveness. Based on the HOT diagram, 27 sub-factors were identified to facilitate the evaluation of the major factors (see Table 5-11). These proposed factors and sub-factors were used in a set of formal data acquisition interviews with key experts in BCP development (see Chapter 6).

Safety

Safety is an ever-existing concern for all parties involved in BCP development. A BCP has a direct impact on the safety of both the traveling public and the construction crew. Sixteen sub-factors were identified to evaluate this major factor (Table 5-11).

Accessibility

Construction work coupled with often-restricted ROW affects site accessibility and impedes traveler access to desired destinations. In addition, access to businesses is usually interrupted during bridge construction. The proposed accessibility factor includes seven sub-factors to evaluate both traffic and business accessibility issues.

Carrying Capacity

This factor was devised to examine the extent to which a BCP impacts the carrying capacity of the highway. The reduction of highway carrying capacity resulting from construction work will increase travel time for highway users. It will also generate additional traffic volumes on other major arterials in the city. Such impacts affect overall user cost and the citywide traffic flow. Two sub-factors were proposed to evaluate this factor.

Schedule Performance

Schedule performance is desirable for reduction of project duration, which has a direct impact on project indirect cost, user cost, and business interruptions. A BCP has a direct relation to project duration, and an effective BCP with larger work zones and parallel execution of work activities will have a shorter duration.

Budget Performance

Given that almost every project has a budget limit, direct cost is usually an important decision criterion. A BCP has a strong relation to project budget. An effective BCP with fewer detours and less rework can reduce project cost significantly.

Selected Sub-Factors and BCP Objectives

The five selected major factors serve all the objectives of a BCP as set in the previous chapter. Figure 5-2 shows the relation between BCP objectives and these five factors. Other parameters considered in the analysis process were eliminated for the following reasons.

a. User cost. Though very important, this factor is difficult to evaluate. There is always controversy about the dollar amount of its ingredients. The proposed carrying capacity and accessibility factors cover the user cost issue in a more practical and easy-to-perform procedure.

b. Macro technology. This parameter is an input variable affecting a BCP and is part of the value engineering phase of the project which proceeds the BCP. A BCP, as defined in this research, has no control over such decisions.

c. Micro technology. This parameter was deemed undiscriminating since each of the technologies listed under it can be applied to any BCP.

d. Productivity. BCP impact on productivity is minimal. Productivity is mainly influenced by the workers' skill level, staffing, and activity design, all of which are not part of a BCP. It is also redundant with cost and schedule factors.

e. Efficiency of work zoning. This factor is controlled by ROW and site topology, which is common to all plans. Hence, it is not a discriminating parameter. The evaluation of this factor is excessively subjective. In addition, its impacts are fully accounted for by the schedule performance factor.

f. Material management. This parameter is mainly controlled by ROW, which is common to all BCP's. In addition, its impacts are reflected in the budget performance factor.

g. Site drainage. All items under this parameter are applicable to any BCP. Hence, it is undiscriminating.

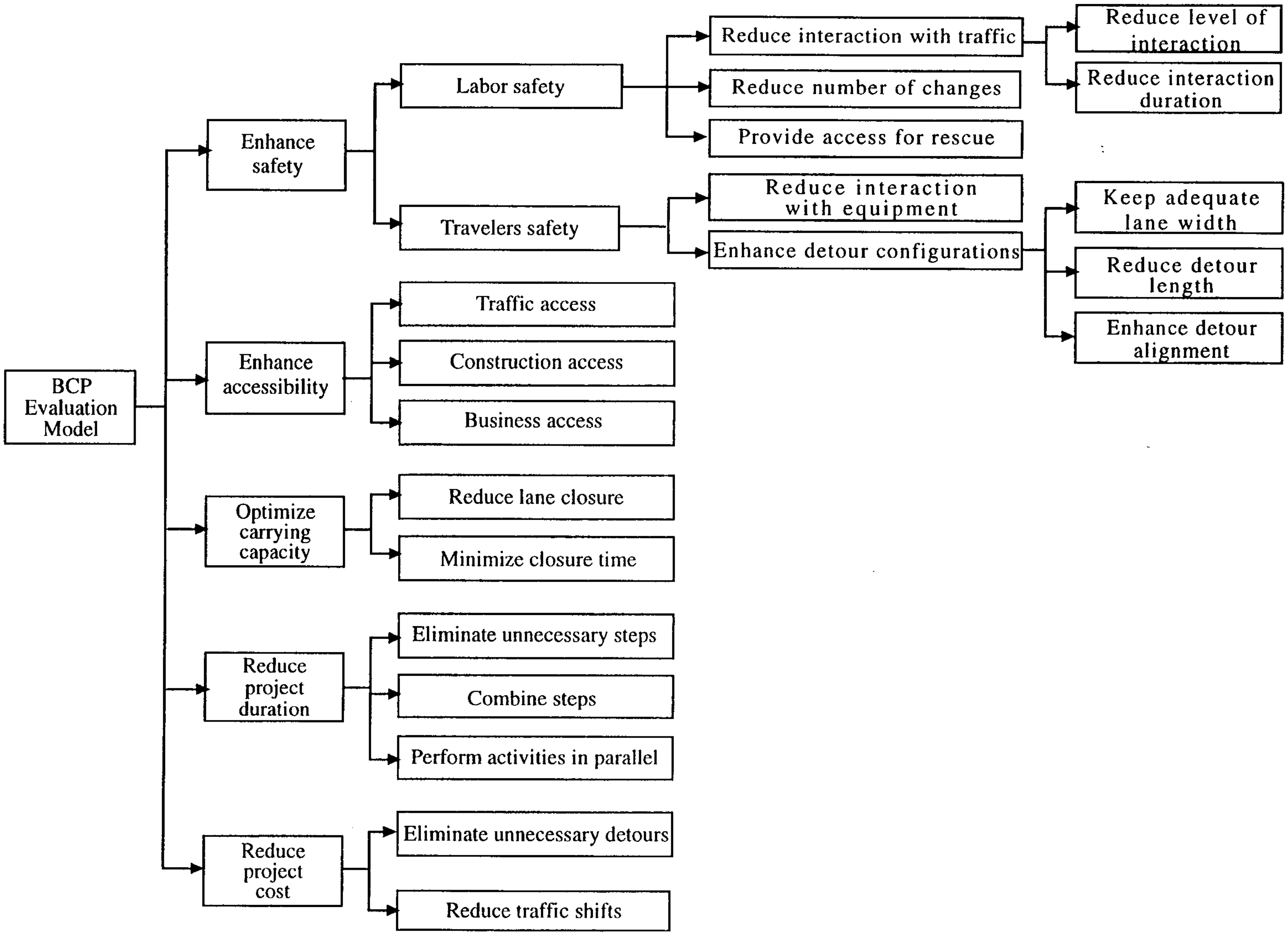

Figure 5-1. BCP Evaluation Model Objectives HOT Diagram

Table 5-11. Initial BCP Evaluation Factors

Major Factor	Sub Factors	
Safety		
	Travelers interaction	
		• Over Hanging equipment
		• Adequacy of traffic barrier
		• Traffic-Activity interaction length
		• Machine interruption to traffic line
		• Distance between traffic and constr.
	Detour configuration	
		• Lane width
		• Detour length
		• Detour quality
	Crew interaction w/ traffic	
		• Working on one side of traffic vs.....
		• Working at high traffic volumes vs...
		• Day shift vs night shift
		• Working toward traffic vs
		• Construction activity intensity level
	Traffic changes	
		• Type of change
		• Type of road on which change takes ...
	Access to accidents	
		• Total time to evacuate accidents
Accessibility		
	Traffic accessibility	
		• Reduction of number of accesses
		• Number of forced diversions
		• Reduction in running speed
	Business accessibility	
		• Reduction of access points...
		• Reduction in parking space
		• Additional distance from ramp
		• Constr. congestion in front ...
Carrying Capacity		
	Number of cars blocked	
	Blockage duration	
Schedule Performance		
	% Savings in duration	
Budget Performance		
	% Savings in cost	

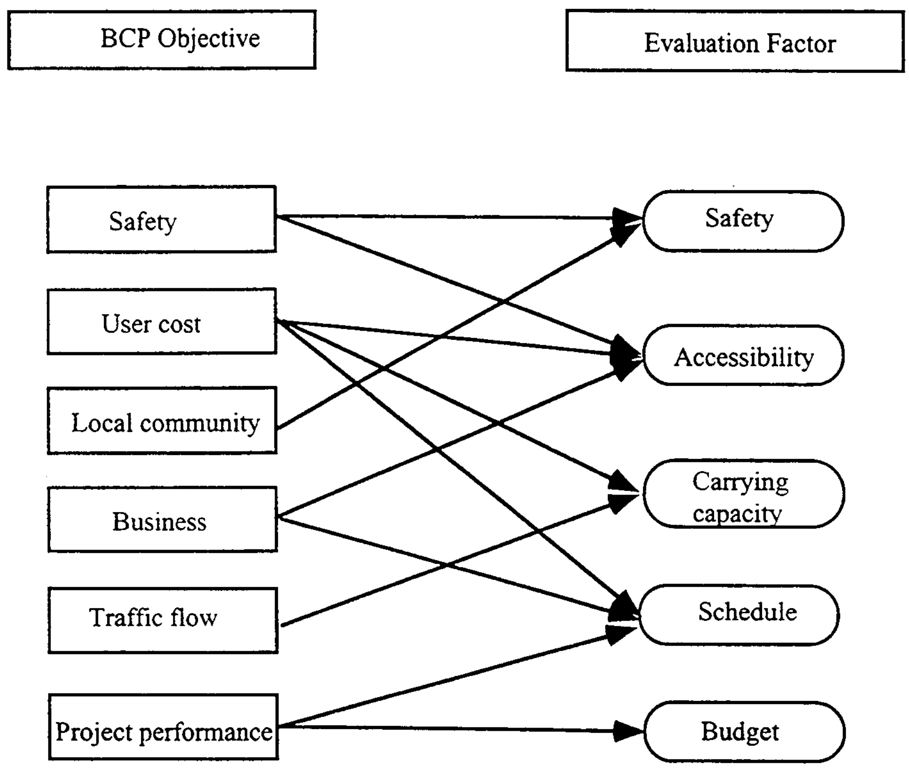

Figure 5-2. Proposed Evaluation Factors and BCP Objectives

6. DATA ACQUISITION INTERVIEWS

The data collection tools used in this research include interviewing key experts in the field of urban bridge development. Such interviews are vital to statistical, internal, and external validity, and widen the data collection scope to include the vast expertise of people who have designed, built and managed urban bridges. Moreover, because of the lack of formal lessons-learned documentation mechanisms in the construction industry, such experts are the only source for defining unique evaluation factors that cannot be solicited by reviewing previous project documents or by visiting sites.

Nonetheless, interviews in the construction field usually have some shortcomings. Most experts in the construction field do not usually document their expertise. In essence, when they are interviewed, they tend to emphasize obvious or macro factors and overlook specific factors. Therefore, a detailed list of several evaluation factors was compiled through other data collection tools. These factors were then sorted into major factors and sub-factors, after which they were compiled in a structured interview. This approach induced the interviewees to suggest specific, new, and relevant evaluation parameters.

This interview format provided ample information for the research. The experts' input proved to be very valuable, especially in formally assessing the high interest in the model, generating a general understanding for model applicability (an external validity concern), collecting additional relevant factors (an internal validity concern), and assessing the relative significance and ease of measuring all factors.

6.1 INTERVIEW RESULTS

Tables 6-1 through 6-14 and Figures 6-1 through 6-4 show the abstract results of the interviews along with their relevant statistical measures. The detailed response tally is presented in Appendix B.

Notes:

Kurtosis is a statistical measure used to test the peakedness of a curve. If it has a value of zero, it reflects a perfect normal distribution. A negative value reflects a flatter than normal curve; while a positive value reflects a narrow curve. This measure will be used in the data analysis to test the degree by which the interviewees agree on something.

Abbreviations

Av: Average.

Med: Median.

Mo: Mode.

SD: Standard Deviation.

Kurt: Kurtosis.

Table 6.1. BCP Major Factor Significance Rating

	DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
	D	C	M	AV	MED	MO	SD	KURT
SAFETY	6	5.7	5.6	5.8	6	6	0.62	10
ACCESSIBILITY	5	4.7	4.2	4.6	4	4	0.79	-1.04
CARRYING CAPACITY	4.8	4.7	5.6	4.6	4	4	0.79	-1.04
SCHEDULE PERFORMANCE	3.5	5	4.8	4.4	4	4	1.00	-0.41
BUDGET PERFORMANCE	4	4	5.6	4.5	4	4	1.09	-1.44
OVERALL				4.8	5	4	0.98	-1.2999

AV	4.7	5	4.8
MED	4.0	5	5.0
MOD	4.0	4	4.0
ST DEV	1.1	1	0.9
KURT	-1.5	-2	-1.3

Legend: D: Designers; C: Construction Engineers; M: Managers.
Av: Average; Med: Median; Mo: Mode; SD: Standard Deviation; Kurt: Kurtosis.

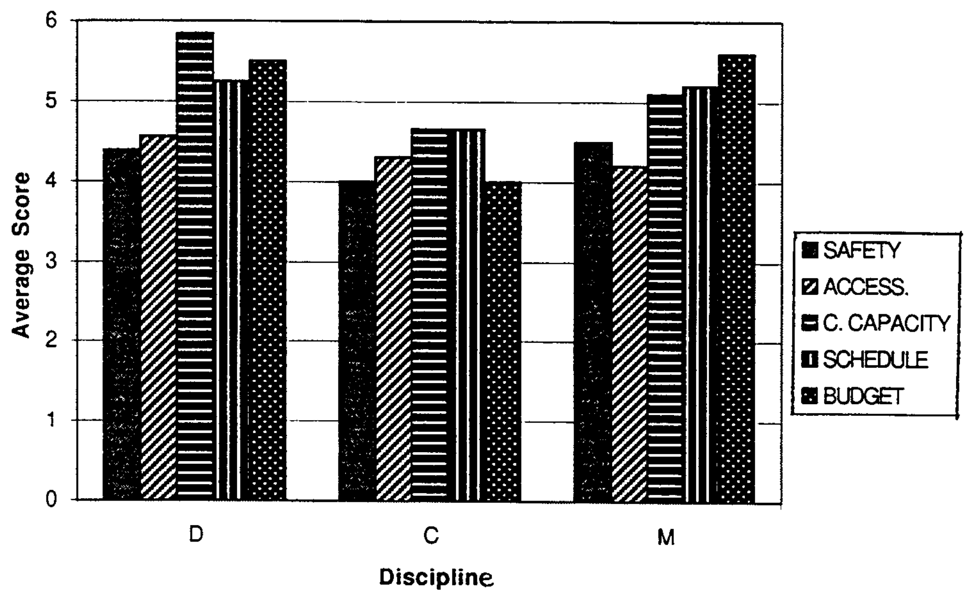

Figure 6-1. Sub Factor Average Significance Score

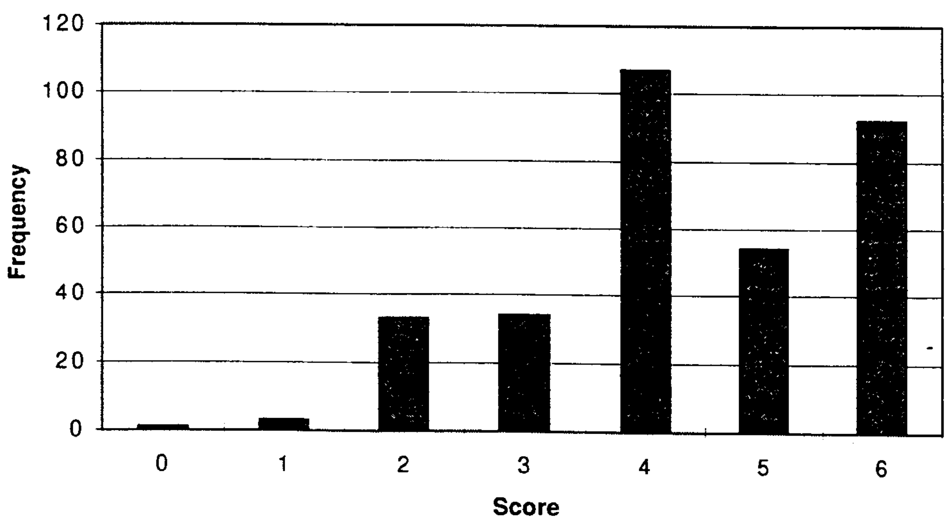

Figure 6-2. Significance Score Frequencies

Table 6-2. Overall Ease of Measurement Score

	DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
	D	C	M	AV	MED	MO	SD	KURT
SAFETY	4.0	3.48	3.31	3.6	4	4	1.8	-0.6
ACCESSIBILITY	3.9	3.38	3.23	3.5	4	4	1.3	0.2
CARRYING CAPACITY	2.6	3.00	2.8	2.8	2	2	1.3	0.8
SCHEDULE PERFORMANCE	3.5	3.33	3	3.5	2.5	2	1.5	-1.1
BUDGET PERFORMANCE	4.5	3.67	3	3.7	3	3	1.6	-1.3
OVERALL				3.5	4	4	1.6	-0.5
AV	3.8	3.41	3.24					
MED	4.0	3.84	3.00					
MOD	4.0	4.00	2.00					
ST DEV	1.6	1.76	1.36					
KURT	0.1	-0.65	-0.22					

Legend: D: Designers; C: Construction Engineers; M: Managers.
Av: Average; Med: Median; Mo: Mode; SD: Standard Deviation; Kurt: Kurtosis.

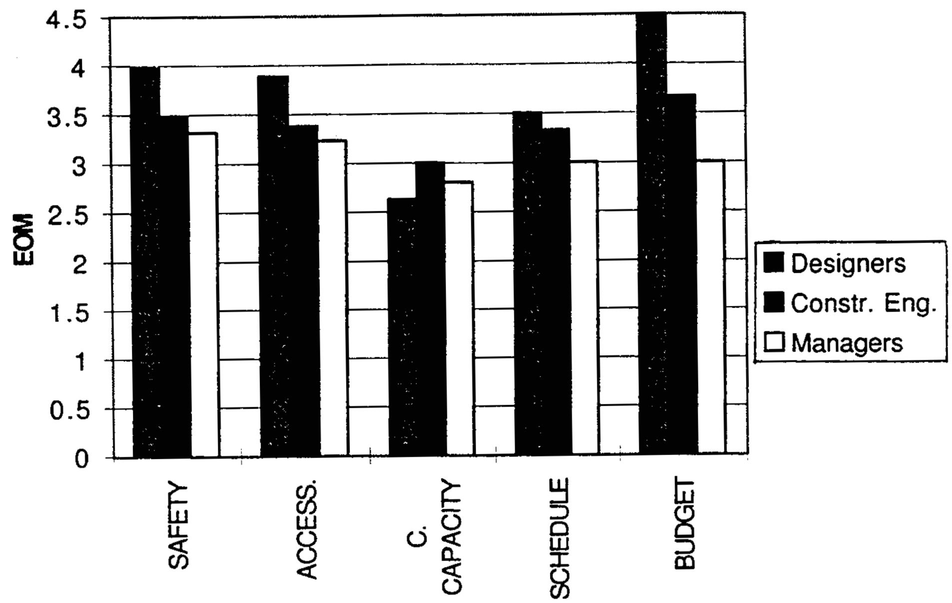

Figure 6-3. Sub Factor Average Ease of Measurement

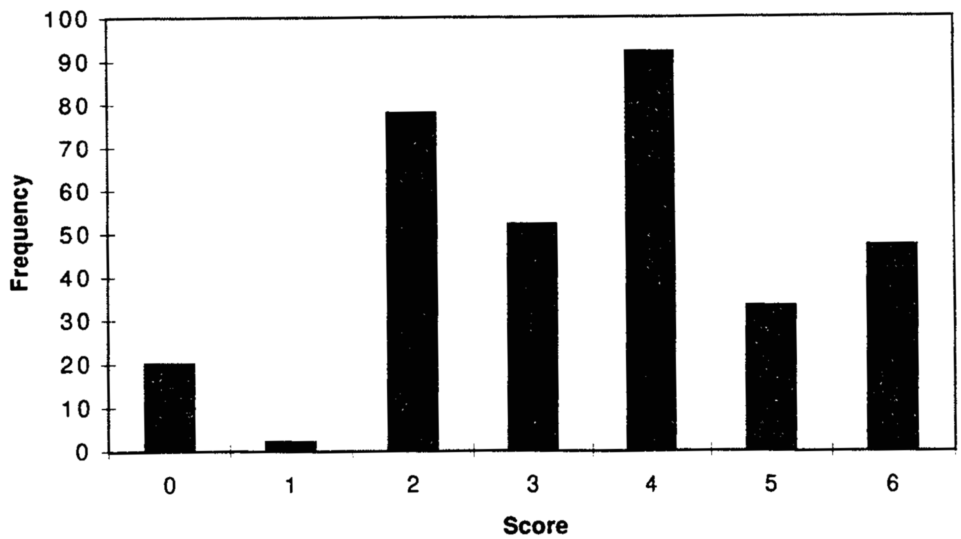

Figure 6-4. Ease of Measurement Score Frequencies

Table 6-3. Safety Factor Significance Rating

	DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
	D	C	M	AV	MED	MO	SD	KURT
Travelers interaction w. constr.	4.5	5.3	5.2	5	5	6	0.9	-2.1
1 Over Hanging equipment	4.75	4.3	5.8	4.9	6	6	1.4	-1.6
2 Adequacy of traffic barrier	5.75	4.0	5.2	5.1	5	6	1.0	-0.5
3 Traffic-Activity interaction length	3.75	2.7	3.2	3.3	3.5	4	1.4	0.4
4 Machine interruption to traffic line	5.75	3.3	4.6	4.7	5	6	1.3	-0.4
5 Distance between	3.5	5.3	3.8	4.1	4	4	1.5	0.0
Detour configuration	5	4.7	4.8	5	5	4	0.8	-1.4
6 Lane width	3.75	5.3	4.6	4.6	4	4	1.3	-0.8
7 Detour length	3	3.7	3.6	3.2	3	3	1.2	2.2
8 Detour quality	5.5	3.7	4.8	4.8	5	6	1.2	0.8
Crew interaction with traffic	3.75	5.0	5	4.7	4.5	6	1.4	-1.3
9 Working on one side of traffic Vs between....	5	5.0	5.2	5.17	5.5	6	0.9	-1.6
10 Working at high traffic volumes Vs at low...	4.75	4.0	5.2	4.9	5	6	1.4	-1.9
11 Day shift VS night shift	4.75	4.7	4.6	4.6	4	4	1.1	-1.3
12 Working toward traffic Vs away	2.25	2.0	3.6	2.6	2	2	1.2	-1.3
13 Construction activity intensity level	4.25	4.0	4	4	4	4	1.2	-0.7
Traffic changes	4	4.3	4.4	4.1	4	4	1.2	-0.4
14 Type of traffic change	4.5	4.0	4.8	4.5	4	4	1.1	-0.9
15 Type of road where change takes place	4	3.3	4.6	3.9	4	4	1.2	0.9
Access to accidents	4.5	3.0	3.2	3.7	4	4	1.2	-0.1
16 Total time to evacuate accidents	5	2.7	5.2	4.4	4	6	1.6	-1.5
OVERALL				4.35	4	4	1.3	-0.8

Legend: D: Designers; C: Construction Engineers; M: Managers.
Av: Average; Med: Median; Mo: Mode; SD: Standard Deviation; Kurt: Kurtosis.

Table 6-4. Accessibility Factor Significance Rating

	DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
	D	C	M	AV	MED	MO	SD	KURT
Traffic accessibility	5.25	4.33	4.6	4.8	5	4	0.75	-1.07
17 Reduction of number of accesses	5.75	4.66	4.4	4.9	5	4	0.90	-1.81
18 Number of forced diversions	4.75	3.66	4	4.2	4	4	1.03	0.91
19 Reduction in running speed	3.5	3.66	3	3.3	3.5	4	0.98	-1.24
Business accessibility	5	5	4.8	4.9	5	5	0.90	1.19
20 Reduction of access points to business	5.5	5.33	4.6	5.1	5	6	0.90	-2.13
21 Reduction in parking space	3.75	4.33	4.2	4.1	4	5	1.08	0.08
22 Additional distance from ramp	3.5	3	3.4	3.3	3	2	1.78	-0.66
23 Constr. congestion in front of business	4	4.66	5	4.6	5	5	1.24	-0.13
OVERALL				4.3	4	4	1.27	0.33

	D	C	M
AV	4.56	4.30	4.22
MED	5.00	4.00	4.00
MOD	6.00	4.00	5.00
ST DEV	1.50	1.03	1.11
KURT	0.97	0.02	0.05

Legend: D: Designers; C: Construction Engineers; M: Managers.

Av: Average; Med: Median; Mo: Mode; SD: Standard Deviation; Kurt: Kurtosis.

Table 6-5. Carrying Capacity Significance Rating

		DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
		D	C	M	AV	MED	MO	SD	KURT
24	Number of cars blocked	6	4.67	5	5.3	6	6	1.2	4.36
25	Blockage duration	5.5	4.67	5.2	5.2	5.5	6	0.93	-1.93
	OVERALL				5.2	6	6	1.06	1.96
	Discipline Average	5.84	4.66	5.1					

Table 6-6. Schedule Performance Significance Rating

		DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
		D	C	M	AV	MED	MO	SD	KURT
26	% Savings in duration	5.25	4.66	5.2	5.1	5	6	1.0	-0.01

Table 6-7. Budget Performance Significance Rating

		DISCIPLINE AVERAGE			SUB FACTOR STATISTICAL INFO				
		D	C	M	AV	MED	MO	SD	KURT
27	% Savings in cost	5.5	4	5.6	5.2	5.5	6	0.94	-1.9

Legend: D: Designers; C: Construction Engineers; M: Managers.
Av: Average; Med: Median; Mo: Mode; SD: Standard Deviation; Kurt: Kurtosis.

Table 6-8. Safety Factor Ease of Measurement

		DISCIPLINE AVERAGE			STATISTICAL INFO				
		D	C	M	AV	MED	MO	SD	KURT
1	Over Hanging equipment	4	3	2.6	3.17	3	2	1.59	0.5
2	Adequacy of traffic barrier	5.75	4	3.8	4.50	5	5	1.45	-0.5
3	Traffic-Activity interaction length	4.5	4.33	2.8	3.75	4	2	1.54	-1.4
4	Machine interruption to traffic line	2.25	1.33	1.6	1.75	2	2	0.87	1.9
5	Distance between traffic and construction	4.75	3.00	3.6	4.33	4	4	1.15	0.3
6	Lane width	5.25	5.33	4.6	5.00	5	6	0.85	-1.7
7	Detour length	5	3.00	4.4	4.83	5	6	1.27	0.6
8	Detour quality	4.5	4.00	3.6	4.00	4	4	1.41	-0.8
9	Working on one side of traffic Vs between...	4.75	4.00	3	3.83	4	4	1.34	-0.6
10	Working at high traffic volumes Vs at low...	3.75	3.33	4.4	3.92	4.5	6	2.07	-1.0
11	Day shift VS night shift	3.5	2.67	4	3.50	4	6	2.15	-0.9
12	Working toward traffic Vs away ...	2.25	1.33	3	2.33	2.5	0	1.67	-0.9
13	Construction activity intensity level	1.75	1.67	2.2	1.92	2	3	1.38	-1.2
14	Type of traffic change	4	4.00	2.8	3.42	4	4	1.56	1.1
15	Type of road on which change takes place	4.5	4.67	4.4	4.50	4	4	1.00	-0.8
16	Total time to evacuate accidents	4	1.67	2.2	2.42	3	0	2.07	-1.0
OVERALL					3.57	4	4	1.75	-0.6

Table 6-9. Accessibility Factor Ease of Measurement

		DISCIPLINE AVERAGE			STATISTICAL INFO				
		D	C	M	AV	MED	MO	SD	KURT
17	Reduction of number of accesses	3.25	3.67	3.2	3.33	3.5	4	1.30	0.76
18	Number of forced diversions	4	3.67	3.4	3.67	4	4	1.07	1.38
19	Reduction in running speed	4	2.67	3.2	3.33	4	4	0.89	-1.27
20	Reduction of access points to business	3.25	4.67	3.2	3.58	4	4	1.24	-0.21
21	Reduction in parking space	5	2.67	3.6	3.83	4	4	1.85	0.09
22	Additional distance from ramp	4.75	4.00	3	3.83	4	4	1.47	4.23
23	Constr. congestion in front of business	3	2.33	3	2.83	2	2	1.27	2.54
OVERALL					3.49	4	4	1.32	0.158

AV	3.38	3.23
MED	4.00	3.00
MOD	4.00	2.00
ST DEV	1.40	1.29
KURT	0.84	0.34

Table 6-10. Carrying Capacity Factor Ease of Measurement

	DISCIPLINE AVERAGE			STATISTICAL INFO.				
	D	C	M	AV	MED	MO	SD	KURT
Number of cars blocked	2.75	3.3	3	3	3	2	1.60	0.44
Blockage duration	2.5	2.66	2.6	2.58	2	2	0.90	-0.91
OVERALL				2.8	2	2	1.28	0.83
AV	2.625	3	2.8					

Table 6-11. Schedule Performance Factor Ease of Measurement

	DISCIPLINE AVERAGE			STATISTICAL INFO.				
	D	C	M	AV	MED	MO	SD	KURT
% Savings in duration	3.5	3.33	3	3.25	2.5	2	1.48	-1.08

Table 6-12. Budget Performance Factor Ease of Measurement

	DISCIPLINE AVERAGE			STATISTICAL INFO.				
	D	C	M	AV	MED	MO	SD	KURT
% Savings in cost	4.5	3.67	3	3.67	3	3	1.61	-1.34

Legend: D: Designers; C: Construction Engineers; M: Managers.
Av: Average; Med: Median; Mo: Mode; SD: Standard Deviation; Kurt: Kurtosis.

6.2 DATA ANALYSIS

This section analyzes the major findings of the interviews as regards the need for the model and the major evaluation factors.

Macro Level Analysis

There were no suggestions for additional major factors other than the five already existing, as they effectively cover the domain. The average score for all major factors was 4.76 (out of 6), with a median of 5 (50% of all factors scored 5 or 6). This indicates a high level of approval for the suggested factors and sub-factors (Table 6-1).

The interviewees were in general agreement (Kurt=10) that safety is the most important factor (av=5.75). The other four factors—accessibility, carrying capacity, schedule, and budget—received ratings of 4.58, 4.58, 4.41, and 4.5, respectively. See Table 6-1 for more details.

It should be noted that managers tended to give higher ratings. Their average rating was 4.84, which is greater than the overall average of 4.76. This may be due to their higher level of responsibility and wider focus. Construction engineers gave the next highest ratings, with an average of 4.8. Designers gave an average of 4.7 (Fig 6-1).

The kurtosis of the major factors rating is negative (-1.44), resulting in a curve flatter than the typical curve. This indicates that, despite their belief in the importance of factors (as expressed in average and median values), the interviewees tended to disagree about the relative importance of these factors. This is clear in their ratings for schedule and budget factors, with managers favoring budget (av = 4.3) and construction engineers considering schedule more important (av = 5). Designers were more evenly divided in their ratings (av = 4 for both). See Tables 6-6 and 6-7 for more details.

Budget was the most disputed major factor (kurt = -1.44). This may be attributed to the fact that some interviewees thought that direct budget outlay is very important, while others thought that other indirect costs to traffic and businesses are more important.

The majority of interviewees indicated that it is easy to estimate factors during the design phase (av = 3.48, median = 4, mode = 4), and is shown in Table 6-2. Designers' average rating was 3.85, which is higher than the overall average. Managers and construction engineers were more skeptical about the ease of measuring these factors and gave average ratings of 3.23 and 3.42, respectively.

In comparing the ease of measuring the major factors, interviewees ranked them as follows (based on the average rating of all sub-factors): budget, 3.67; safety, 3.57; accessibility, 3.48; schedule, 3.25; and carrying capacity, 2.8.

Designers gave similar rankings with mostly higher ratings than average: budget, 4.5; safety, 4; accessibility, 3.9; schedule, 3.5; and carrying capacity, 2.63. See Tables 6-2, and 6-8 through 6-12 for more details.

Tables 6-13 and 6-14 show the overall rank of the sub-factors' significance and ease of measurement. In significance, the top ranks were evenly shared by all major factors. However, when it came to ease of measurement, safety dominated the top ranks. The evaluators ranked some safety sub-factors higher (easier to evaluate) than those for the current dominating evaluation parameter (budget). This indicates that not only should other parameters be included in the analysis of a BCP, but also that they may be easier to evaluate.

Table 6-13. Sub Factors Ranked by Significance

#	Sub Factor	Major Factor	Signficance Score
24	Number of cars blocked	C.C.	5.25
9	Working on one side of traffic Vs both	Safety	5.16
25	Blockage duration	C.C.	5.16
27	% Savings in cost	Budget	5.16
2	Adequacy of traffic barrier	Safety	5.1
20	Reduction of access points to business	Access.	5.08
26	% Savings in duration	Schedule	5.08
17	Reduction of number of traffic accesses	Access.	4.91
1	Over Hanging equipment	Safety	4.9
10	Working at high traffic volumes Vs low	Safety	4.9
8	Detour quality	Safety	4.8
4	Machine interruption to traffic line	Safety	4.7
6	Lane width	Safety	4.6
11	Day shift VS night shift	Safety	4.6
23	Constr. congestion in front of business	Access.	4.58
14	Type of traffic change	Safety	4.5
16	Total time to evacuate accidents	Safety	4.4
18	Number of forced diversions	Access.	4.16
5	Distance between traffic and construction	Safety	4.1
21	Reduction in parking space	Access.	4.08
13	Construction activity intensity level	Safety	4
15	Type of road where change takes place	Safety	3.9
19	Reduction in running speed	Access.	3.33
22	Additional distance from ramp	Access.	3.33
3	Traffic-Activity interaction length	Safety	3.3
7	Detour length	Safety	3.2
12	Working toward traffic Vs away	Safety	2.6

Access: Accessibility Factor; C.C.: Carrying Capacity Factor.

Table 6-14. Sub Factors Ranked by Ease of Measurement

#	Sub Factor	Major Factor	Ease of Measurment
6	Lane width	Safety	5
7	Detour length	Safety	4.83
2	Adequacy of traffic barrier	Safety	4.5
15	Type of road where change takes place	Safety	4.5
5	Distance between traffic and construction	Safety	4.33
8	Detour quality	Safety	4
10	Working at high traffic volumes Vs low	Safety	3.92
9	Working on one side of traffic Vs both	Safety	3.83
21	Reduction in parking space	Access.	3.83
22	Additional distance from ramp	Access.	3.83
3	Traffic-Activity interaction length	Safety	3.75
18	Number of forced diversions	Access.	3.7
27	% Savings in cost	Budget	3.7
20	Reduction of access points to business	Access.	3.6
11	Day shift VS night shift	Safety	3.5
14	Type of change	Safety	3.4
17	Reduction of number of traffic accesses	Access.	3.3
19	Reduction in running speed	Access.	3.3
26	% Savings in duration	Schedule	3.3
1	Over Hanging equipment	Safety	3.2
24	Number of cars blocked	C.C.	3.0
23	Constr. congestion in front of business	Access.	2.8
25	Blockage duration	C.C.	2.6
16	Total time to evacuate accidents	Safety	2.4
12	Working toward traffic Vs away	Safety	2.3
13	Construction activity intensity level	Safety	1.9
4	Machine interruption to traffic line	Safety	1.75

Access: Accessibility Factor; C.C.: Carrying Capacity Factor.

Micro Level Analysis

This section analyzes the factor-level results of the interviews. The sub-factor level details are shown in Appendix B.

Safety factor

Significance

The interviewees agreed (kurt = -.7) that the proposed sub-factors are meaningful and representative of the domain (av = 4.34, median = 4, mode = 4). Managers were more convinced of the significance of these sub-factors (av = 4.5), and were in general agreement (kurt = -.01). Designers were next, with an average of 4.38. The lowest scores were given by construction engineers, with an average of 4.02 (Table 6-3 and Figure 6-1).

In terms of their significance, sub-factors were ranked as follows:

- Travelers interaction with construction activities (5)
- Detour configuration (5)
- Crew interaction with traffic (4.7)
- Traffic changes (4.1)
- Access to accidents (3.7)

The highest ranked sub-factors (scores above 4.75) were:

- Working on one side of traffic vs. between traffic lines (5.1)
- Adequacy of traffic barrier (5.1)
- Overhanging equipment (4.9)
- Working at high traffic volumes vs. low traffic volumes (4.9)
- Detour quality (4.8)

The lowest ranked sub-factor (factors below 3) was:

- Working toward traffic vs. away from traffic (2.6)

Ease of measurement

In general, all interviewees thought it easy to measure the proposed parameters (av = 3.57). Designers thought it easier to do the evaluation than did managers and construction engineers (av = 4, i.e., easy to estimate) and were in general agreement (kurt = 0.4).

Nonetheless, one sub-factor, crew interaction with traffic, drew mixed opinions as to the ease of measurement. While one designer gave the majority of sub-factors under this title a score of six, another designer gave them a score of zero. However, three out of four designers interviewed thought it easy to make the estimate. They rated it at four or higher (Table 6-8 and Figure 6-3).

The following sub-factors were ranked as easiest (score of 4.5 or higher):

- Lane width (5)
- detour length (4.8)
- Adequacy of traffic barrier (4.5)

The following-sub-factors were ranked the lowest (scores of 2 or lower):

- Machine interruption to traffic line (1.75)
- Construction activity intensity level (1.9)

Accessibility factor

Significance

Again, interviewees expressed their satisfaction with the meaningfulness of the proposed sub-factors. The average score was 4.3, with a median of 4 and a mode of 4. Furthermore, they tended to strongly agree (kurt = 0.33) (Table 6-4 and Figure 6-1).

Designers rated the sub-factors' significance the highest (av = 4.56). Construction engineers gave the next highest rating (av = 4.3), while the managers rated it the lowest (av = 4.22).

The highest ranked sub-factors were:

- Reduction of access points to business (5)
- Reduction of number of accesses for traffic (4.9)

The lowest ranked sub-factors were:

- Reduction in running speed (3.33)
- Additional distance from ramp (3.33)

Overall, interviewees tended to favor issues of business access over traffic access. The average rating was 4.9 and 4.75 for business and traffic access, respectively (Table 6-4).

Ease of measurement

The average score for ease of measuring all sub-factors was 3.48, indicating that interviewees thought it relatively easy to make the estimate in the design stage. Again, designers thought it easier to make the assessment than did managers and construction engineers. Their average rating was 3.9, indicating an easy assessment. Managers and construction engineers gave average ratings of 3.23 and 3.38, respectively. It should be noted that the input of all respondents was fairly consistent and close (kurt = 0.157) (Table 6-9).

Carrying capacity factor

Significance

The average significance score of all sub-factors was 5.2, the highest score among all sub-factors. This indicates that the interviewees strongly agree (kurt = 1.96) that these sub-factors significantly represent the need to evaluate the proposed factor in the design phase. The opinions of designers, construction engineers and managers were very close and consistent in rating this factor (Table 6-5).

Ease of measurement

The interviewees agreed that it is difficult to measure the sub-factors in the design stage. The average score was 2.8

Schedule performance factor

Significance

The interviewees gave the suggested sub-factor (% savings in duration) an average rating of 5, which indicates that they are satisfied with this parameter as an indicator of schedule performance. The ratings were consistent and close among all interviewees (Table 6-6, Fig 6-1).

Ease of measurement

The interviewees gave the suggested sub-factor a score of 3.25 in ease of measurement. Again, designers gave it the highest rating (3.5), followed by construction engineers with 3.3, and mangers with 3 (Table 6-11, Fig 6-3).

Budget performance factor

Significance

The interviewees gave the suggested sub-factor (% savings in cost) an average rating of 5.1, which indicates that they are satisfied with this parameter as an indicator of budget performance. The ratings were consistent among all interviewees (Table 6-7, Fig 6-1).

Ease of measurement

The interviewees gave the suggested sub-factor a score of 3.67 for its ease of measurement. Again, designers gave it the highest rating (4.5). Construction engineers rated it at 3.67, and mangers gave it a rating of 3 (Table 6-12, Fig 6-3).

6.3 MODEL ADJUSTMENT

Redundancies and Interdependencies

Several interviewees expressed concerns about the possible redundancy among some sub-factors under the safety factor. The first concern was between "adequacy of traffic barrier" and "distance between traffic and construction." They explained that if the barrier is adequate, the distance between traffic and construction is of little significance. Accordingly, the second sub-factor will be re-defined as "distance between traffic and construction if there is no traffic barrier." The interviewees agreed on this new definition and rated it accordingly as shown in the original response tally in Appendix B.

Another concern was the redundancy between "adequacy of traffic barrier" and "interaction length between traffic and construction." Some interviewees explained that if the barrier is adequate, the second sub-factor is of little significance. The second sub-factor will be redefined as "interaction length between traffic and construction if there is no traffic barrier." The interviewees based their ratings on this definition, as shown in the response tally in Appendix B.

Additional Parameters

Several interviewees suggested that a few parameters be added to the model. As previously explained, most of them were non-discriminating and were reflections of site characteristics or contract provision (something that is shared by all BCP's under study). These parameters are as follows:

Additional major factors

Following are additional parameters suggested by some of the interviewees.

Bridge Aesthetics

This is part of the value engineering and structural design phase of the bridge; hence, it is outside the scope of this study.

Constructability

As defined by the Construction Industry Institute at The University of Texas at Austin, constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project success. It covers two major areas: design philosophy and details, and construction sequencing and planning. The first area is outside the study scope. The second area is the core of this study and is included in almost every parameter, including overhanging equipment, construction activity intensity level, traffic-construction interaction length, and day-vs.-night shifts. It was decided that adding constructability as a separate factor would be redundant.

Additional safety sub-factors

Lighting conditions

This sub-factor is very important for ensuring the safety of crew and travelers at night. Higher accident rates are usually recorded at night (Ref 11). However, this sub-factor can be added to any plan by the designers, making it a non-discriminating parameter. While this sub-factor is very important for enhancing BCP performance, it cannot be part of the evaluation process.

Average running speed on highway

Again, this parameter is a major factor in accident rates within freeway construction zones (Ref 11). However, it is something shared by all BCP's under evaluation, and as such is non-discriminating.

Type of construction activity

This parameter was suggested as a way of distinguishing between the pavement and structural activities of a bridge. It was decided that the difference between the two types of activities is insignificant.

Detour pavement quality (smoothness)

Pavement skid resistance has an effect on safety (Ref 11). However, every BCP can enhance skid resistance by using a higher quality mix. Therefore, this parameter is included within the budget performance factor.

Additional accessibility sub-factors

Contractor access to construction activities

This sub-factor evaluates provisions in a BCP for the contractor to easily access the site, including access to such machinery as cranes and hauling equipment. It was decided that this is a valuable and important suggestion. Moreover, it is a discriminating parameter that can give one plan an edge over another. Hence, this parameter will be added to the model.

Parking for workers

Although parking can be a problem in some areas, it was decided that this parameter is not significant and general enough for inclusion in the model.

Additional sub-factors for schedule evaluation

Plan adaptation to weather conditions

This was suggested as a way of testing whether a plan works to mitigate bad weather periods (i.e., whether or not it requires intense levels of work during bad weather periods). The parameter was not added because (1) it depends on bridge location, (2) given that bridge projects span several years on average, it will be difficult to assess this parameter, and (3) given also that the weather pattern is the same for all BCP's, this parameter can hardly be discriminating.

Additional sub-factors for budget evaluation

Cost savings/time unit

This proposal was rejected because it is redundant. Cost and time savings are already included in the major evaluation factors.

6.4 SELECTING FINAL PARAMETERS AND THEIR VALUE

Though the majority of interviewees gave high ratings for the suggested factors on average, some of the sub-factors scored low either in significance or ease of measurement (Tables 6-13, 6-14). Both criteria are important to the validity of the model. Significance indicates the importance and meaningfulness of a parameter; hence, it indicates the model's statistical and internal validity. Ease of measurement is directly related to the applicability of the model; hence, its external validity.

It was decided to include any factor in the final model based on both criteria. The simplest way of combining two criteria is either by adding them or multiplying them (Ref 21) but multiplication is more sound when the two criteria have different units, as in the present case. The combined measure of significance and ease of measurement was defined as the value of a parameter. It is the product of a parameter's significance and ease of measurement ratings (see Equation 6-1).

*Parameter Value = Significance Rating * Ease of Measurement Rating* *6-1*

A perfect parameter will have a value score of 36. A totally irrelevant parameter will have a score of zero. Given that the middle of both scores is 3, a threshold parameter value of 12.25 (3.5 X 3.5) was selected to be the cutoff score. However, as a traditional linear programming problem, it is not an abrupt cutoff point. For example, a score lower than 12.25 can present a relatively desirable sub-factor with 3.6 and 3.3 ratings.

The following selection rule was then devised:

1. Accept sub-factor if:

   Value $\geq$ 12.25 and

   significance > 3.5 and

   Ease of measurment > 3.5

2. Reject sub-factor if:

   Significance $\leq$ 2.5 and

   Ease of measurment $\leq$ 2.5

3. Analyze sub-factor if:

   it lies between these two domains.

Figure 6-5 shows a value analysis matrix that explains the three solution domains.

The analysis of the value score of all sub-factors is shown in Table 6-15 and Figure 6-6. The five most valuable sub-factors belong to the safety factor, followed by cost savings. Except for the five sub-factors, all sub-factors satisfy the first rule in decision rationale. Hence, they will be recommended for inclusion in the final model.

The value analysis matrix for all sub-factors is shown in Figure 6-7. The five sub-factors under 12.25 lie in the analysis domain and are discussed below.

#19 Reduction in running speed

This sub-factor scored moderately in both significance and ease of measurement (3.3 in both). Such a relatively low significance score indicates that the sub-factor may not be discriminating enough to give one plan an edge over another. In addition, the relatively low score regarding ease of measurement suggests that this parameter is not objective enough for evaluation during the design phase. Accordingly, this sub-factor will not be included in the final model. Nonetheless, a design team may wish to add it to the analysis for sites where it would be more discriminating.

 # 16 Total time to evacuate accidents

This sub-factor scored very low on ease of measurement (2.4), while its significance score was 4.4. Clearly, interviewees had concerns over its ease of measurement. It will not be included in the model in the interest of applicability. Again, designers are encouraged to utilize it whenever site/project conditions make it more important to the analysis or easier to evaluate.

#4 Machine interruption to traffic line

Though highly significant to the safety of both travelers and crew, interviewees explained that this parameter depends on the contractor equipment selection, which is not known during the design stage. This sub-factor will be removed in the interest of model applicability.

#12 Working toward traffic vs. away from traffic

This sub-factor scored lowest for significance among all sub-factors (2.6). Most of the interviewees felt that this concern is well covered by other parameters such as "adequacy of traffic barrier" and "distance between traffic and construction." This sub-factor will be excluded from the model to avoid redundancy.

#13 Construction activity intensity level

This sub-factor was rated second lowest for ease of measurement (1.9). Most of the interviewees were concerned about its subjectivity and evaluation time. Because of concerns over applicability, this sub-factor will be excluded.

Aware of the fact that the model is a new tool, the research followed a conservative approach in eliminating all five sub-factors under 12.25 (especially #19 and #16). No matter how significant, a sub-factor that seemed hard to measure was eliminated in the interest of model applicability. Conflicts caused by hard-to-measure parameters may hinder the application of the model. In the future, when the model is institutionalized in the design process, these sub-factors can be revisited. In fact, all sub-factors should be reviewed periodically to amend them to reflect site lessons.

6.5 CONCLUSIONS

Six major conclusions can be drawn from these interviews.

1. There is a need for developing a model to evaluate a BCP. This was made clear from the high ratings (especially regarding parameter significance) and from the after-interview discussions.
2. Five major factors are key to the evaluation: safety, accessibility, carrying capacity, schedule performance, and budget performance.
3. Interviewees considered that most of the proposed evaluation factors and sub-factors were meaningful and easy to apply. The final approved factor list is shown in Table 6-16.
4. Measurement ratings were generally lower than significance ratings. This could be due to the interviewees' aversion to adding new and lengthy tasks to the already stressed design department. The final model should work, then, to simplify the evaluation procedures.
5. The research can move to the next step in developing a detailed model.
6. Based on interviewees' comments, the design process will need to undergo some changes to allow the application of this model.

Table 6-15. Sub Factor Value Analysis

#	Sub Factor	Major Factor	Sub Factor Value	Value Analysis	Decision
6	Lane width	Safety	23	ABOVE TARGET SCORE	RECOMMEND
2	Adequacy of traffic barrier	Safety	22.95		
9	Working on one side of traffic Vs	Safety	19.81		
8	Detour quality	Safety	19.20		
10	Working at high traffic volumes Vs	Safety	19.19		
27	% Savings in cost	Budget	18.91		
20	Reduction of access points to business	Access.	18.22		
5	Distance between traffic and constr	Safety	17.77		
15	Type of road where change takes place	Safety	17.55		
26	% Savings in duration	Sched.	16.52		
17	Reduction of #of traffic accesses	Access.	16.39		
11	Day shift VS night shift	Safety	16.10		
24	Number of cars blocked	C.C.	15.75		
21	Reduction in parking space	Access.	15.65		
1	Over Hanging equipment	Safety	15.52		
7	Detour length	Safety	15.47		
14	Type of traffic change	Safety	15.38		
18	Number of forced diversions	Access.	15.28		
25	Blockage duration	C.C.	13.35		
23	Constr. congestion in front of business	Access.	12.99		
22	Additional distance from ramp	Access.	12.78		
3	Traffic-Activity interaction length	Safety	12.38		
19	Reduction in running speed	Access.	11.11	*PERFORM*	*REMOVE*
16	Total time to evacuate accidents	Safety	10.63		
4	Machine interruption to traffic line	Safety	8.23	*MORE*	*FROM*
13	Construction activity intensity level	Safety	7.67		
12	Working toward traffic Vs away	Safety	6.07	*ANALYSIS*	*MODEL*

Access: Accessibility Factor; C.C.: Carrying Capacity Factor; Sched.: Schedule Factor

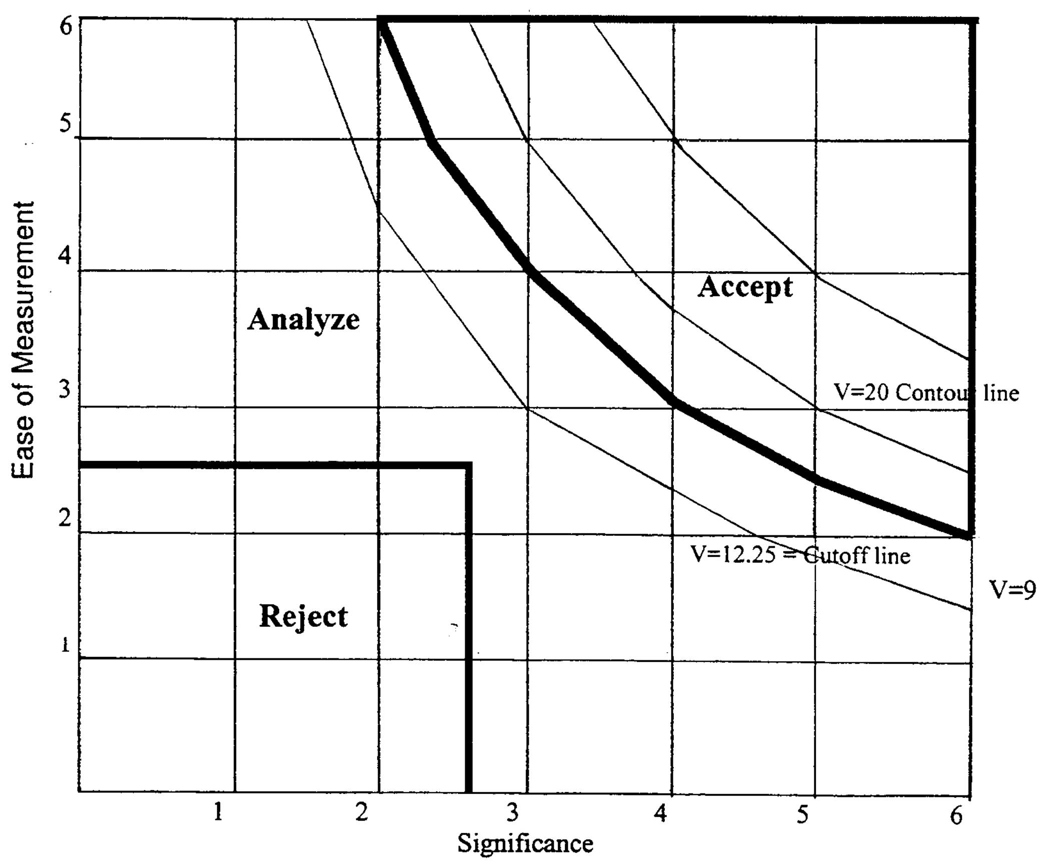

Figure 6-5. Sub Factor Value Analysis Matrix

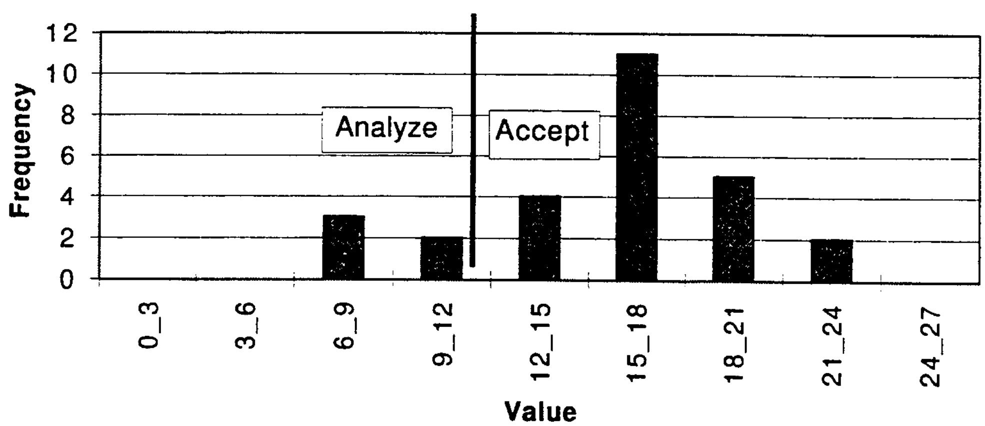

Figure 6-6. Sub Factor Value Frequencies

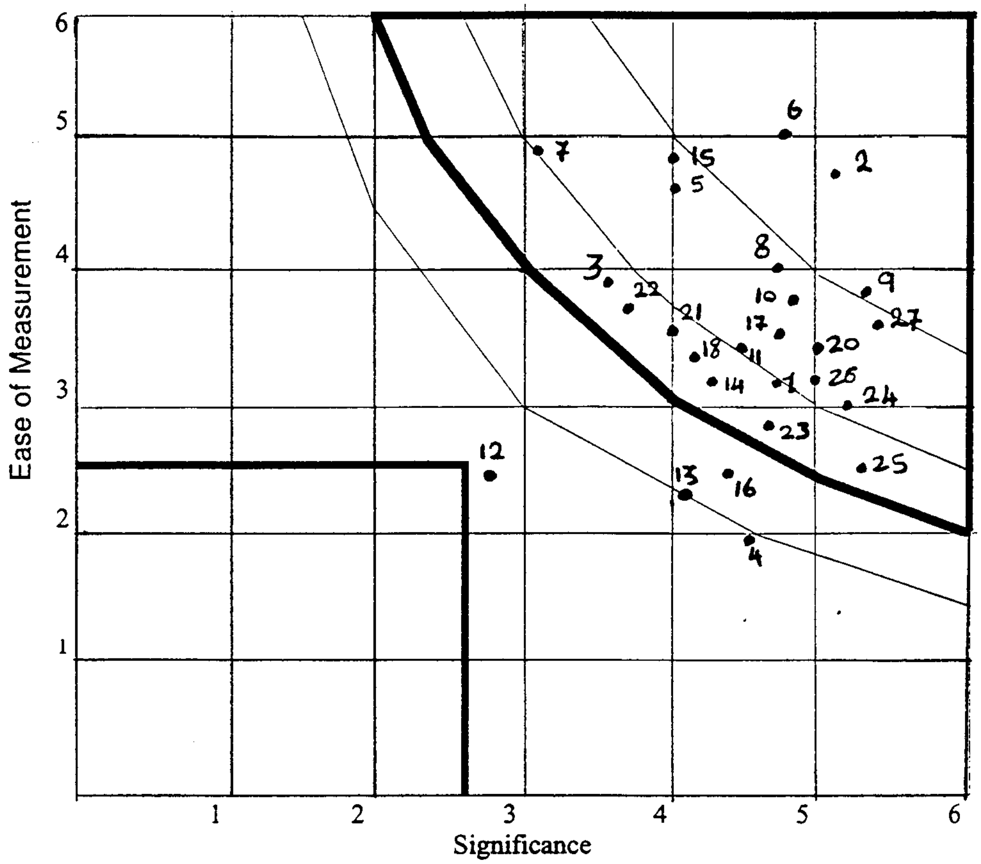

Figure 6-7. Sub Factor Value Analysis

Table 6-16. Final Sub Factor List

MAJOR FACTOR	SUB FACTOR
SAFETY	Over Hanging equipment Adequacy of traffic barrier Traffic-Activity interaction length Distance between traffic and construction
	Lane width Detour length Detour quality
	Working on one side of traffic vs between traffic lines Working at high traffic volumes vs at low traffic volumes Day shift vs night shift
	Type of traffic change Type of road on which traffic change takes place
ACCESSIBILITY	Reduction of number of traffic accesses Number of forced diversions
	Reduction of access points to business Reduction in parking space Additional distance from ramp Constr. congestion in front of business
	Contractor access to work zone*
CARRYING CAPACITY	Number of cars blocked Blockage duration
SCHEDULE	% Savings in duration
BUDGET	% Savings in cost

* Added based on interview results.

7. FINAL BCP EVALUATION MODEL

This chapter presents a model for evaluating BCP effectiveness during the design phase. The model is built in a multiple objective decision-making (MODM) format to allow the inclusion of the various factors controlling the optimality of the BCP. The model is composed of a collection of evaluation factors and sub-factors that can be used for measuring BCP performance, a general structure and procedures for evaluation, and a set of suggested relative weights for the proposed evaluation factors.

It is important to mention that the purpose of this model is not to act as an expert system. Rather, the model is meant to encourage BCP analysis and to assist in the decision-making process during the design phase. Toward this purpose, the model includes only generic evaluation parameters that apply to the majority of bridge projects. Additional project-specific factors and sub-factors are still needed to meet the special needs of each individual project. Therefore, the design team is encouraged to analyze the project at hand and to develop additional parameters that are project specific. As a result, the evaluation procedures were designed in a format sufficiently flexible to include new factors.

7.1 RECOMMENDED BCP EVALUATION FACTORS

Throughout the data collection phase of this research effort, several evaluation factors were developed. However, not all of them were ultimately recommended. Some factors were irrelevant, project specific, or excessively subjective. To test the relevance, stepwise analysis was conducted to examine the meaningfulness and value of all proposed factors.

Consistently, five major factors survived and dominated every phase of the analysis: safety, accessibility, carrying capacity, schedule, and budget. Therefore, these five factors are recommended for evaluating a BCP. Several sub-factors were developed to assist in evaluating these major factors. Table 7-1 presents the recommended list of evaluation factors, along with their sub-factors.

Table 7-1. Recommended Factor List

Major Factor		Sub-factor	Symbol
Safety			S
	1	Overhanging equipment	h
	2	Adequacy of traffic barrier	a_t
	3	Traffic-Activity interaction length	t_a
	4	Distance between traffic and construction	d
	5	Lane width	l
	6	Detour length	d_l
	7	Detour curve quality	q
	8	Working on one side of traffic vs working between traffic lines	k_s
	9	Working at high traffic volumes vs working at low traffic volume	k_h
	10	Day shift vs night shift	d_s
	11	Traffic change	t_c
Accessibility			A
	12	Reduction of number of traffic accesses	r_t
	13	Number of forced diversions (to traffic)	f
	14	Reduction of access points to businesses	r_b
	15	Reduction in businesses parking space	p
	16	Additional distance from ramp (for businesses)	a_d
	17	Constr. congestion in front of business	g
	18	Contractor access to work zone	z
Carrying capacity			C
	19	Number of cars blocked or delayed	c
	20	Blockage/Delay duration	b
Schedule			T
	21	% savings in time	_
Budget			B
	22	% savings in cost	_

This factor list was the product of site observation, analysis of previous project documents, and formal and informal interviews with design, construction, and management personnel in owner, consulting, and contracting firms. A brief description of these factors/sub-factors follows, with complete descriptions of each presented in Appendix C.

Safety Factor

The safety factor is proposed for ensuring the level of safety a BCP can provide to both the traveling public and the construction crew above and beyond the minimum standards. It includes the following sub-factors:

1. Overhanging equipment: situations in which construction equipment is overhanging or swinging over traffic.
2. Adequacy of traffic barrier: how well the traffic barrier separates traffic from construction activities.
3. Traffic-activity interaction length: the length of construction activity adjacent to traffic.
4. Distance between traffic and construction activity: the cross distance between traffic and construction activity.
5. Lane width: the average lane width of the freeway and frontage road during construction.
6. Detour length: measures total detours required to perform the construction.
7. Detour curve quality: measures the sharpness of horizontal and vertical curves which is related to sight line and detour alignment.
8. Working on one side of traffic vs. between traffic lines: the location of crew relative to traffic. Working between traffic lines is a more dangerous situation.
9. Working at high traffic volume vs. low traffic volume: the intensity of traffic around construction activity. A crew working within high traffic volumes is in a more dangerous situation than a crew working within low traffic volumes.
10. Day shift vs. night shift: crew visibility to traffic. Night shifts are more dangerous than day shifts.
11. Traffic changes: the changes to traffic path such as lane drop, traffic diversion, and freeway closure. It also differentiates between changes to highway, frontage road, and secondary roads.

Accessibility Factor

The evaluation factor is proposed for assessing the BCP's effect on traffic, business, and contractor accessibility during construction. It includes the following sub-factors:

12. Reduction of number of traffic accesses: evaluates the frequency of closing highway on/off ramps.

13. Number of forced diversions (to traffic): forced diversions to traffic, like diverting traffic to another road.
14. Reduction of access points to businesses: evaluates the frequency of closing/impeding access to businesses.
15. Reduction of parking space: the reduction in business parking spaces caused by construction work.
16. Additional distance from ramp (for business): evaluates the impact of changing ramp locations on business activity.
17. Construction congestion in front of business: the level of work around the business that may impede access to business.
18. Contractor access to work zone: the availability of access to such contractor equipment as cranes or hauling equipment.

Carrying Capacity Factor

This factor evaluates BCP impact on the carrying capacity of the freeway. A BCP usually requires closing portions of the freeway, which results in more congestion on other city roadways as well as increased user cost. Two sub-factors were developed to evaluate this factor:

19. Number of cars blocked/delayed: estimated number of cars blocked or delayed on the highway in each closure.
20. Blockage/delay duration: total estimated time in which cars are being blocked or delayed on the highway.

Schedule Performance

This factor evaluates the effectiveness of a BCP's schedule. It is measured through the following sub-factor:

21. Percentage of savings in schedule

Budget Performance

This factor evaluates the effectiveness of a BCP's budget. It is measured by the following sub-factor:

22. Percentage of cost savings.

Of all sub-factors, 14 were consistently rated high for their significance. Each of these sub-factors was scored at 4.5 or more (out of 6) in the data acquisition interviews and the model validation interviews (Chapter 8). These 14 sub-factors are highly recommended for evaluation in any BCP. If time constraints during the design phase do not allow the full application of the model, designers can use the reduced list shown in Table 7-2.

Table 7-2. Reduced Factor List

Major Factor		Sub-factor
Safety		
	2	Adequacy of traffic barrier
	5	Lane width
	7	Detour curve quality
	8	Working on one side of traffic vs working between traffic lines
	9	Working at high traffic volumes vs working at low traffic volume
	10	Day shift VS night shift
	11	Type of traffic change
Accessibility		
	12	Reduction of number of traffic accesses
	13	Number of forced diversions (to traffic)
	14	Reduction of access points to businesses
Carrying capacity		
	19	Number of cars blocked or delayed
	20	Blockage/Delay duration
Schedule		
	21	% savings in time
Budget		
	22	% savings in cost

7.2 MODEL GENERAL STRUCTURE

A major research concern was the selection of an appropriate technique for scoring the individual sub-factors and then aggregating these scores into one final metric. Two criteria were developed to guide the selection of the most appropriate technique: (1) the technique should allow for the addition of more parameters without affecting the model's general structure (flexibility); and (2) the technique should be fairly simple. Design teams usually work with a restricted schedule.

Because a BCP has to satisfy a wide spectrum of factors for it to be optimum, its evaluation lends itself to multiple objective decision-making (MODM). MODM is a branch of decision-making science that refers to making decisions (e.g., evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes (Ref 21). Recently, MODM has replaced cost-benefit analysis as the leading technique in public planning and administration (Ref 22).

MODM usually includes several steps, including defining a set of decision (evaluation) attributes, assessing the attributes' relative importance, assessing a score for each alternative against each attribute, and aggregating each alternative's scores to define the optimal one.

There are numerous methods for defining the optimal alternative. Some of them are fairly simple in terms of their mathematical procedures while others are rather complex. In referring to complexity of evaluation, Hogarth noted that "people naturally resist the analysis of a problem in a 'language' they do not fully comprehend" (Ref 29). With that in mind, simplicity was emphasized in selecting the final technique.

Several research studies were conducted to compare various techniques of MODM analysis. Karni and others (Ref 28) compared three widely used techniques: the analytical hierarchical technique (AHP), the simple additive weighting (SAW), and goal programming. They found that there is no significant difference in the outcome of the three techniques when applied to the same decision situation.

Another study (Ref 21) analyzed more than 13 different MODM methods and concluded that method choice is not as crucial to a successful MODM analysis as the generation of appropriate attributes. However, among the various techniques of MODM, SAW is widely accepted as the simplest and most flexible technique (Refs 21, 28). In its simplest format, it defines the optimal decision based on the weighted sum of all attributes' scores.

Of significance to this study, Riggs (Ref 26) devised a modified version of the SAW, which he called objective matrix technique (OM). OM has a fairly simple and flexible scoring mechanism that can be "adapted to fit most any production/construction situation." Tucker and others (Ref 20) recommended the use of OM for evaluating construction industry issues. OM has the ability to measure and track performance of various difficult-to-measure functions and is suitable for the needs of the construction industry.

The OM was selected to be the aggregation technique for the model based on the literature analysis surrounding MODM. The OM is simple, flexible, and general. Different MODM techniques yield the same decision, and potential users of the proposed model tend to be averse to time-consuming or sophisticated evaluation techniques.

7.3 MODEL STEPS

Appendix C presents the details of model evaluation steps for a generic BCP. Appendix E explains the evaluation process for a real case. Figure 7-1 shows the model's relative position within the BCP development process. The major steps of the model are as follows:

a. analyze project conditions and needs,
b. develop any additional evaluation factors,
c. select/combine the final evaluation list,
d. adjust relative weights to the project needs (see Section 7.4),
e. evaluate each sub-factor for each plan (see Section 7.2.5 and Appendix C),
f. calculate major factors' scores for each plan (see equations 7-2 to 7-4), and
g. calculate each plan's final score (see equation 7-1).

7.4 MODEL EQUATIONS

In OM, every sub-factor is evaluated on a scale of 1 to 10, with 10 being the best score. The score of each major factor is the weighted sum of all its sub-factors. The final score of a BCP is the weighted sum of the scores of all major factors. For more details about the scoring of each individual sub-factor see Section 7.5, Appendix C, and Appendix E.

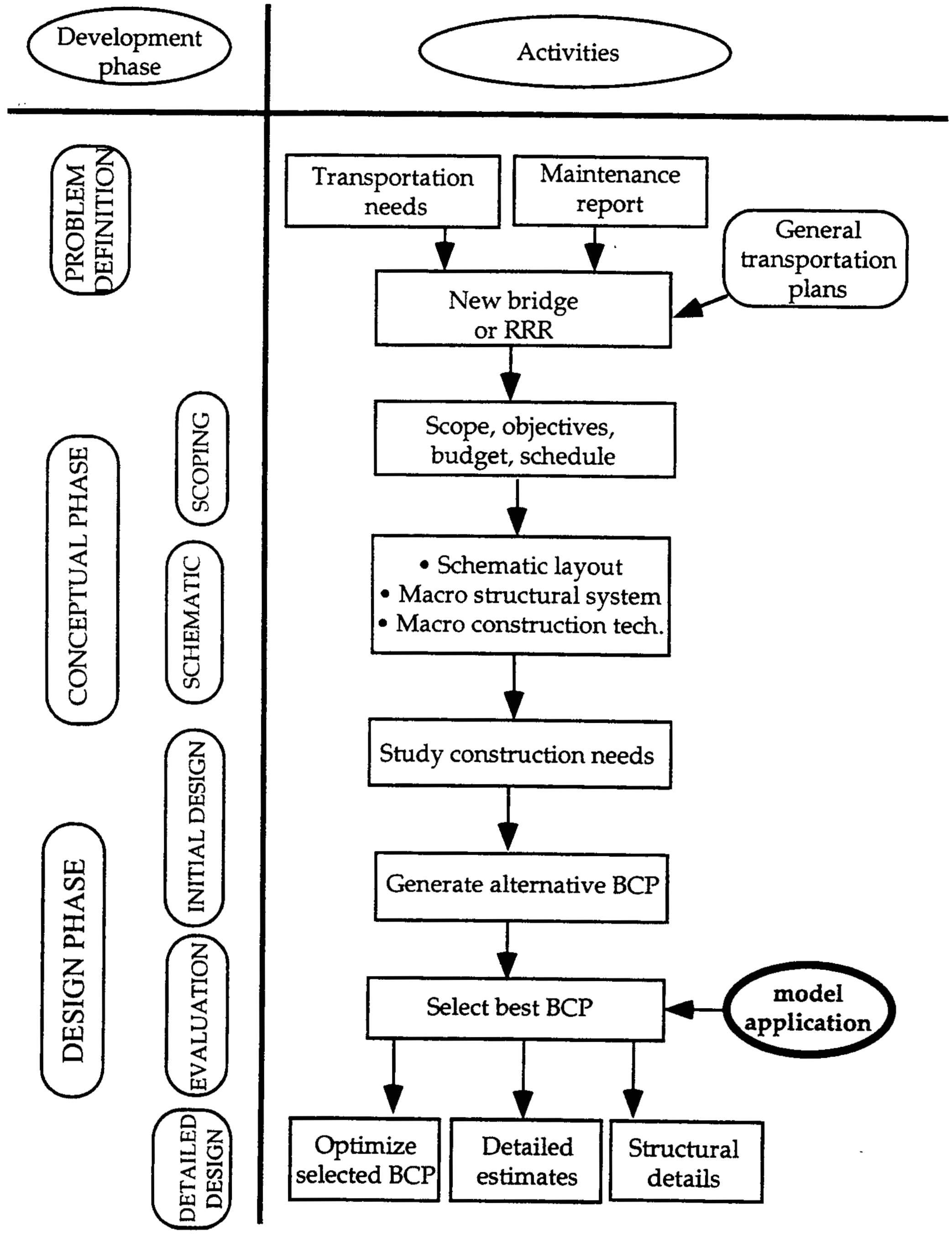

Figure 7-1. BCP Evaluation Model Application as Part of the Design Process

The evaluation equations of the model are presented below in equations 7-1 through 7-4. Figure 7-2 also shows the final OM, while Figures 7-3 and 7-4 show the OM for safety and accessibility, respectively.

BCP Final score (F)

$$F = w_1 * S + w_2 * A + w_3 * C + w_4 * T + w_5 * B + w_6 * Q \quad 7\text{-}1$$

Safety Score (S)

$$S = \sum_{i=1}^{i=12} w_i * SF_i \quad 7\text{-}2$$

Accessibility score (A)

$$A = \sum_{i=13}^{i=19} w_i * SF_i \quad 7\text{-}3$$

Carrying capacity score (C)

$$C = \sum_{j=1}^{j=n} c_j * b_j \quad 7\text{-}4$$

where:

i: Sub-factor counter

n: Number of blockage/delay incidents in a plan

c: Number of cars blocked or delayed in each condition

b: Duration of each delay or blockage condition

SF: Sub-factor score

w: Relative weights

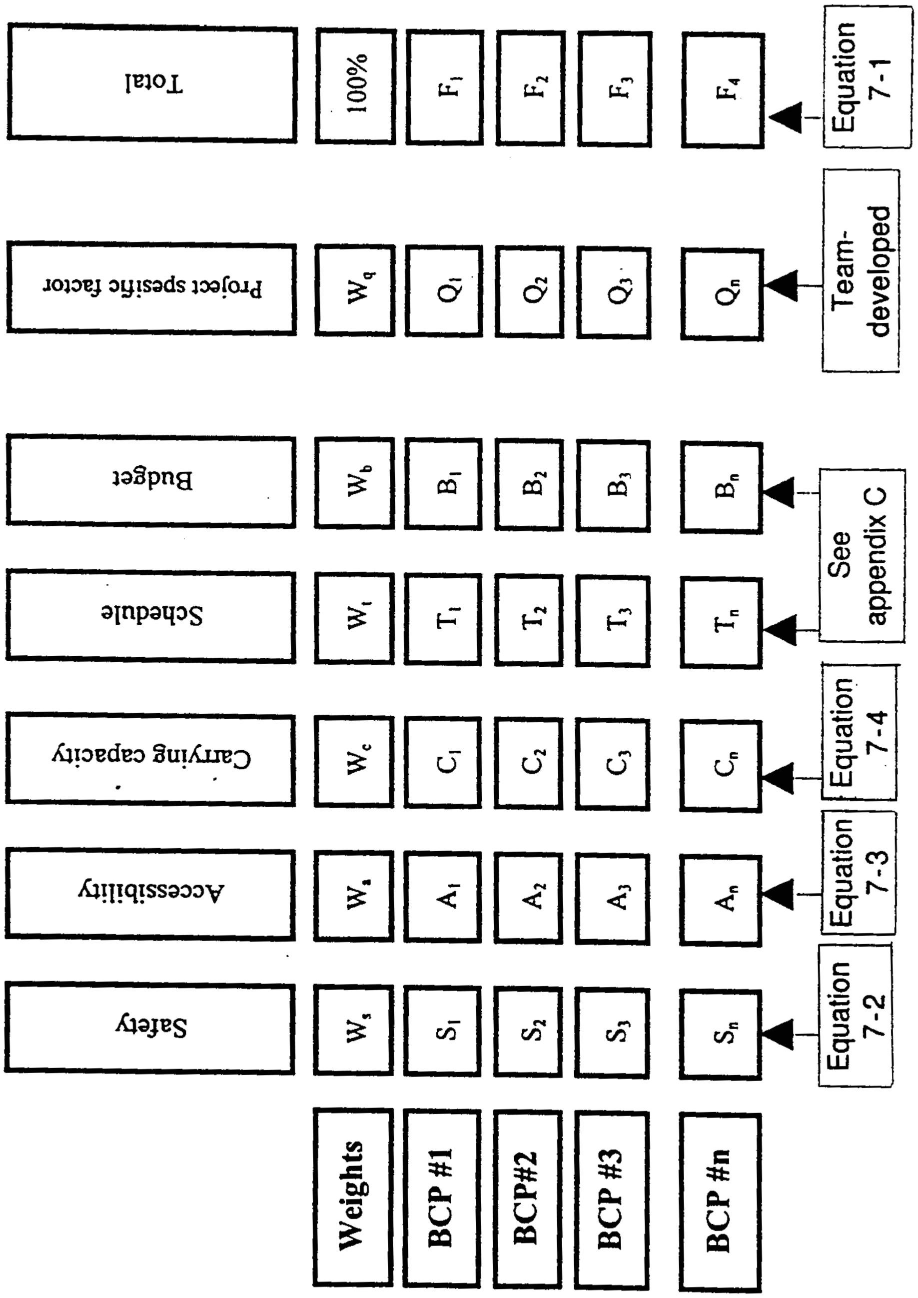

Figure 7-2. Final Objective Matrix

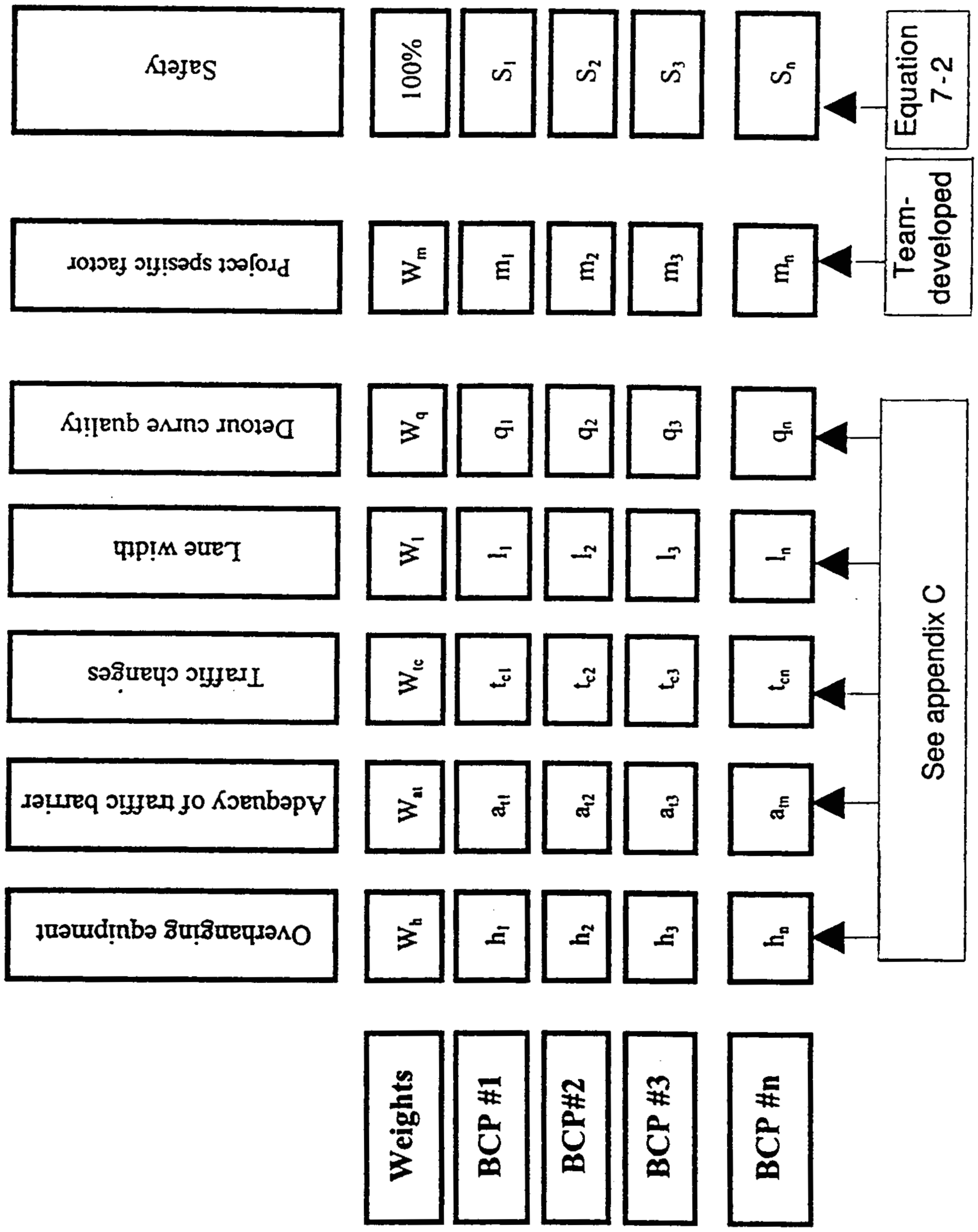

Figure 7-3. Safety Objective Matrix

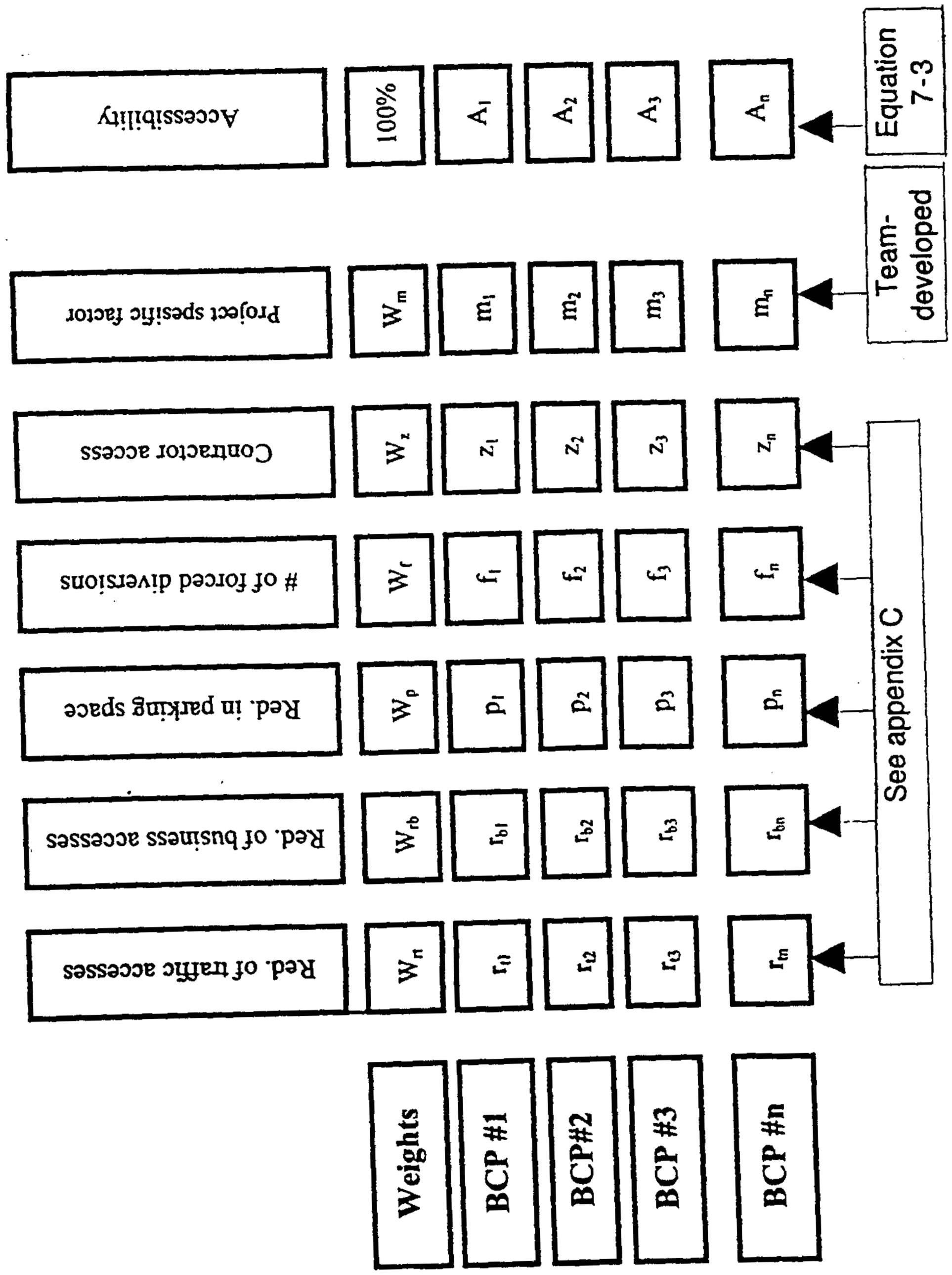

Figure 7-4. Accessibility Objective Matrix

Schedule score (T)

Follow the scoring rule explained in Section 7.5.

Budget Score (B)

Follow the scoring rule explained in Section 7.5.

Additional factors score (Q)

Any additional factor should be evaluated with a score of one to ten. The model user for each new factor must develop a specific scoring technique. The scoring techniques in Appendix C can be used as a guide in this regard.

7.5 SCORING INDIVIDUAL SUB-FACTORS

The development of a scoring technique for each sub-factor presented a challenge to this research effort. Every sub-factor has its own characteristics and units that are different from the others. As a result, the following simple rule was developed to overcome the diversity of evaluation sub-factors:

a. Measure each sub-factor in its own units (length, traffic count, area, number of times a condition occurs, dollars, time, etc.).
b. Compare the different sub-factors in all BCP's under study. The BCP with the best performance, regarding the sub-factor under consideration, is scored a 10 in this sub-factor. Other BCP's are scored relative to their performance.

Such a simple rule adds tremendous flexibility to the model. Now every design team can add any additional factor/sub-factor with its own units and still use the model. Thus, there is no need to develop a standard performance scale for every sub-factor, as required by the OM technique. This deviation is the only change that was introduced to the OM standard technique. A standard scale does not suit the variable nature of a BCP.

A scoring sample using this rule is presented in Section 7.6. The details of the evaluation procedures are presented in appendix C. A summary of these procedures is presented below.

Safety Factor Evaluation

The scoring of safety sub-factors is as follows:

a. Overhanging equipment: the BCP will be credited an extra point for each overhanging condition.

b. Adequacy of traffic barrier: the BCP will be credited an extra point for each inadequate traffic barrier condition.

c. Traffic-activity interaction length. the BCP will be credited points commensurate to total interaction length.

d. Distance between traffic and construction activity: a threshold distance of 3' has been selected to scale this parameter.

e. Lane width: find the average lane width throughout the BCP, then use Table C-2 in Appendix C to assign a score to each plan.

f. Detour length: find the total detour length for each BCP. Give the BCP with the shortest detour length a score of ten and score others relative to that.

g. Detour curve quality: calculate the average vertical slope and average curve degree of each BCP. Use Table C-3 in Appendix C to give each plan a score.

h. Working on one side of traffic vs. between traffic lines: the BCP will be credited an extra point each time a crew is working between traffic lines.

i. Working at high traffic volume vs. low traffic volume: the BCP will be credited an extra point each time a crew works within high traffic volumes.

j. Day shift vs. night shift: the BCP will be credited an extra point for each night shift.

k. Traffic changes: the weighted sum of all traffic changes will be used to score this factor, as explained in Equation 7-5.

$$T_c = \sum_{k=1}^{k=m} (c_f * t_r)_k \qquad 7\text{-}5$$

where:

m: total number of traffic changes

C_f: Change factor

T_r: Road factor

The change factor (C_f) was introduced to perform the task of differentiating between the various types of change. Table C-4 in Appendix C presents one suggestion for the values of C_f. In addition, different roads in the site have variable importance and effect on safety. For example, a change on the freeway is more dangerous than one on the frontage road. Next, the road index (T_r) was introduced to differentiate between the various roads in the project. Table C-5 in Appendix C presents one way of assessing this index.

Accessibility Factor Evaluation

The accessibility sub-factors are evaluated as follows:

a. Reduction of number of access points in and out of the site: the BCP will be credited an extra point for each access reduction condition.

b. Number of forced diversions (to traffic: the BCP will be credited an extra point for each forced diversion.

c. Reduction of access points to business: the BCP will be credited an extra point each time an access point to a business is closed.

d. Reduction in parking space: the BCP will be credited points commensurate to the reduction of parking space.

e. Additional distance from ramp (for business): the BCP will be credited a point for every time a ramp is moved over a 1000'.

f. Construction activity congestion in front of business: the BCP will be credited an extra point each time a congested construction activity takes place in front of a business.

g. Contractor access to work zone: the BCP will be credited an extra point each time construction equipment access is impeded.

Carrying Capacity Factor Evaluation

This factor is assessed depending on the amount of cars blocked or delayed on the highway due to construction. The score will be the sum of the product of the number of cars blocked and the blockage duration.

Schedule Performance Evaluation

Percent savings in total project duration will be used to score this factor.

Cost Performance Evaluation

Percent savings in total project direct costs will be used to score this factor.

7.6 SCORING SAMPLE

This scoring sample shows how the model would be applied to score sub-factors. For example, suppose a design team is evaluating two plans: A and B. The sub-factors under consideration are (1) working on one side of traffic vs. between traffic lines, (2) lane width, (3) carrying capacity, and (4) budget. Table 7-3 shows the details of scoring these sub-factors within a hypothetical situation.

The first sub-factor, working on one side of traffic vs. between traffic lines, is evaluated by counting the number of times it occurs. If, after reviewing both plans, the designers found that this condition existed seven times in Plan A and 11 times in Plan B, then Plan A is better than Plan B. Accordingly, Plan A receives a score of 10 in this sub-factor. The score given to Plan B is (7/11) X 10 = 6.3.

The second sub-factor, lane width, is evaluated through average lane width throughout the plan. Suppose that the average lane width is 10.5' for Plan A and 11.2' for Plan B. According to Table C-2 in Appendix C, Plan A receives a score of 9 and Plan B a score of 10.

Regarding carrying capacity, suppose the design team estimated that the weighted sum of all cars blocked/delayed in Plan A is 30,000 car-hour (the sum of the product of number of cars delayed and the delay duration). For Plan B, it was 20,000 car-hour. Plan B is obviously better and receives a score of 10. Therefore, Plan A gets a score of (20,000/30,000) X 10 = 6.6.

Suppose that the cost of Plan A is estimated at $10.5 million and Plan B at $11.7 million. Plan A gets a score of 10 and Plan B gets a score of (10.5/11.7) X 10 = 8.9.

Table 7-3. Scoring Sample

Factor		Sub Factor	Sub Factor Unites		Score		Go To
			Plan A	Plan B	Plan A	Plan B	
Safety							**Eq. 2**
	2	Adequacy of traffic barrier					
	5	Lane width	10.5'	11.2'	9	10	Eq. 2
	7	Detour curve quality					
	8	Working on one side of traffic Vs working between traffic lines	7 times	11 times	10	6.3	Eq. 2
	9	Working at high traffic volumes Vs working at low traffic volum					
	10	Day shift VS night shift					
Accessibility							**Eq. 3**
	12	Reduction of number of traffic accesses	35 times	21 times	6	10	
	13	Number of forced diversions (to traffic)					
	15	Reduction in businesses parking space					
	16	Additional distance from ramp					
Carrying capacity					6.6	10	**Eq. 1**
	20	Number of cars blocked or delayed	30,000	20,000			
	21	Blockage/Delay duration	Car.Hour	Car.hour			
Schedule							
	22	% savings in time					
Budget					10	8.9	**Eq. 1**
	23	% savings in cost	$ 10.5 M	$ 11.7 M			

7.7 DATA SOURCES

The bulk of the evaluation data can be found in a well-developed schematic of the BCP. Additional data may be required to evaluate accessibility and carrying capacity factors. Table 7-4 shows the required data and their sources.

Table 7-4. Data Sources

Required Data	Source
Bridge layout	Output of the conceptual phase.
Design standards	State / Federal agency
ROW	Local planning agency
Traffic counts and configuration	Transportation section
Activity duration	CPM
Land uses around the project	Local planning agency, Tax assessor's office, State or local historic preservation agencies, State recreation or natural resource agency

7.8 RELATIVE FACTOR WEIGHTS

The weight assigned to each factor/sub-factor reflects their relative importance to the success of the BCP. In the case of this model, a universal set of weights will not be used because every project has its own unique needs and conditions. However, several facts should guide the assignment of the weights. The following are factors that may influence the weight assignment (Fig 7-5):

a. available ROW,
b. site topology,
c. weather conditions,
d. project objectives (budget and schedule),
e. complexity of design,
f. traffic volume,
g. level of business activity around the project, and

h. community input regarding preferences to construction-access trade-off.

Furthermore, weight assignment is a function of decision maker's utility. It provides them with an opportunity to direct attention to more important factors. As noted by Tucker (Ref 20) "more optimal results occur when all [model] users have input into the weight assignment process, as the analysis of the relative merits of the [factors] provides excellent insight into the importance of each factor to the [participants]."

Table 7-5 presents a set of proposed weights that has been developed based on the interviewees' responses to the significance question in both the data acquisition interviews and the model validation interviews.

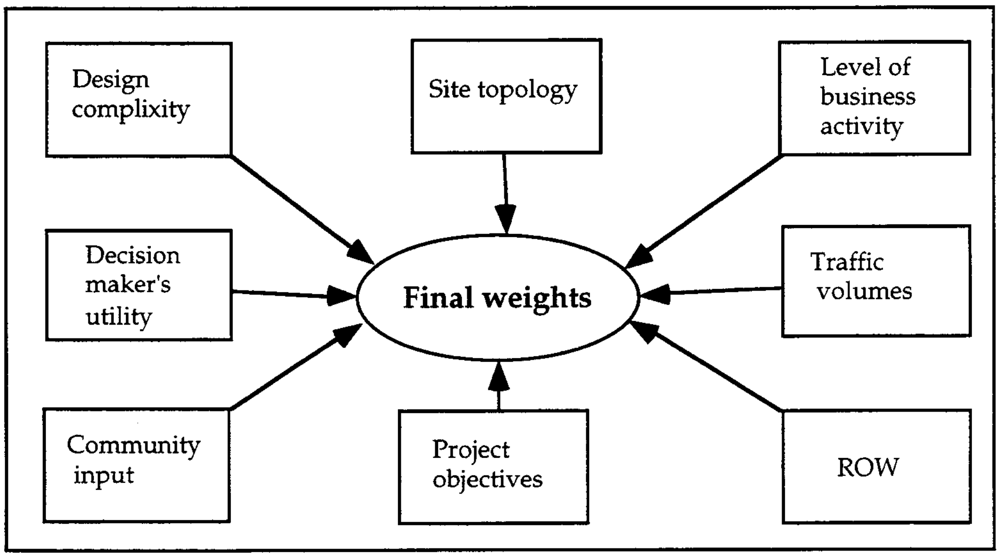

Figure 7-5. Factors Influencing Weight Assignment

Table 7-5. Major Factor's Relative Weights

	Average	Designers	Constr. Eng	Managers
Safety	24%	26%	24%	22%
Accessibility	19%	22%	19%	16%
Carrying capacity	19%	18%	19%	21%
Schedule performance	19%	17%	21%	20%
Budget performance	19%	17%	17%	21%

The proposed weights for safety and accessibility sub-factors are listed in Tables 7-6 and 7-7. Note that carrying capacity sub-factors need not have weights because the final score of carrying capacity factor will be calculated through the sum of the product of both sub-factors.

Table 7-6. Safety Sub-Factor's Relative Weights

	Average	Designers	Constr. Eng	Managers
Overhanging equipment	9%	8%	9%	11%
Adequacy of traffic barrier	10%	11%	9%	10%
Traffic-Activity interaction length	7%	7%	6%	7%
Distance between traffic and construction	8%	7%	11%	8%
Lane width	9%	9%	11%	9%
Detour length	8%	8%	8%	7%
Detour quality	10%	11%	8%	10%
Working on one side of traffic vs.	10%	10%	9%	9%
Working at high traffic volumes vs.	9%	9%	9%	9%
Day shift vs. night shift	9%	9%	10%	9%
Type of change	9%	9%	9%	10%

Table 7-7. Accessibility Sub-Factors' Relative Weights

	Average	Designers	Constr. Eng	Managers
Reduction of number of accesses	16%	17%	16%	16%
Number of forced diversions	15%	16%	12%	15%
Reduction of access points to...	16%	17%	18%	15%
Reduction in parking space	13%	11%	15%	14%
Additional distance from ramp	12%	11%	10%	13%
Construction congestion in front ...	14%	13%	16%	15%
Machine access to work zone	14%	15%	13%	12%

8. MODEL VALIDATION

The major hypothesis of this research is that a model can be developed to evaluate a BCP during the design phase. While previous chapters have discussed the development of a specific model for this purpose, this chapter explains the steps taken to validate the proposed model.

The most reliable way of validating a model is to test it against actual circumstances. However, in the case of a BCP, this testing was not possible because average BCP design activities span several years. Moreover, a single case cannot validate a model. Using this technique, the validation exercise would have required many years.

These constraints led to the adoption of a more practical validation approach: relying on the wisdom and experience of several experts in the field to assess or project the effectiveness of the model. Having experienced challenges and successes on many projects, these experts know what makes a BCP more successful. Thus, the knowledge of experts was used to test how well the model represents the actual needs of BCP evaluation. In addition, those experts provided valuable insights about the projected impacts of the application of the model on BCP effectiveness that could not have been obtained through any other feasible method.

After getting experts' opinions regarding model validity, one final issue remained to be ascertained: the time required to apply the model in an evaluation. Though experts can provide such information, it was decided that an actual demonstration of the model application in a real case would be more insightful. Therefore, the model was applied to the Mockingbird Bridge project. In this case, an original BCP was developed during the design phase. However, upon construction, the contractor and the owner felt that the BCP was complex and lengthy. The owner contracted with UT to develop another BCP. The new BCP was eventually adopted for construction and the two BCP's were used as design alternatives to demonstrate the application of the model.

In summary, the research utilized two techniques to validate the model: expert assessment and a model application demonstration. The two techniques were designed to cover the following concerns about research validity:

a. comprehensiveness of the proposed evaluation factors,
b. applicability of the proposed factors to a generic bridge project,
c. availability of evaluation data during the design phase,

d. consistency and clarity of evaluation procedure,
e. amount of time required for conducting the evaluation, and
f. impact of applying the model on BCP effectiveness

Results of the expert assessment and the demonstration are presented in this chapter. A more complete presentation of both techniques is presented in Appendix D and Appendix E.

8.1 MODEL VALIDATION INTERVIEWS

Eleven experts at TxDOT, the Federal Highway Administration (FHWA), and two consulting companies were interviewed for this purpose.

These interviews focused on testing the applicability of the model, the significance of evaluation parameters, the availability of evaluation data, comprehensiveness of the evaluation sub-factors, and projected impact of model application.

This set of interviews was conducted with designers and managers in owner and consulting organizations because they are the target users of the model. Their satisfaction with the model is vital for its application.

8.2 INTERVIEW RESULTS

Tables 8-1 through 8-5 summarize results of the second interview regarding sub-factor significance. Table 8-6 shows the interview results regarding sub-factor comprehensiveness and model impact. As for model generality and applicability to a generic bridge, 93% of all responses were positive (Yes). For data availability, 97% of all responses were positive (Yes). A full analysis of the results follows in Section 8.3.

Table 8-1. Safety Significance Score

Sub-Factor	Av	Med	Mo	SD	K
Travelers' interaction with construction					
Over-hanging equipment	4	4	4	1.48	-1.06
Adequacy of traffic barrier	5	5	6	0.89	-1.88
Traffic-activity interaction length	3.45	4	4	0.93	-0.50
Distance between traffic and construction	3.82	3	3	1.54	-1.16
Detour configuration					
Lane width	4.64	5	4	0.67	-0.29
Detour length	3.82	4	3	1.17	-0.29
Detour quality	5.09	5	6	0.83	-1.49
Crew interaction with traffic					
Working on one side of traffic vs. between traffic lanes	4.27	4	6	1.49	-1.55
Working at high vs. low traffic volumes	4.18	4	4	0.75	-0.88
Day vs. night shift	4.55	4	4	1.21	-1.65
Traffic changes					
Type of change	4.73	5	4	1.01	-1.00
Type of road where change takes place	4.09	4	3	1.04	-0.93

Av=average; Med=median; Mo=mode; SD=standard deviation; K=kurtosis

Table 8-2. Accessibility Significance Score

Sub-factor	Av	Med	Mo	SD	K
Traffic accessibility					
Reduction of number of accesses	4.36	5	5	0.81	-0.76
Number of forced diversions	5.00	5	5	1.00	-0.13
Business accessibility					
Reduction of access points to business	4.64	5	5	1.12	-1.22
Reduction in parking space	3.55	3	3	1.04	2.62
Additional distance from ramp	3.64	3	3	1.12	0.81
Construction congestion in front of business	3.91	4	4	0.94	1.21
Contractor access					
Machine access to work zone	4.09	4	4	0.94	1.21

Table 8-3. Carrying Capacity Significance

Sub-factor	Av	Med	Mo	SD	K
Number of cars blocked	4.73	5	5	0.90	-0.05
Blockage duration	4.91	5	5	0.94	0.20

Table 8-4. Schedule Performance Significance

Sub-factor	Av	Med	Mo	SD	K
Percent savings in duration	5.18	5	5	0.750	-0.87

Table 8-5. Budget Performance Significance

Sub-factor	Av	Med	Mo	SD	K
Percent savings in cost	5	5	4	0.89	-1.85

Table 8-6. Impact and Comprehensiveness Score

Issue	Av	Med	Mo	SD	K
Comprehensiveness	5	5	5	0.63	0.42
Impact	4.7	5	5	0.65	-0.21

8.3 DATA ANALYSIS

Significance of Sub-Factors for BCP Evaluation

The average significance score of all sub-factors was 4.39 out of 6. This score is very close to that of the first interview group (4.45). Table 8-7 and Figure 8-1 show the significance score of each sub-factor as recorded in the first and second rounds of interviews. Table 8-7 also shows the overall average significance score of each sub-factor. These values were used in Section 7-4 to assign relative weights to the different sub-factors. None of the sub-factors scored below the pre-set threshold significance score of 3.5, which indicates a high approval rate of the sub-factors by the second group.

For the second interview group, the most significant sub-factors were percent savings in duration, adequacy of traffic barriers, number of forced diversions, detour quality, percent savings in cost, and blockage/delay duration. Clearly, there is a difference in rankings between the two groups and this difference, again, emphasizes the role of the design team in selecting the final factors and their relative weights.

The fact that significance scores were considerably high in both rounds proves that the proposed sub-factors are meaningful and important to BCP evaluation, which was a major objective of this research effort.

In addition, the fact that no one factor scored lower than 3.3 in the first round and 3.5 in the second proves that the proposed factors are independent. If two factors were redundant, one should have received a low score during one of the rounds. This information proves that the factors are independent, which is crucial to the internal validity of the model.

Though the interviewees came from different organizations, occupations, and backgrounds, they gave consistent responses to the only question common to both rounds (significance). While agreeing about the significance of the proposed sub-factors, none of the experts required the addition of a new sub-factor. This indicates that the proposed sub-factors cover the wide spectrum of BCP evaluation. Furthermore, such close agreement shows that gathering similar groups of experts to conduct an evaluation during the design phase will, most likely, not create conflict. Instead, it may enrich the evaluation process.

Consistent expert scores also indicate that there was no bias in sampling either of the two sets of interviewees. The two sets were representative cross sections of the population of BCP developers. This information is important for model statistical validity.

Finally, the experts' close agreement about the sub-factors' significance proves that the decision to use multiple data sources was a sound one. By presenting the proposed sub-factors to different groups of experts, the results of one group supported the other.

The fact that the second round results are more skewed to the right (see Figure 8-2) indicates that the second group had less dispersion about the meaningfulness of the proposed factors. No single interviewee gave a score lower than 3, indicating that the analysis done following the first round was sound. It shows that such analysis had eliminated disputable items and presented a clear set of sub-factors for the second group.

Table 8-7. Comparison of Sub-Factor Significance Score

#	Sub-factor	1st round	2nd round	Average
Safety				
1	Over-hanging equipment	4.90	4.00	4.45
2	Adequacy of traffic barrier	5.10	5.00	5.05
3	Traffic-activity interaction length	3.30	3.45	3.38
4	Distance between traffic and construction	4.10	3.82	3.96
5	Lane width	4.60	4.64	4.60
6	Detour length	3.20	3.82	3.51
7	Detour quality	4.80	5.09	4.95
8	Working on one side of traffic vs. between lanes	5.17	4.27	4.73
9	Working at high vs. low traffic volumes	4.90	4.18	4.54
10	Day vs. night shift	4.60	4.55	4.57
11	Type of change	4.50	4.73	4.60
Accessibility				
12	Reduction of number of accesses	4.92	4.36	4.64
13	Number of forced diversions	4.17	5.00	4.58
14	Reduction of access points to business	5.08	4.64	4.84
15	Reduction in parking space	4.08	3.55	3.81
16	Additional distance from ramp	3.33	3.64	3.48
17	Construction congestion in front of business	4.58	3.91	4.24
18	Contractor access to work zone	3.00	4.09	4.09
Capacity				
19	Number of cars blocked	5.25	4.70	4.98
20	Blockage duration	5.17	4.90	5.03
Schedule				
21	Percent savings in duration	5.08	5.20	5.14
Budget				
22	Percent savings in duration	5.17	5.00	5.08
	OVERALL AVERAGE	**4.45**	**4.39**	**4.43**

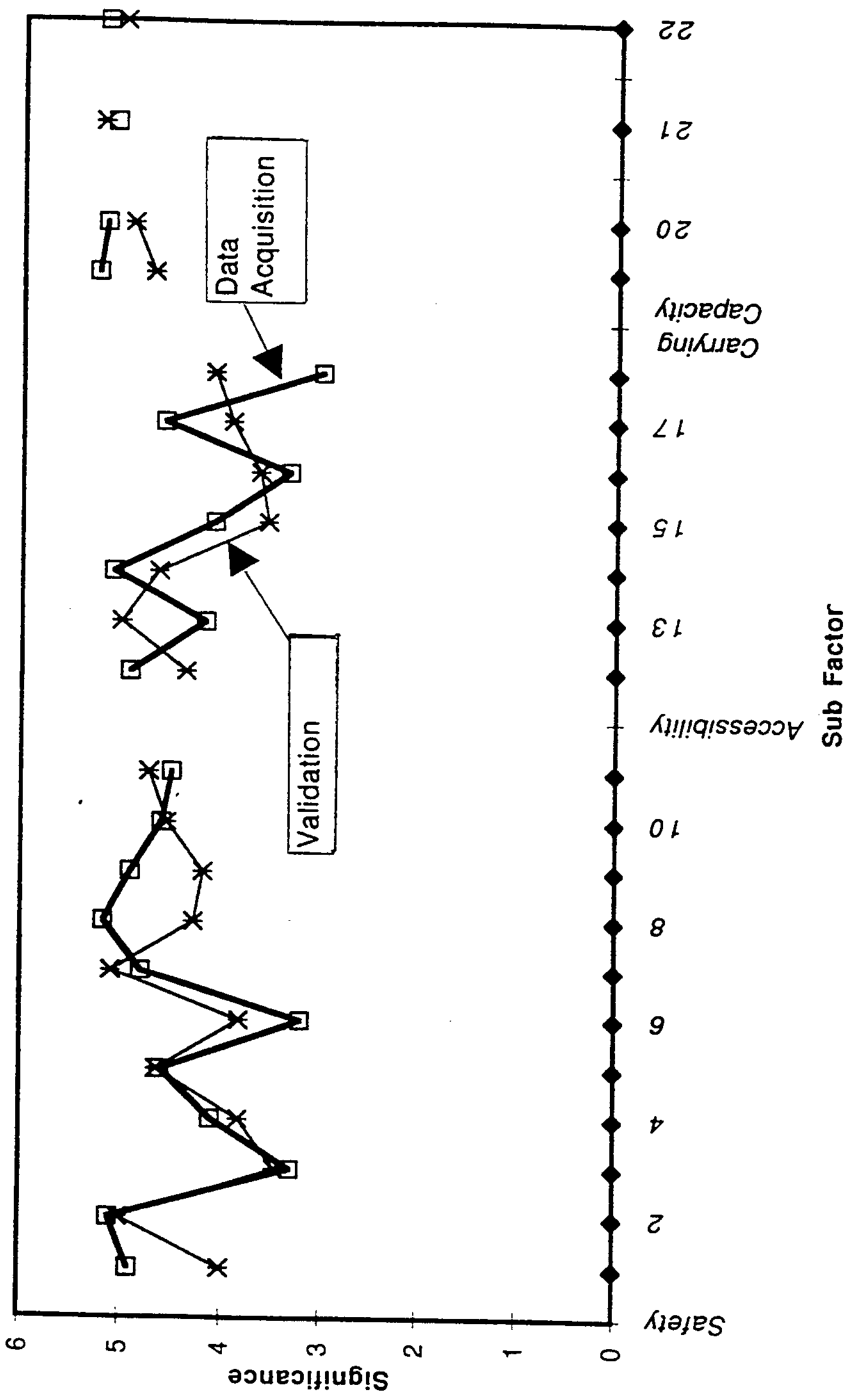

Figure 8-1. Comparison of Significance Score in the Two Rounds of Interviews

Figure 8-2. Comparison of Significance Score Frequencies in Both Rounds of Interviews

Applicability of Sub-Factors to a Generic BCP

About 93% of all responses to this question were positive. Moreover, no single sub-factor received a negative score from more than one interviewee, indicating that the proposed sub-factors can be applied to a generic bridge project. The generic quality of the sub-factors is important to model external validity.

Availability of Evaluation Data

About 97% of all responses to this question were positive. Moreover, no single sub-factor received a negative score from more than one interviewee. Again, this high score proves that the data required to evaluate the proposed sub-factors can be obtained during the design phase. The obvious availability of evaluation data and the generic nature of the sub-factors confirm that the model is applicable to a general bridge project.

Comprehensiveness of Evaluation Factors

The average score for this question was 5 (out of 6) indicating a high level of satisfaction of the interviewees. It also proves that the proposed factors cover the majority of issues that may arise during a BCP design. Once again, the high level of agreement among experts proves the statistical validity of the model.

Potential Impacts of Model Application

The interviewees were optimistic about the possible impact of the model. Their average score in responding to this question was 4.7 (out of 6) indicating that experts felt positive about the potential impact of model application on BCP effectiveness.

8.4 CONCLUSIONS FOR VALIDATION INTERVIEWS

The results of the validation interviews, along with the results of the data acquisition interviews, prove the validity of the proposed model. The average significance score of the proposed sub-factors was considerably high in both interviews (4.39 and 4.45 out of 6, respectively). These scores show that both groups of professional experts believe that the sub-factors are truly representative and meaningful to BCP effectiveness—a crucial issue to model statistical validity. The consistency of the scores in both interviews proves that the sub-factors are not only important, but also independent, which is an important concern for internal validity.

The high score associated with Question #4 (comprehensiveness of sub-factors) proves that experts believe the model has covered the domain, which also serves the statistical validity of the model.

As to the external validity of the model, the 97% score on the question regarding data availability proves that the model is applicable in the design stage. Furthermore, the 93% score on the question regarding generality of the sub-factors proves that the model is applicable to a generic bridge project.

Finally, there is a strong indication that the application of the model will yield a positive impact on potential bridge projects, as expressed in the score of the impact question (4.7 out of 6).

In summary, the second round of interviews positively validated the research hypothesis. Specifically, the second group of interviewees (see Table 8-8) positively received the following issues:

a. The proposed sub-factors are meaningful and significant to BCP effectiveness.
b. The proposed sub-factors are generic and applicable to all bridges.
c. The proposed sub-factors comprehensively cover the major concerns of a generic bridge project.
d. Data required for evaluation are available or estimable during the design phase.
e. A positive impact is expected if the model is applied.

Table 8-8. Outcomes of Validation Interviews

Validity type	Concern	Proof
Statistical	• Representation • Meaningfulness • Coverage	• Significance score >4.3/6 • Comprehensiveness score=5/6 • Consistent response from two different groups
Internal	• Independence	• Significance Score > 4.3/6 • Consistent response from two different groups
Construct	• Familiar parameters	• Ease of measurement score=3.5/6
External	• Applicability • Generality • Data availability • Impact	• Generality score=93% • Data availability=97% • Impact score=4.7/6

8.5 MODEL APPLICATION DEMONSTRATION

After evaluating the data from the interviews, a demonstration was conducted on an actual bridge project to demonstrate the evaluation techniques for the sub-factors, test the availability of evaluation data, and record the time required for evaluation.

The model was applied to the Mockingbird Bridge project in Dallas. As previously explained, the proposed model was used to evaluate the original as well as the new BCP. The original BCP is referred to as BCP #1, and the new BCP is referred to as BCP #2.

An abstract version of both BCPs is presented in Appendix E. Note that BCP #1 included 16 steps for building the bridge, with a total duration of 662 days at a total estimated cost of $3 million. BCP #2 included 11 steps with a total duration of 463 days and a total estimated cost of $2.5 million.

Selecting Evaluation Parameters

The Mockingbird Bridge is a typical urban bridge. The site is highly congested with traffic and construction activities. In addition, a considerable number of businesses are located near the bridge. As a result, the evaluation factors and sub-factors proposed by the model were all applicable to this case. No additional factors were deemed necessary. Furthermore, the sub-factors were weighted, as previously presented in Tables 7-5 through 7-7.

The Evaluation Process

The evaluation process took approximately 46 hours, or 5.7 working days. It is expected that a team of three engineers, as proposed in Chapter 9, would probably conduct the evaluation of similar projects in two days, a reasonable time frame given the complexity of the Mockingbird situation and the volume of BCP #1 (over 100 sheets).

The data required for evaluation were readily available. Well-developed schematics of both BCPs were sufficient to extract most of the necessary information. Data for carrying capacity factor evaluation were obtained from traffic counts on the highway. Additional data for the evaluation of the accessibility factor were extracted from the land use map of the area. In addition, the majority of factors were easy to quantify. Only a few sub-factors required relatively longer times to evaluate. This was mainly because of their subjective nature (see Appendix E for more details about sub-factor evaluation).

Final Objective Matrix

Figure 8-3 shows the final objective matrix for both BCPs. BCP #2 scored 9.7 out of ten while BCP #2 scored 7.4. This is attributed to the fact that BCP #2 has a shorter duration and caused less interruption to traffic. Both criteria resulted in better performance in carrying capacity, schedule, and budget factors. In addition, BCP #2 included better work zoning and phasing, which enhanced safety and accessibility.

Safety Evaluation

Figure 8-4 shows the safety objective matrix for both BCPs. Details of each sub-factor evaluation are found in Appendix E.

Accessibility Evaluation

Figure 8-5 shows the accessibility objective matrix for both BCPs. Details of each sub-factor evaluation are contained in Appendix E.

Carrying Capacity Evaluation

Table 8-9 shows the results of the carrying capacity factor evaluation. The details of blockage incidents and their duration for both BCPs are found in Appendix E.

Schedule and Budget Performance Evaluation

The UT project team developed the duration and cost estimates for each BCP. Table 8-9 shows the results obtained by evaluating these two factors. According to the project team, the total time required to estimate the schedule and cost of both BCPs was two working days, and is included in the previously mentioned 5.7 days.

Table 8-9. Remaining Factors Evaluation

Factor	BCP #1		BCP #2	
	Factor units	Model score	Factor units	Model score
Carrying capacity	2.9 million car-hour	6.2	1.8 million car-hour	10
Schedule	662 days	6.6	463 days	10
Budget	$3 million	8.3	$2.5 million	10

8.6 CONCLUSIONS FOR MODEL DEMONSTRATION

Using the Mockingbird BCPs as a case study demonstrated the application of the model to a real BCP evaluation situation. The evaluation consumed a relatively short time relative to the complexity of BCP #1. In all sub-factors, evaluation data were easily attained.

The fact that the model selected BCP #2 is interesting because BCP #2 was actually approved by TxDOT field engineers and safety committee and by contractor field engineers. This proves that the model results are consistent with expert opinion. Such consistency adds to the validity of the proposed model.

	Safety	Accessibility	Carrying capacity	Schedule	Budget	Total
Weights	24%	19%	19%	19%	19%	100%
BCP #1	8	7.5	6.2	6.6	8.3	7.4
BCP#2	9.3	9.2	10	10	10	9.7

Figure 8-3. Final Objective Matrix for Model Demonstration Case

	Overhanging equipment	Adequacy of traffic barrier	Traffic-activity interaction	Distance between traffic &	Lane width	Detour length	Detour curve quality	Working on one side..	Working at High...	Day shift Vs Nigh Shift	Traffic changes	Safety
Weights	8%	10%	7%	8%	10%	7%	10%	10%	10%	10%	10%	100%
BCP #1	6.6	6.6	9.2	10	9	8	8.6	7.7	10	5.7	6	8
BCP#2	10	10	10	6.6	10	10	8.2	10	7.7	10	10	9.3

Figure 8-4. Safety Objective Matrix for Demonstration Case

	Red. of traffic accesses	# of forced diversions	Red. of business accesses	Red. in parking space	Additional distance from ramp	Constr. congestion	Contractor access	Accessibility
Weights	16%	12%	15%	13%	12%	14%	14%	100%
BCP #1	5.2	5.7	7.1	8.6	10	10	6.6	7.5
BCP#2	10	10	10	10	7.5	7	10	9.2

Figure 8-5. Accessibility Objective Matrix for Demonstration Case

9. PROPOSED CHANGES TO BCP DEVELOPMENT PROCESS

The utilization of site experience in BCP development is the key to ensuring a safe, efficient, fast construction project (Ref 4). Knowledge gained from field experience should be fed back into the design process and should guide the design procedures, the evaluation of the BCP, and the structural details of the final design.

The proposed model is one way of utilizing site knowledge in the area of BCP evaluation. However, the overall BCP development process has to be modified to put the model into action.

By analyzing the current process of BCP development, the following drawbacks have been identified:

a. Area engineers depend solely on subjective judgment in selecting the construction sequence.
b. The final evaluation of bridge designs is predominantly based on short-term economic considerations, i.e., project cost.
c. There is no formal way of documenting the lessons learned during the design or the execution phase.
d. The process is serial. Any changes to the original concepts are usually difficult to implement.
e. The contractor, who possesses a considerable amount of expertise, is not involved in pre-project analysis.

As explained in the HOT diagrams in Chapter 4, the success of a bridge project depends on the effectiveness of three major components:

1. The bridge layout design: does it have an optimal geometrical design from functionality and constructability points of view?
2. The bridge structural design: does it have an optimal structural system from economic and constructability points of view?
3. The BCP: does the BCP present the optimum way to construct the previously approved layout and structural system?

The design process should ensure that each of these three components has bean produced according to the best practice in the industry.

Until now, most research efforts have focused on collecting technical lessons learned from the field. However, lessons learned collection efforts have minimal value unless they are implemented in the design procedures.

The procedures for developing a new bridge are equally important as the tools of the design. These procedures guide the designers to specific steps for BCP development. The procedures also set the standards for the final product and define the major participants and their roles in the development, all of which ensure an optimal BCP.

It is not within the scope of this study to redesign the process of bridge design. Nonetheless, a framework for implementing the proposed model within the process is presented in the following section. Additional research is still needed in order to redesign the entire process.

9.1 A FRAMEWORK FOR CHANGING THE PROCESS OF DESIGNING URBAN BRIDGES

The process of designing a new bridge should be geared to promote the use of construction knowledge and should provide the project team with tools to make more effective decisions. Furthermore, the process should incorporate the use of such tools into the procedures of developing a new bridge.

The following proposal for process changes was developed to integrate the model into the development of BCP.

Conceptual Stage

- Area engineer and design section structural engineers will begin the process by investigating bridge constructability problems. The team will also analyze traffic, community, and business conditions and needs.
- Based on the previous step, the team will develop the bridge design policy that includes:
    - ◊ A list of major constructability concerns
    - ◊ A list of tentative project objectives

  - ◊ A list of specifications/recommendations for layout design and the structural system selection
  - ◊ A list of BCP evaluation factors

- The area engineer will develop, with the help of the planning section, the detailed bridge layout. This layout will take into consideration traffic needs, future expansion, and constructability issues.

Initial Design Stage

- The design section will select the bridge structural system. The section, with the help of the area engineer and other related departments, will select the macro construction technology (segmental, cast-in-place, pre-cast, etc.).
- The area engineer and design section engineers will work on developing several BCP alternatives.

Evaluation Stage

- The BCP evaluation model will be used to evaluate the available BCP alternatives. Then, a single BCP will be adopted.

Detailed Design Stage

- The design section will develop structural design details and specifications.
- The area engineer will produce the initial budget estimate and the initial project duration and milestones.

Delivery Stage

- The final product—layout, structural design, and BCP—will be sent to the home office or to FHWA for review.

Figure 9-1 gives a general outline of the proposed process structure. Figure 9-2 shows the relative position of the model in the development of a BCP. Table 9-1 presents the suggested evaluation team members. Those members, along with structural engineers, will constitute the design team.

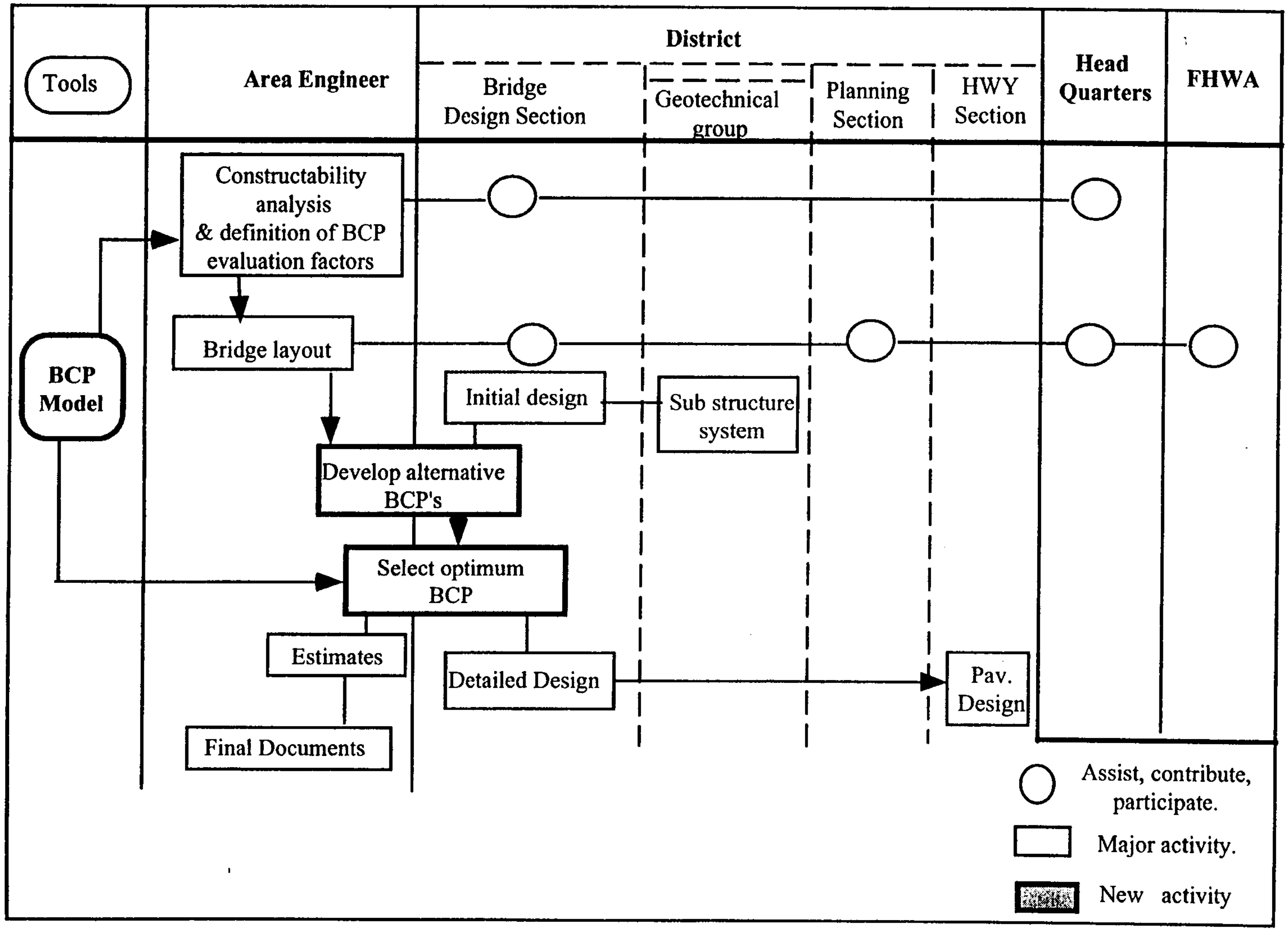

Figure 9-1. General Steps of the Proposed Bridge Design Process

Development phase		Major tasks	Analysis techniques	Output
PROBLEM DEFINITION		• Transportation needs • Long term plans • Politics	• Lexicographic analysis	• Go / No go decision
CONCEPTUAL PHASE	SCOPING	• Functional analysis	• Value Engineering • Cost / Benefits analysis	• Bridge Configurations • Budget • Schedule
	SCHEMATICS	• Traffic Paths • ROW • Soil Analysis	• Traffic analysis • CAD • Simulation	• Schematic layout • Macro structural system • Macro construction tech.
DESIGN PHASE	INITIAL DESIGN	• Study construction needs • Develop plans	• Brain storming	• Several BCP
	EVALUATION	• Optimize construction plans	• **The BCP evaluation model**	• Optimum BCP
	DETAILED DESIGN	• Enhance plans • Design details	• Lessons learned	• Final Plan
DELIVERY PHASE		• Specs • Drawings	• CAD • Primavera • Estimation Programs	• CPM • Final drawings • Estimate

Figure 9-2. The Evaluation Model and the Development of BCP

Table 9-1. BCP Model Participants

Major Factor		Sub-factor	Recommended Evaluator
Safety			
	1	Overhanging equipment	Area Engineer
	2	Adequacy of traffic barrier	Area Engineer
	3	Traffic-activity interaction length	Area Engineer
	4	Distance between traffic and construction	Area Engineer
	5	Lane width	Highway Engineer
	6	Detour length	Highway Engineer
	7	Detour curve quality	Highway Engineer
	8	Working one side of traffic vs. between traffic lanes	Area Engineer
	9	Working at high vs. low traffic volume	Area Engineer
	10	Day shift vs. night shift	Area Engineer
	11	Traffic change	Highway Engineer
Accessibility			
	12	Reduction of number of traffic accesses	Transportation Engineer
	13	Number of forced diversions (to traffic)	Transportation Engineer
	14	Reduction of access points to businesses	Transportation Engineer
	15	Reduction in businesses parking space	Transportation Engineer
	16	Additional distance from ramp (for businesses)	Transportation Engineer
	17	Construction congestion in front of business	Area Engineer
	18	Contractor access to work zone	Area Engineer
Carrying capacity			
	19	Number of cars blocked or delayed	Transportation Engineer
	20	Blockage/delay duration	Transportation Engineer
Schedule			
	21	Percent savings in time	Area Engineer
Budget			
	22	Percent savings in cost	Area Engineer

9.2 ANTICIPATED ADVANTAGES OF MODEL APPLICATION

The proposed model is the first of its kind, and presents an objective tool for evaluating the effectiveness of a BCP. The proposed model takes the design process into a very important dimension—testing the quality of the BCP before scheduling it.

Currently, considerable time is spent in developing and optimizing project schedules. The quality and effectiveness of the logic behind this schedule are usually assessed subjectively. The resulting gains from optimizing a BCP schedule are far fewer than what can be achieved by thorough analysis of the plan's effectiveness. Such analysis can yield tremendous savings at the macro level, where efforts are leveraged.

The following sections describe some of the anticipated advantages of model application. These advantages were developed from input provided by experts interviewed during the research. However, these advantages are merely estimates; additional research is needed to track the model impact on the quality of BCP.

Encouragement of Developing Alternative BCP's

Because the model enables designers to conduct an objective evaluation for each design alternative, its implementation within the design process will encourage designers to develop more alternatives for a BCP.

Currently, the design team of a new bridge develops a basic BCP. This initial BCP usually reflects the most direct and obvious way of building the bridge. Different participants of the design process then introduce step-wise modifications to the BCP. Eventually, a detailed BCP emerges from these amendments to the initial BCP.

This practice goes against the better practice of creating alternatives and selecting the most optimal among them. It limits the design option and does not allow new and innovative ideas to surface easily. Such practice is mainly attributed to the lack of evaluation tools that enable a design team to select among options. The availability of the model will facilitate such evaluation; hence, it will encourage designers to develop several options.

Even in the case of an incrementally developed single BCP, the model can bring to the surface the sub-factors with sub-optimal performance. The design team can then redesign BCP elements that are causing such inefficiencies.

Enhanced Pre-Project Analysis

The application of the model can encourage thorough analysis of project elements. The analysis required by the model extends beyond the traditional schedule and budget issues to more critical factors like safety and highway carrying capacity. The lack of such comprehensive analysis may be the cause of inefficiency in several urban bridge projects (Ref 4).

The application of the model will enhance pre-project analysis because:

a. The design team is required to develop a specific factor list for each project, which can only be done after detailed analysis of project needs and conditions. Moreover, the weight assignment task assures that the relative importance of all BCP objectives has been investigated.

b. The evaluation procedure for each sub-factor requires extracting specific and actual data from the BCPs under study. This requires understanding and analyzing almost every component of each BCP.

Enhanced Communication Between Field and Design Engineers

The fact that design engineers will team with area engineers to conduct the evaluation encourages communication, the lack of which can lead to construction problems (Ref 39). The model will require both parties to work together at various stages of the design process.

Early Consideration of Constructability

Though not explicitly used as an evaluation factor, constructability is evaluated through several sub-factors. Most of the sub-factors under the safety and accessibility factors address genuine constructability concerns. Moreover, the new process begins the design effort by investigating BCP construction needs.

The model application will, then, ensure constructability analysis within BCP development and evaluation. Furthermore, this analysis will take place at the early stages of BCP design, ensuring increased beneficial constructability analysis. Late constructability analysis is far less effective than front-end analysis (Ref 40).

In addition, the fact that the BCP model induces the development of several BCP alternatives is crucial for bridge constructability. New and innovative techniques can now be introduced to overcome construction problems during the design phase.

Objectivity of BCP Evaluation

The model presents a set of objective factors along with systematic procedures for evaluating a BCP. The model ensures the decision-maker that the selected BCP has considered all the important issues that may affect project execution. Furthermore, it can aid project engineers in evaluating and justifying change orders during construction.

Enhanced Project Performance

The up-front and detailed analysis of anticipated site problems in the area of business access and traffic flow will reduce the probability of severe site problems during construction. This will reduce BCP revisions and change orders and, hence will enhance project performance.

9.3 THE MODEL AND PRESERVING CONSTRUCTION KNOWLEDGE

This model presents one way of preserving knowledge on the decision support dimension. As defined in Chapter 1, this knowledge spans three major dimensions: procedures, decision making, and technology.

The real benefits of construction field knowledge can only be realized through the development of such models and systems that would guarantee that the final product of the design phase has incorporated ideal performance.

The fact that the design team develops the project-specific factor list results in transforming team members' knowledge into decision-making factors. Knowledge is no longer preserved as a collection of technical notes. Rather, it actively guides the design to generate and select a better BCP.

Updating the model after each project can also be a tool for preserving site knowledge. Post-project analysis can modify the existing factor list to fit new construction concerns. It can also propose new evaluation techniques and recommend changes to the roles and responsibilities of the design team. Figure 9-3 shows the BCP model role in preserving field knowledge through updates. Changes introduced after each project can enhance the development of future BCPs on the decision making and procedural dimensions.

The application and update of the model in this form will allow the organization to constantly learn from site knowledge. The selection of future BCPs will depend on how site problems are mitigated. In other words, to what extent they satisfy the model.

The model can also serve in preserving site knowledge on the technology dimension. The sub-factors can act as "knowledge pins" around which lessons learned accumulate. Every time a new lesson is learned from the site, it can be recorded and sorted under the appropriate sub-factor. As in Figure 9-3, each sub-factor will act as a core for collecting lessons learned. Eventually, a sorted database of lessons learned will be established around and connected to the appropriate sub-factor. Later, when a design team evaluates sub-factors for a new BCP, it will find pre-sorted lessons as to how to improve the sub-factor's performance.

This database can include the following elements:

a. who and when to evaluate the sub-factor,
b. data sources,
c. evaluation check list,
d. troubleshooting tips,
e. adequate technology selection tips,
f. staffing an adequate construction team for supervising or troubleshooting sub-factor related problems during construction, and
g. audio-video material about the sub-factor.

For example, in the construction of one of the bridges in the NCE, the original BCP included building a double-span bridge in one step. This required using heavy form-work. The project team developed a simpler construction sequence to build the bridge as two simple spans, saving the project a considerable amount of time and money.

If such a lesson had been attached to the traffic change sub-factor, it would have induced the designers to rethink the effectiveness of the original BCP. It would also have introduced the previous simple solution.

In summary, the model can help preserve knowledge in the three major dimensions because it provides a means to transfer site knowledge into decision support tools, helps document technical lessons learned in a sorted manner, establishes procedures for evaluating every element of the BCP, and facilitates team work and the exchange of expertise during the design phase.

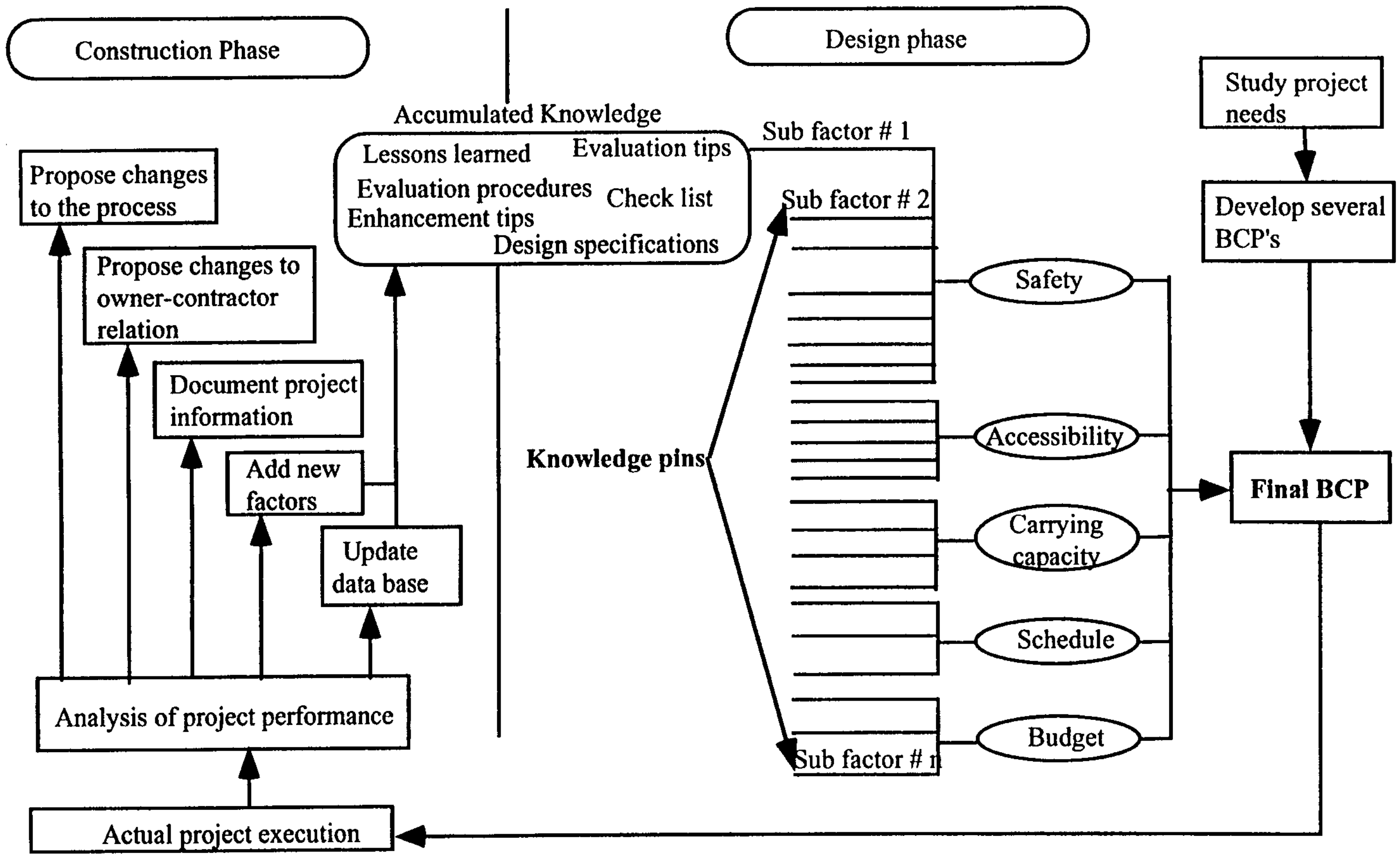

Figure 9-3. BCP Evaluation Model Role in Preserving Field Knowledge

Looking Ahead

Learning from field knowledge should not stop at BCP development. It should be extended to the area of layout design and the selection of a bridge structural system.

A model for evaluating bridge layout design effectiveness is needed. This model will present a tool similar to the BCP evaluation model for evaluating layout effectiveness and can help designers select the most optimum layout design. For example, the model can consider the following important parameters for evaluating different layout alternatives:

a. future traffic needs, such as capacity changes, alignment, and ramps locations;
b. construction needs, such as access to work activity, clearances, and curve construction problems; and
c. environmental impact, such as land use, ground water, and noise levels.

A similar model can help the designers select the most appropriate structural system and can include the following factors to evaluate the different structural systems:

a. construction material such as concrete, steel, and composite;
b. macro construction technology, such as super structure (segmental, pre-cast girders) and sub-structure system (cast-in-place, pre-cast);
c. design constructability such as rebar design and placement, joint construction, and temporary drainage sytems.

The three models can be viewed as the core of an extensive bridge design knowledge base, and can be linked to a query lessons-learned database. The database will include several suggested evaluation factors, weights, evaluation procedures, and tips to enhance the performance of each sub-factor. The whole system can be linked to local and national databases, which will provide the design team with a means for extracting additional data that may be required for the evaluation. Figure 9-4 shows a schematic of this knowledge base.

Specific simulation packages can be developed to help visualize the different options for any of the three bridge components. Such packages can help designers coordinate between the needs of each of the three components. The design team can analyze a multitude of layouts, structural systems, and BCPs at the same time, thereby transferring the process from serial consideration of each component to the integration of all three components.

Furthermore, the already existing traffic analysis model can be linked to the system. These models can assist the design team in evaluating the impacts of any decision regarding traffic flow locally and on a citywide scale. They can provide information about average travel time on each highway, areas of traffic jams, and changes in carrying capacity. They can also be effective in coordinating traffic shifts and in selecting the appropriate detour location and timing.

9.4 BCP EVALUATION AND PARTNERING

The optimization of a BCP is a concern for all project parties. For the owner, it means a safer project, less interruption to traffic, and shorter project duration. For the contractor, it means a safer work place and shorter project duration (hence better turnover to his capital).

Both owner and contractor possess valuable expertise that can enhance a BCP considerably. It would make sense to join their efforts in one initiative. Such a combined effort would have a considerable impact on the project.

Moreover, if the joint BCP analysis was conducted in the early stages of the project, the results could be of greater value for both parties. Such early project analysis by the owner and contractor team could result in (1) defining a clear set of project objectives, (2) improved understanding of project conditions, needs and potential problem areas, (3) the launching of a team initiative, and (4) combining valuable expertise for the benefit of the project.

In this way, each party will understand the problem areas of the project, investigate solutions, and agree on a decision. This team initiative and responsibility sharing will minimize the possibility of future disputes.

It is the understanding of project objectives and conditions and the exchange of expertise that define a true partnering relationship; not words, meetings, or even partnering contracts. In the Mockingbird Bridge project, owner and contractor jointly developed a new BCP. In true partnering spirit, the contractor volunteered to perform several additional activities to allow the execution of the new BCP. In return, the owner was willing to consider all contractor suggestions for many minor job enhancements. Furthermore, community representatives appreciated the efforts of both owner and contractor. They agreed to provide more ROW for the new BCP because they were convinced that the new plan was a better one. The idea of involving the contractor in pre-project analysis is not new (Ref 41). However, regulations and conventional practice did not allow such initiatives to become a reality.

The owner should seek to achieve this goal without violating the regulations. One way of doing so could be through holding a pre-construction symposium between owner and interested contractors. During this symposium, several BCP alternatives can be generated and an initial round of evaluations be conducted to select a major construction approach.

However, public owners are still concerned about the possible legal implications of having contact with a group of contractors before bidding (Ref 37).

An easier way to conduct this symposium could be through the local area network. Owner organizations can furnish BCP ideas/concerns on the Internet. Contractors can access this information before bidding and participate in the design by providing insights about BCP development. On-line owner-contractor communication is already in practice in Japan and Scandinavia (Ref 42).

Such an act would have dual benefits to the owner and the contractor. For contractors, they can get project information very early, enabling them to plan ahead for their resources and financing, which will lead to a more stable business cycle for them.

In return, the contractor can provide the owner with constructability tips. They are not expected to provide any data that will reduce their competitiveness; however, they can still provide valuable insights as to how to select a structural system or layout or how to promote safety or traffic flow, all of which will reduce the project cost (not profit). In addition, a better-informed contractor usually means a reduced contract price.

The model can be a very effective tool in this regard. A computer version of the model can be put on the Internet to furnish, through the sub-factors, the exact concerns of BCP development. The model will act as an on-line symposium director, allowing interested contractors to provide their advice or concerns through adding or commenting on sub-factors. This will help owner engineers define an exact set of evaluation factors. It can also provide valuable insights about effective solutions to the problems associated with each sub-factor.

For example, contractors can provide valuable suggestions about safety evaluation. especially regarding equipment mobility and overhang. They can provide new suggestions for detouring traffic. They can also provide techniques to reduce business impacts. All of these examples are areas where contractors have a great deal of expertise; at the same time these areas do not affect competitiveness.

After developing several BCPs, contractors can participate in the evaluation process. In fact, they can be more efficient in the evaluation of the safety factor because the safety factor is closely related to construction activity design and equipment mobility (something the contractor knows better than the owner). Design engineers can average the scores recorded by responsible contractors to find the final safety score. Table 9-2 presents a suggestion for the involvement of the contractor in the evaluation of 10 sub-factors. This may cut the evaluation time for the owner team by as much as 25%. A study needs to be conducted to investigate the legal and administrative issues associated with putting the model on the Internet.

9.5 THE MODEL AND INFORMATION MANAGEMENT

Information about BCP activities is not effectively transferred to business owners. Businesses are in need of periodic information about the BCP, such as times and locations of detours, and possible changes to access ramps, parking lots, and frontage road traffic. An on-line version of the model can provide such details to business. A table similar to Table E-4 in Appendix E can provide details about most of these concerns. The table is a by-product of the evaluation process. However, it contains a list of all possible traffic and business activity interruptions. Figure 9-5 shows the possible communication channels that can be set up between project parties and interested entities.

Currently, BCP analysis information is lost after developing the final BCP. The application of the model in its computerized version will mean that information about BCP development will be kept in a more efficient manner. All information can be stored in a small file listing the major alternatives, their analysis, and the reason for refusing any of them.

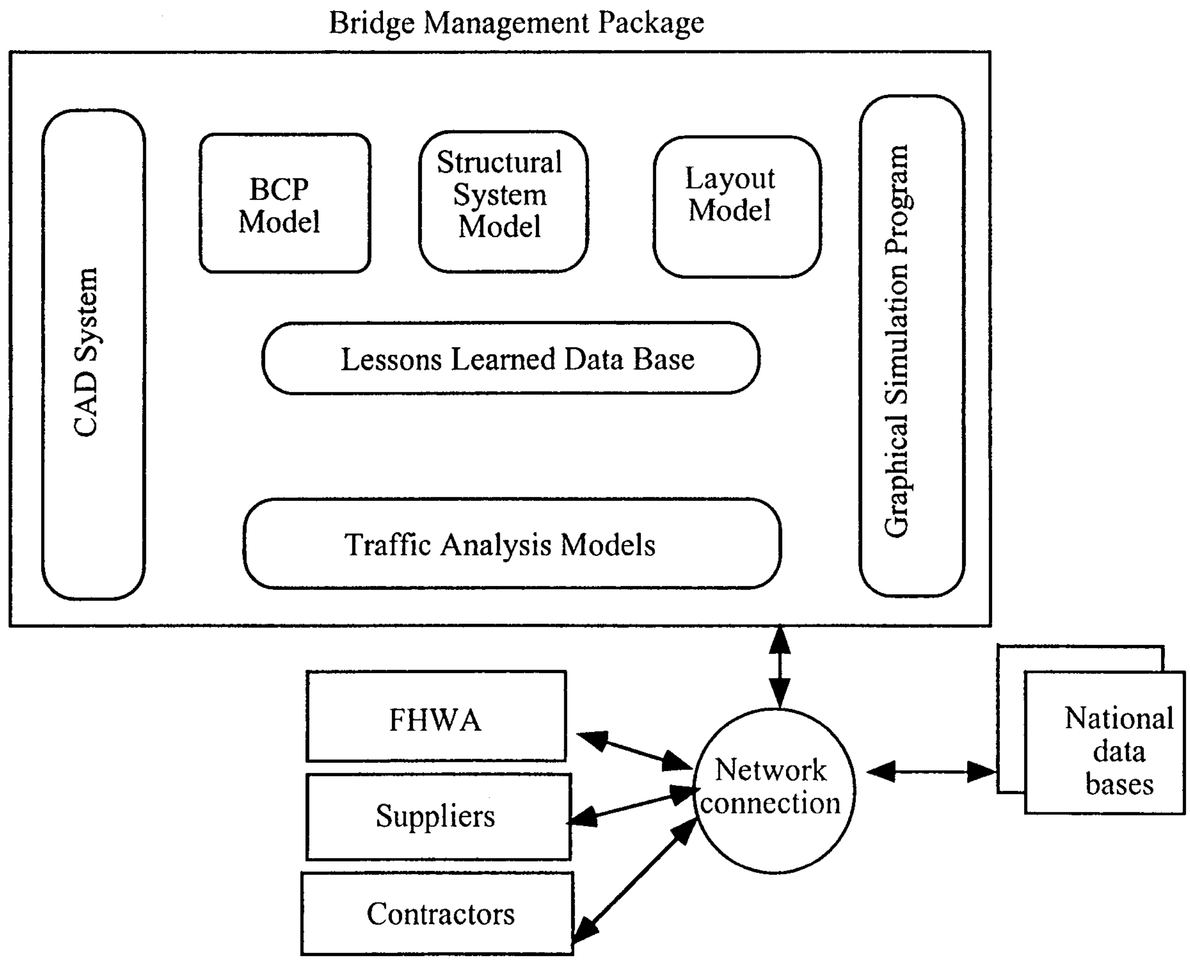

Figure 9-4. Possible Configuration for Bridge Knowledge Base

Table 9-2. Contractor as Participant in BCP Evaluation

Major Factor		Sub-factor	Proposed Evaluator
Safety			
	1	Overhanging equipment	Contractor
	2	Adequacy of traffic barrier	Contractor
	3	Traffic-Activity interaction length	Contractor
	4	Distance between traffic and construction	Contractor
	5	Lane width	Highway Engineer
	6	Detour length	Highway Engineer
	7	Detour curve quality	Highway Engineer
	8	Working on one side of traffic vs. working between traffic lines	Contractor
	9	Working at high traffic volumes vs. working at low traffic volume	Contractor
	10	Day shift vs. night shift	Contractor
	11	Traffic change	Contractor
Accessibility			
	12	Reduction of number of traffic accesses	Transportation Engineer
	13	Number of forced diversions (to traffic)	Transportation Engineer
	14	Reduction of access points to businesses	Transportation Engineer
	15	Reduction in businesses parking space	Transportation Engineer
	16	Additional distance from ramp (for businesses)	Transportation Engineer
	17	Construction congestion in front of business	Contractor
	18	Contractor access to work zone	Contractor
Carrying capacity			
	19	Number of cars blocked or delayed	Transportation Engineer
	20	Blockage/Delay duration	Transportation Engineer
Schedule			
	21	% savings in time	Area Engineer
Budget			
	22	% savings in cost	Area Engineer

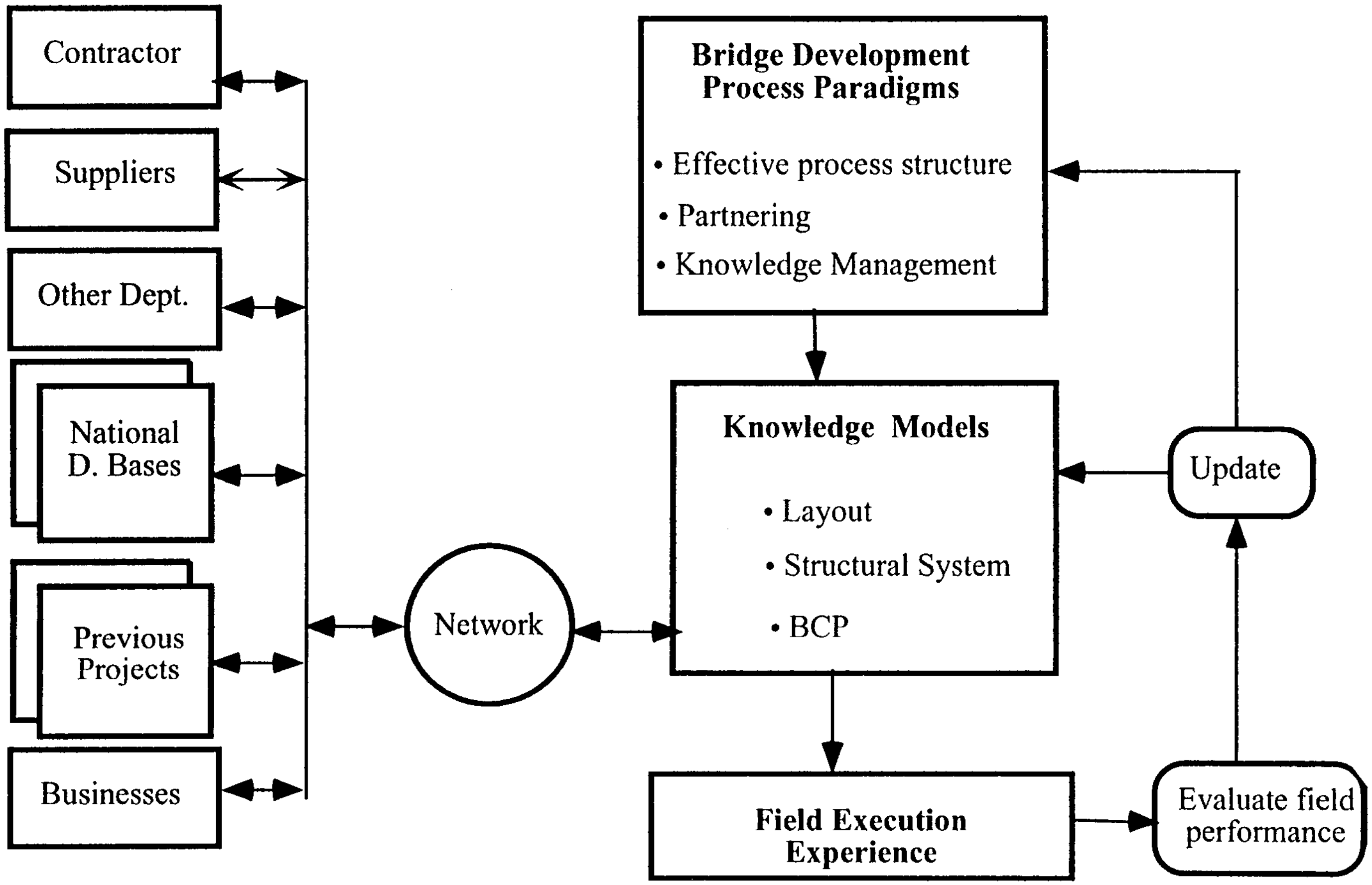

Figure 9-5. Evaluation Model's Role in Partnering and Information Sharing

10. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions and recommendations based on the research findings.

10.1 REVIEW OF RESEARCH OBJECTIVES

The focus of this research was to develop a model for evaluating BCP during the design phase.

To accomplish this goal, the research objectives were(1) develop a list of evaluation factors that are meaningful to BCP evaluation, (2) develop specific BCP evaluation procedures, and (3) suggest a framework for implementation of the proposed evaluation procedures within the bridge design process.

10.2 RESEARCH CONTRIBUTION

This research is a pioneering study focused on improving the bridge design process by offering a rational procedure for evaluating BCP effectiveness. The resulting contribution to the body of knowledge in this field can be categorized into contribution to academic research and to practical construction process.

Contribution to Academic Research

1. The research presented a detailed definition of BCP and its objectives.
2. The research documented the existing BCP development process.
3. The research analyzed and documented BCP impacts on surrounding neighborhoods. An influence diagram of input variables controlling BCP development was also developed.
4. A series of HOT diagrams to enhance BCP effectiveness were established.

Contribution to Construction Practice

The contribution to actual process of BCP design includes:

1. a list of meaningful parameters for evaluating a BCP, and
2. systematic procedures for evaluating a BCP.

10.3 CONCLUSIONS

1. Five major factors were identified with which a BCP can be evaluated during the design phase. These factors are safety, accessibility, carrying capacity, schedule performance, and budget performance.
2. Based on input from 23 experts in the industry, the recommended relative weights of the five major factors are as follows:
    - Safety: 24%
    - Accessibility: 19%
    - Carrying capacity: 19%
    - Schedule performance: 19%
    - Budget performance: 19%
3. Twenty-two additional sub-factors were identified to facilitate the evaluation of the previous major factors.
4. The proposed model has been proven to be applicable to any generic bridge project.
5. The model is fairly easy to apply according to experts in the field.
6. The model in its final format covers the majority of concerns that can arise in a general bridge project.
7. The data needed for BCP evaluation is generally available during the design phase.
8. Industry experts believe that the model could have a positive impact on BCP development.

10.4 GENERAL RECOMMENDATIONS

1. The BCP evaluation model should be applied during the design phase.
2. The BCP development process needs to be modified to include the evaluation model. The process improvements proposed by this research can be the starting point.
3. Design teams should emphasize the development of several BCP alternatives before making any decision about the final construction sequence.
4. Design teams should be expanded to include structural engineers, area and construction engineers, and highway and transportation engineers. This is needed to conduct the BCP evaluation. It will also boost project communication and enrich the pool of expertise involved in the design process.

5. Each design team prior to developing BCP alternatives should develop project-specific evaluation factors and weights.

10.5 RECOMMENDATIONS FOR FUTURE RESEARCH

1. A study needs to be conducted to test the model application in an actual design process. Such a study should follow the design process from the conceptual phase through the adoption of the final BCP.
2. All of the evaluation factors and most of the sub-factors apply to highway projects. A follow-up study should seek to expand the model to evaluate generic urban highway construction plans.
3. A comprehensive study needs to be conducted to reengineer the whole process of bridge development using the framework presented by this research as the basis.
4. A similar model to evaluate bridge layout design effectiveness needs to be developed. This model should help designers evaluate different layout schemes in order to select the optimal one.
5. A similar model to evaluate structural system effectiveness needs to be developed. This model should help designers select the best structural system for the bridge.
6. The possibilities of employing a 3-D simulation package in BCP development should be studied.
7. The inclusion of traffic analysis models in the evaluation of BCP impacts on citywide traffic patterns should be investigated.
8. The legal and administrative aspects of putting the model on the Internet and allowing contractors to participate in BCP development before contract letting should be studied.

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APPENDIX A

MOCKINGBIRD BRIDGE RECONSTRUCTION PROJECT

This appendix summarizes the procedures used and the results obtained in a constructability study undertaken by the Center for Transportation Research of The University of Texas at Austin. This study investigated the reconstruction of Mockingbird Bridge in Dallas, Texas. The bridge is one of several bridges being reconstructed as part of the reconstruction of North-Central Expressway in Dallas. The project was sponsored by the Texas Department of Transportation.

The objective of thestudy was to develop an integrated construction zone/traffic control plan that optimizes project duration without jeopardizing safety. The final plan developed through this effort reduced construction time by 30% percent of the total planned duration; direct costs were cut by $450,000. The indirect, user, and business costs have not been accounted for.

A.1 North-Central Expressway reconstruction Project

Built in 1955, North Central Expressway (NCE) is one of Dallas's oldest and most important highways. Running north-south, it connects the downtown area with north-east Dallas suburbs. The current highway is 16.1 km long, with two lanes in each direction in the southern part and three lanes in the northern part. The traffic volume on the highway is estimated at 155,000 vehicle/day.

The Texas Department of Transportation (TxDOT) and the City of Dallas are now engaged in a massive reconstruction of the entire expressway to accommodate four lanes in each direction. The project also includes widening the frontage road (FR) and all of the bridges overpassing the expressway. Getting underway in September 1990, the reconstruction is expected to be completed by the year 2003 at an estimated cost of $550 million.

The project is divided into five major areas: N1, N2, M, S1, and S2. At the time the CTR effort was initiated, the reconstruction of N1 and N2 was completed, S2 and M were in progress, and S1 had not yet started.

A.2 Mockingbird Bridge reconstruction project

In widening the NCE, construction crews had to demolish all its old overpassing bridges. In S2, five of these will have to be demolished, including one of the expressway's most important: Mockingbird Bridge. Mockingbird Lane crosses the NCE from east-west. It is a major link to many important areas in Dallas (e.g., Southern Methodist University and Love Field Airport). The traffic volume on the bridge is estimated at 35,000 vehicle/day.

The existing bridge has a double-span frame, with each span 14.6 m wide. The current bridge width — at 24.3 m — accommodates a single U-turn and two lanes in each direction. The new bridge will deploy double-span, pre-cast girders. Each span will be 27.6 m long. The bridge is designed to accommodate four lanes in each direction and double U-turns. The width of the new bridge varies from 78 to 111 m. The project also includes rebuilding Mockingbird Lane east and west of the bridge to accommodate the new bridge traffic capacity. The frontage roads on both sides of NCE will also be rebuilt. Owing to limited ROW, this frontage road (FR) will be built as a cantilever over the new main lanes.

Site and Scope

The site is congested with traffic and construction activities. Being in the heart of Dallas, the site is surrounded by existing buildings, facilities, and businesses. The available ROW in the location is extremely limited. Because of this limited ROW, most of the widening work on the FR and on Mockingbird Lane had to be divided into small parts to accommodate both traffic and construction work. This division forced the construction sequence in these two areas to be sequential, slow, and to include many traffic shifts.

The main lanes work space is also restricted. The available space around the main lanes is confined by the piers of the old bridges and by the existing frontage road. The construction of the new highway will require shifting the highway traffic back and forth many times within this limited space.

Thus the major problem in the reconstruction of Mockingbird Bridge is the heavy traffic volume within a confined space that must be shifted many times to allow for demolition and rebuilding. In addition, another massive project is running parallel to the NCE project. This project is being conducted by the Dallas Area Rapid Transit Authority (DART). Many activities of both projects take place in the same space and occasionally at the same time.

Budget and Schedule Objectives

The S2 part of the project started in September 1993 and is scheduled for completion by late 1999. The total project length is 3 km. In addition to rebuilding the highway and the frontage road, the project includes demolishing and building five bridges: Macommas, Mockingbird, University, Yale, and Lovers Lane. The project total cost is $108.2 million.

Project Parties

TxDOT is financing the entire project. The Federal Highway Administration (FHWA) has not been involved because the project did not meet FHWA's minimum ROW specifications. However, the City of Dallas is contributing 25 percent of the cost of ROW acquisition. Because of the tremendous effect of the project on the central Dallas area, a supervising committee was formed to overview the project and coordinate its actions. This committee includes representatives from:

- TxDOT field office
- City of Dallas
- DART
- University Park and Highland Park tenant representatives
- The general contractor (Granite Construction Company)
- Zachary Construction Company (which is responsible for the M part of the project)

In addition to this committee, TxDOT's district office, safety committee, and structural division must approve all aspects of the construction.

A.3 Overview of Original Sequence and Traffic Control Plan

The original reconstruction plans for S2 were developed in 1992 by Brown and Root, Inc. The company required five years to develop the plans because of the complexity of the site. The plans included 1,900 drawings, 420 of which were for traffic control. The plan included a total of 16 diversions for the main lanes' traffic, and another 6 diversions of Mockingbird bridge traffic. The plan also included building a complete temporary bridge east of the existing bridge to carry traffic during construction.

The owner and the contractor believed that the planned construction sequence could be improved. With 155,000 vehicles using NCE daily, any improvement could potentially have a significant impact. The two parties agreed to re-investigate the issue.

A.4 STUDY OBJECTIVES

In May of 1994, TxDOT contracted with the Center for Transportation Research of The University of Texas at Austin to investigate alternatives to the planned reconstruction of Mockingbird overpass — alternatives that would minimize traffic interruptions. TxDOT specified that the project should (1) reduce construction duration and (2) reduce traffic interruption. To assure good traffic flow during the project, TxDOT imposed the following restrictions:

1. A minimum carrying capacity of two lanes in each direction of both the main lanes and the bridge should be maintained throughout the project.
2. Diverting main lanes' traffic to the frontage road can only occure on a weekend only. During any diversion, a minimum of three lanes should be open to traffic: two lanes for main lanes and one for the frontage road.
3. During demolition of any portion of the bridge, Mockingbird Bridge must be closed.
4. Frontage road traffic should not be blocked, and a minimum of two lanes must be open during weekdays.

On the basis of owner's requirements and on the information gathered about the project, the CTR team realized that any construction plan should balance and integrate both the traffic needs and the construction needs. Thus, the objective was to develop an integrated construction zone/traffic control plan that optimized project duration without jeopardizing safety.

The team then developed a more specific list of objectives in the following priority:

1. Maximize safety both for labor and travelers
2. Minimize traffic interruption
3. Reduce the construction duration
4. Reduce the project direct cost

A.5 STUDY ACTIVITIES

After setting the objectives, the CTR team crafted a plan of action. The following items, describe the sequential steps taken in this effort.

Step 1. Site visit

The team visited the site to assess its actual characteristics as regards space availability, traffic flow, and business locations and access. During this visit, the team discussed ideas with the contractor and with owner representatives.

Step 2. Review original plans

TxDOT provided the team with a complete set of the original plans, which the team reviewed carefully. Each step was analyzed to assess the possibility of eliminating it, combining it with another step, or at least simplifying it. The team immediately detected a number of redundant steps that could be easily eliminated.

The original plans included building a complete two-lane detour to carry the main lanes' traffic during bridge construction. This detour was allocated just east of the existing bridge abutment . Putting the main lanes' traffic on this detour requires excavating east of the existing Mockingbird Bridge, which necessitates the construction of a temporary bridge . This bridge has to be demolished before building the final bridge. The team noticed that the east span of Mockingbird can, with a sight change in sequence, be used to accommodate this detour. This eliminated the need for the detour and the temporary bridge. This suggestion alone saved three months of construction time and a total direct cost of $160,000.

Step 3. Development of performance measures

Early in this effort, many suggestions as to how to rebuild the bridge were developed by either the CTR team or the contractor. The team realized the need for a system to evaluate these ideas before going to the detailed planning phase. The team developed a list of performance measures that should be satisfied by any acceptable plan. This list was derived directly from the project objectives, owner's restrictions, and team members' experience with traffic control plans.

Step 4. Developing and evaluating new alternatives

With all necessary background information about the project in hand, the project team generated alternative plans. During this brainstorming process, several creative approaches were advanced. The team then combined these ideas into more concrete plans. These plans were then evaluated against the performance measures developed by the team.

During this evaluation, safety was the dominant issue. The team aimed at reducing to the lowest level possible the interaction between construction activities and traffic. All plans and ideas generated during this phase were carefully investigated to ensure that the construction workers had adequate work space away from traffic.

As for travelers' safety, the team focused on reducing the total number of traffic diversions on the main lanes and on the overpass. Horizontal and vertical curves were carefully examined to ensure sufficient sight distance and complete compliance with OSHA's standards.

Site accessibility was another important issue in the team's analysis of the BCP. Each plan was analyzed to evaluate its effect on public traffic accessibility, construction equipment, and on surrounding businesses.

Construction activities cause traffic congestion along the highway. With the heavy traffic volume on NCE, any reduction in project duration will have a considerable impact on user cost. In addition to that, the negative impact on businesses will be reduced. The team focused on:

1. Eliminating unnecessary steps
2. Rearranging the construction logic to combine several steps in one step
3. Performing different activities in parallel instead of in serial sequence
4. Simplifying (and thus accelerating) the construction sequence

The new plan reduced the project's duration by 52 percent, which in turn lead to a significant reduction in indirect costs. As to direct costs, the elimination of unnecessary steps (e.g., the temporary bridge) saved a substantial amount of money. In this regard, the team focused on:

1. Eliminating the need for the temporary bridge
2. Eliminating unnecessary detours
3. Reducing the number of traffic shifts

On the basis of this approach, several plans were developed. The team applied the performance measures on these plans. These plans were then reduced to only two plans.

Step 5. Final plans

The team held another meeting with the owner and the contractor to evaluate the two plans. In this meeting, one plan received initial approval from both parties. The team then concentrated on developing a more detailed plan. In subsequent meetings, the owner and the contractor's preferences were elicited and added to the plan. After a series of meetings and modifications, the plan was finally approved by both parties. At that time the team put this plan on computer using Microstation 5. This allowed the team to discus and add the more finer details.

Step 6.Execution and documentation

It took 2 months to reach an agreement about the general construction approach. Three more months were spent in detailing and optimizing the plan. By December, 94 the plan was presented to TF. After its approval, the plan was presented to TxDOT safety committee, which approved it also.

The reconstruction of Mockingbird Bridge began in January 1995. The CTR team continued to monitor the actual execution of the project. The team focused on developing as-built plans and on documenting the actual activities.

The plan was executed successfully on time and budget with no significant changes to the proposed plan

During implementation of the plan and throughout the work on main lanes, TxDOT field office induced all workers and superintendents to record their suggestions for enhancement. A standard sheet was distributed in the field. By the time of this paper, 300 suggestions have been collected, of which 200 were implemented.

A.6 Study Methodology

An initial analysis was conducted to assess the existing project situation. Based on this analysis, the following concerns were identified:

- Site conditions are hazardous.
- The project has a tremendous impact on the neighborhood; it is also relatively long (662 days).
- Different parties are involved in the decision cycle: TxDOT, the contractor, and the City of Dallas.
- Different entities are directly affected by the plans: Traveling public, the contractor, and businesses.

In approaching the problem, the team focused on two major goals:

1. optimizing the overall project objectives: safety, accessibility, carrying capacity, project duration, and project cost; and
2. simplifying the plans.

In order to achieve these two goals, the team conducted several meetings with the owner and the contractor to explore the problem areas and elicit their knowledge about the site and the project. The two parties provided the team with numerous insights about the project. The basic information gathered included the following items:

- Project general documents: Contract, bill of quantities, etc.
- Original project plans
- Traffic counts
- Business locations

Using this information, the team developed a list of the most significant factors governing the development of a BCP. The team also developed a list of performance measures to evaluate the effectiveness of a BCP - see table A-1.

A.7 DETAILS OF FINAL PLAN

Plan general concept

There were two major problems with the reconstruction of mockingbird bridge. The first was the question of how to demolish the old bridge and build the new one. The original plan tackled this problem by dividing the old bridge into six parts. Each one was to be demolished in a separate step. Immediately after the demolition of one part a part of the new bridge was to be built.

Table A-1. Performance measures

OBJECTIVE	MEASUREMENT PARAMETER
Traveler Safety	Interaction w/equipment Detour configuration • Lane width. • Detour alignment • Detour length.
Worker Safety	Interaction w/ traffic • Interaction level • Interaction duration Number. of traffic changes Proximity to accidents
Accessibility	Traffic Business access Construction equipment
Carrying Capacity	Number of lane closures Duration of lane closure
Project Duration	% duration saving
Project Direct Cost	% Budget savings

The new plan handled the matter in a different way. The bridge was divided into two parts north and south. The north part is two lanes width and the south part is four lanes width. The north part will be demolished first. Immediately after that the whole northern part of the new bridge will be erected to carry four lanes. Shifting the traffic to the new bridge will allow the demolition of the south part of the old bridge and the erection of the other half of the new one.

The second problem involved keeping four running lanes on the highway. Because the old plan divided the bridge into six parts, the new bridge columns on the east side was to be constructed early in the project. These columns are in the middle of the east side of Mockingbird bridge. This means that the east side can no longer be used to carry the main lanes. During the construction of the west side a new detour outside the bridge has to be constructed. This required the construction of a complete detour east of the bridge along with a temporary bridge to overpass it. In the new plan, traffic will be put under the east span before any columns are built. At the same time, a complete detour will be constructed under the west span of mockingbird. For the remaining of the project, traffic will use this detour. Only for two weekends will it be shifted to the frontage road.

Construction sequence

Step 1: Saw cut the northern portion of the existing bridge, then demolish it on a weekend.

Step 2: Shift main lanes traffic east; build North west corner of the new bridge.

Step 3: Shift main lanes traffic west; build north east portion of the new bridge.

Step 4: Shift Mockingbird traffic to new the new bridge; demolish the remaining part of the old bridge.

Step 5: Build South east west corner of the new bridge.

Step 6: Shift main lanes traffic; build south east west corner of the new bridge.

A.8 RESEARCH RESULTS

- fewer steps. Most of them were saved because of traffic switch elimination and the elimination of the temporary bridge. This resulted in
  - ◊ direct cost reduction
  - ◊ duration reduction
- Enhanced access to traffic, businesses, and construction equipment.
- More consistent work zone pattern.
- By the admission of safety committee of TxDOT, a safer project.

A.9 CONCLUSIONS

- The study resulted in tremendous savings to the project in terms of budget, schedule, and traffic flow. Without counting user cost, the rate of return to the owner investment was over 15/1.
- There is a need to develop a systematic procedure to evaluate the effectiveness of bridge construction plan during design phase.
- The analysis of project plans by the owner and contractor proved to have positive impact on project performance both on technical and professional dimensions.

APPENDIX B

DATA ACQUISITION INTERVIEWS

Interview Guide

Interviewee Log

Interview Results

B.1 BACKGROUND AND RESEARCH PROBLEM

More optimal performance of urban freeway bridge projects demand that more attention be placed on bridge construction planning. Construction sequencing and traffic control planning have to be coordinated to assure safe and adequate traffic flow, and at the same time, safe, and efficient construction work. Furthermore, construction sequencing has to be planned to minimize the disruptions to the local community -- especially business activities.

The lack of adequate balance in accommodating construction, traffic, and community needs within such projects can result in excessive project cost and time, traffic flow inefficiency, and most importantly safety hazard to both the traveling public and construction crews.

Currently the design team of a new bridge project lacks an objective tool for evaluating these aspects of different bridge design alternatives.

B.2 PURPOSE OF THE INTERVIEW

This interview is a part of an ongoing research to develop a model to evaluate the effectiveness of urban freeway bridge construction plans.

The aim of this interview is to solicit experts opinion regarding three major issues:

- Parameters that can be used to evaluate BCP.
- Relative importance of parameters.
- Effort level required to estimate evaluation parameters.

B.3 BCP DEFINITION

A bridge construction plan (BCP) is a comprehensive plan for the construction of a new bridge that satisfies project defined objectives. It includes the following major items:

- A detailed description of the bridge construction method.
- General project specification.
- A detailed sequence of bridge construction activities.
- A detailed plan for handling traffic during construction or what is known as traffic control plan (TCP).

The BCP is, then, a plan to execute an already approved layout and structural system. Hence, it is out of the scope of this study to evaluate the effectiveness of those two items. The model -and the interview- will focus only on the execution mechanism and procedures.

B.4 OUTLINE OF PRELIMINARY EVALUATION FACTORS

Table B-1: BCP Evaluation Factors

Evaluation Factor	**Evaluation Sub Factors**	**Assessment Parameter**
Safety (S)	• Travelers interaction w. constr. activities. (Q) • Detour configuration (D) _ Lane width (Lw) _ Detour length (Dl) _ Detour quality(Da) • Crew interaction w. traffic (Li) • Traffic change index (Tc) • Access to accidents - if any (P)	Parameter list Average lane width Total detour length Vt. & Hl Curve sharpness Parameter list No & type of change Total time to evacuate accidents
Accessibility (A)	Traffic accessibility (At) Business accessibility (Ab)	Parameter list Parameter list
Carrying capacity (C)		No. of cars blocked (Nc) Blockage duration (Bd)
Schedule performance (T)		% Time savings
Cost performance (B)		% Cost savings

B.5 GLOSSARY OF TERMS

Evaluation factor: Major evaluation factors. Currently refer to five specific factors: Safety, Accessibility, Carrying capacity, Cost, and Schedule.

Evaluation sub factor: A subsidiary element of an evaluation factor.

Safety

This evaluation factors is proposed to assess the level of safety a BCP can provide to both traveling public and construction crew above and beyond the minimum standards. It includes five sub factors: Travelers interaction with construction activities, Detour quality, Crew interaction with traffic, Traffic changes, and access to accidents - if any.

Travelers interaction with construction activities

A sub factor designated to evaluate all plan's items or conditions that may affect the safety of travelers.

Overhanging construction equipment
Relates to situations in which a construction equipment is overhanging or swinging over traffic.

Adequacy of traffic barrier
Deals with how well the traffic barrier separates traffic from construction activities.

Traffic-construction interaction length
Refers to the length of construction activity adjacent to traffic.

Construction equipment interruption to traffic line
If a BCP is sequenced such that it requires construction equipment to constantly interrupt traffic line, it is inferior to another plan that does not require so.

Distance between traffic and construction activity
Refers to the cross distance between traffic and construction activity.

Detour configuration

A sub factor designated to assess the adequacy of detours.

Detour quality
Measures the sharpness of horizontal and vertical curves.

Crew Interaction with traffic

A sub factor designated to examine the level of hazards the construction individuals are subject to during their work due to running traffic.

Working on one side of traffic Vs working between traffic lines
Refers to the location of crew relative to traffic. A crew working between traffic line is in a more dangerous situation.

Working at high traffic volume Vs working at low traffic volume
Deals with the intensity of traffic around construction activity. A crew working at high traffic volumes is in a much dangerous situation than a crew working at low traffic volumes.

Day shift Vs night shift
Deals with crew visibility to traffic. Night shifts are more dangerous than day shifts.

Working toward traffic Vs working away from traffic
A crew working toward traffic will be trapped between the construction work and traffic. In contrast, a crew working away from traffic is moving to safer ground.

Activity intensity level
Refers to the level of involvement required in the activity. A more intense activity with a lot of equipment and personnel is more likely to cause a sever accident than a less intense one.

<u>Traffic changes</u>
Deals with the changes to traffic path. It includes changes like lane drop, traffic diversion, freeway closure. Such activities include a high risk of accidents to both travelers and construction crew.

<u>Access to accidents</u>
Deals with the ease by which an ambulance can get into the site and evacuate an accident.

Accessibility

This evaluation factor is proposed to assess the BCP effect on both traffic and business accessibility during construction.

<u>Traffic accessibility</u>
A sub factor designated to evaluate access impedance caused by BCP.

Reduction of number of access points in and out of the site
If a BCP requires the closure of several ramps to or from the freeway, then it is less effective than another one that does not require so.

Number of forced diversions
Deals with forced diversions to traffic like diverting traffic to another road or to frontage road.

Reduction in traveling speed
Deals with BCP impact on the running speed. BCP may cause long term interruption to the freeway that can reduce the actual driving speed.

<u>Business accessibility</u>
Refers to the interruption to the business activity around the project.

Reduction of access points to the business
A BCP may mandate the closure of a ramp or a side street that leads to a business. This may affect the business activity.

Reduction of parking space
Refers to the reduction in business parking space caused by construction work.

Additional distance from ramp
If a BCP changes the location of a ramp location that provides access to a business, this may cause some customers to abstain from the business.

Construction activity congestion in front of business
Deals with the level of work around the business that may impede access to business.

Carrying capacity

This factor evaluates BCP impact on the carrying capacity of the freeway. BCP usually require closing portions of the freeway. This usually forces traffic to other roads.

Number of cars blocked
The estimated number of cars blocked from highway in each closure.

Blockage duration
Total estimated time in which cars are being blocked from highway.

Schedule performance

This factors evaluates the effectiveness of BCP schedule

% savings in schedule
A BCP with lesser duration is superior to another one with longer duration.

Budget performance

This factor evaluates the effectiveness of BCP budget.

% savings in cost
A BCP with lesser cost is superior to another one with higher cost.

Interview # ______________________

Date: ______________________

Location: ______________________

Name: ____

Organization name: ____

Title/Position: ____

Field of experience: ____

Years of experience: ____

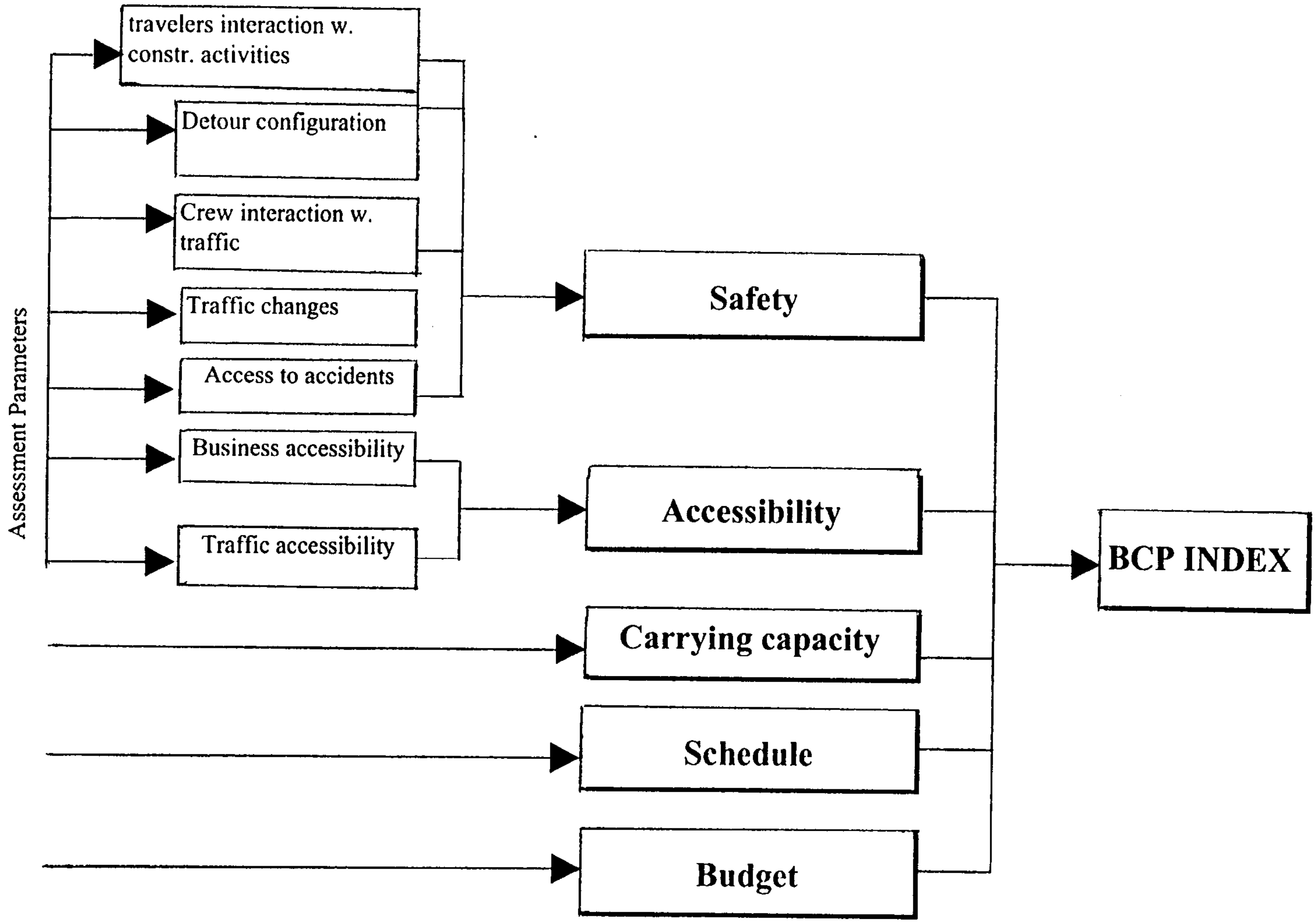


Figure B-1: Evaluation Model General Structure

SAFETY FACTOR	Relative significance to overall effectiveness	Ease of estimation during planning phase
Travelers interaction with constr. activities		
• Over Hanging equipment		
• Adequacy of traffic barrier		
• Traffic-Activity interaction length		
• Machine interruption to traffic line		
• Distance between traffic and construction		
•		
•		
Detour configuration		
• Lane width		
• Detour length		
• Detour quality		
•		
•		
Crew interaction with traffic		
• Working on one side of traffic Vs working between traffic lanes		
• Working at high traffic volumes Vs working at low traffic volumes		
• Day shift VS night shift		
• Working toward traffic Vs working away from traffic		
• Construction activity intensity level		
•		
Traffic changes		
• Type of change		
• Type of road on which change takes place		
•		
Access to accidents		
• Total time to evacuate accidents		
•		
•		
•		
•		

ACCESSIBILITY FACTOR

	Relative significance to overall effectiveness	Ease of estimation during planning phase
Traffic accessibility		
• Reduction of number of accesses		
• Number of forced diversions		
• Reduction in running speed		
•		
•		
•		
•		
Business accessibility		
• Reduction of access points to business		
• Reduction in parking space		
• Additional distance from ramp		
• Constr. congestion in front of business		
•		
•		
•		
•		
•		
•		
•		
•		
•		
•		
•		
•		

Scoring scale	0	2	4	6
Significance	No	low	considerable	major
Ease of estimate	Very hard	hard	easy	very easy
Note: Use numbers, 1, 3, 5 as intermediate scores between these options				

CARRYING CAPACITY FACTOR

	Relative significance to overall effectiveness	Ease of estimation during planning phase
• Number of cars blocked		
• Blockage duration		
•		
•		
•		

SCHEDULE PERFORMANCE FACTOR

	Relative significance to overall effectiveness	Ease of estimation during planning phase
• % Savings in duration		
•		
•		

BUDGET PERFORMANCE FACTOR

	Relative significance to overall effectiveness	Ease of estimation during planning phase
• % Savings in cost		
•		
•		

Scoring scale				
	0	2	4	6
Significance	No	low	considerable	major
Ease of estimate	Very hard	hard	easy	very easy
Note: Use numbers, 1, 3, 5 as intermediate scores between these options				

BCP OVER ALL EVALUATION

	Relative significance to overall effectiveness
SAFETY	
ACCESSIBILITY	
CARRYING CAPACITY	
SCHEDULE PERFORMANCE	
BUDGET PERFORMANCE	
◊	
◊	
◊	

Scoring scale				
	0	2	4	6
Significance	No	low	considerable	major
Ease of estimate	Very hard	hard	easy	very easy
Note: Use numbers, 1, 3, 5 as intermediate scores between these options.				

Table B-2: Interviewee Log

Name	Position	Organization
John Roberts, P. E.	Area Engineer, Austin District	TxDOT
Jay Nelson, P. E.	District Engineer, Dallas District	TxDOT
John F. Becker, P. E.	Head, Structures Dept.	HNTB Corp.
Michael Doninio, P. E.	Heavy Construction Manager	Granite Construction
Patrick Ellis, P. E.	Area Engineer, Dallas District	TxDOT
Alan Matejowsky, P. E.	Asst. State Design Engineer	TxDOT
A. Hennery Pearson, P. E.	Manager of Hwy Planning & Design	Carter & Burgess Inc
John Kelly, P. E.	District Engineer, San Antonio District	TxDOT
Gilbert G. Gavia, P. E.	District Design Eng., San Antonio Dist.	TxDOT
Robert Kovar, P. E.	Director, Field Coordination	TxDOT
Terrel S. Jackson, P. E.	Director of Construction, Austin Dist.	TxDOT
Joe Lee, P. E.	Project Manager	Eby Construction

Table B-3: Safety Factor Significance Score

	Interview #																
	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
Travelers interaction	6	4	4	5	6	6	4	5	6	4	5	5	5	5	6	0.93	-2.1
• Over Hanging equipment	3	6	3	4	6	6	6	5	6	4	6	6	4.9	6	6	1.36	-1.6
• Adequacy of traffic barrier	3	6	6	4	6	5	6	4	6	5	5	5	5.1	5	6	1.00	-0.5
• Traffic-Activity interaction	4	3	2	2	4	4	4	1	6	3	4	2	3.3	3.5	4	1.36	0.4
• Machine interruption to traffic	4	3	6	2	4	6	6	5	6	5	5	4	4.7	5	6	1.30	-0.4
• Distance between traffic..	6	4	4	6	6	4	4	1	2	4	4	4	4.1	4	4	1.51	0.0
Detour configuration	5	4	4	5	6	4	6	6	5	5	4	4	5	5	4	0.83	-1.4
• Lane width	6	4	4	6	6	6	4	3	2	5	4	4	4.6	4	4	1.31	-0.8
• Detour length	3	2	3	4	6	3	4	2	2	3	5	4	3.2	3	3	1.24	2.2
• Detour quality	5	5	6	2	6	4	4	4	6	6	5	4	4.8	5	6	1.22	0.8
Crew interaction w/ traffic	5	6	2	6	6	6	4	3	6	3	4	4	4.7	4.5	6	1.44	-1.3
• Working on one side of traffic ..	5	6	4	6	6	6	6	4	6	4	5	4	5.2	5.5	6	0.94	-1.6
• Working at high traffic volumes ..	6	6	3	4	6	4	4	4	6	6	6	2	4.9	5	6	1.42	-1.9
• Day shift VS night shift	4	5	3	4	6	4	6	4	6	4	4	6	4.6	4	4	1.07	-1.3
• Working toward traffic Vs	2	4	2	2	4	4	2	1	2	3	5	2	2.6	2	2	1.22	-1.3
• Construction activity intensity	3	4	2	4	6	3	4	3	6	5	4	5	4	4	4	1.24	-0.7
Traffic changes	5	3	4	4	6	4	2	3	5	5	6	4	4.1	4	4	1.22	-0.4
• Type of change	4	5	3	4	6	4	4	3	6	5	6	4	4.5	4	4	1.09	-0.9
• Type of road	4	4	3	2	6	4	4	3	4	5	6	4	3.9	4	4	1.16	0.9
Access to accidents	4	4	5	3	2	2	4	4	3	6	4	2	3.7	4	4	1.24	-0.1
• Total time to evacuate..	4	6	6	2	4	3	6	5	2	6	4	2	4.4	4	6	1.64	-1.5

Table B-4: Accessibility Factor Significance Score

	Interview #																
	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
Traffic accessibility	4	4	5	5	4	5	6	5	6	4	5	4	4.8	5	4	0.8	-1.1
• Reduction of number of acc.	4	5	5	4	4	4	6	4	6	6	5	6	4.9	5	4	0.9	-1.8
• Number of forced diversions	3	4	5	4	4	5	4	2	6	4	5	4	4.2	4	4	1.0	0.9
• Reduction in running speed	4	3	5	4	2	4	4	2	2	3	4	3	3.3	3.5	4	1.0	-1.2
Business accessibility	5	5	3	6	4	5	6	5	6	5	5	4	4.9	5	5	0.9	1.2
• Reduction of access points...	4	6	5	6	4	4	6	4	6	5	5	6	5.1	5	6	0.9	-2.1
• Reduction in parking space	5	2	5	4	4	5	4	5	2	4	5	4	4.1	4	5	1.1	0.1
• Additional distance from ramp	4	2	3	2	6	3	6	2	0	5	4	3	3.3	3	2	1.8	-0.7
• Constr. congestion in front ...	6	4	5	4	6	5	6	5	2	3	5	4	4.6	5	5	1.2	-0.1

Table B-5: Carrying Capacity Factor Significance Score

	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• Number of cars blocked	6	6	6	2	4	5	6	5	6	6	5	6	5.3	6	6	1.2	4.4
• Blockage duration	6	6	6	4	6	4	4	5	6	6	5	4	5.2	5.5	6	0.9	-1.9

Table B-6: Schedule Performance Significance Score

	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• % Savings in cost	4	6	6	4	6	5	4	5	6	6	6	4	5.2	5.5	6	0.9	-1.9

Table B-7: Budget Performance Significance Score

	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• % Savings in duration	3	6	5	6	6	4	4	5	6	6	5	5	5.1	5	6	1.0	0.0

Table B-8: Major Factor Significance Score

	Interview #																
	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
SAFETY	6	6	6	6	6	4	6	6	6	6	6	5	5.8	6	6	0.6	10
ACCESSIBILITY	5	4	4	5	4	5	6	4	6	4	4	4	4.6	4	4	0.8	-1
CARRYING CAPACITY	6	4	6	4	4	5	5	5	4	4	4	4	4.6	4	4	0.8	-1
SCHEDULE PERFORMANCE	4	5	3	6	6	4	4	4	4	3	5	5	4.4	4	4	1	-0.4
BUDGET PERFORMANCE	4	6	4	4	6	6	5	3	4	3	5	4	4.5	4	4	1.1	-1.4

Table B-9: Safety Factor Ease of Measurement Score

	Interview #																
	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• Over Hanging equipment	0	2	6	4	2	3	4	3	2	4	3	5	3.2	3	2	1.6	0.5
• Adequacy of traffic barrier	5	3	6	2	2	4	6	5	6	5	5	5	4.5	5	5	1.4	-0.5
• Traffic-Activity interaction length	6	2	4	2	2	2	4	5	4	6	3	5	3.8	4	2	1.5	-1.4
• Machine interruption to traffic line	0	2	2	2	0	2	2	2	2	3	2	2	1.8	2	2	0.9	1.9
• Distance between traffic and constr	6	4	4	4	2	4	4	5	6	5	3	5	4.3	4	4	1.2	0.3
• Lane width	6	4	4	6	4	5	6	5	6	5	5	4	5.0	5	6	0.9	-1.7
• Detour length	6	4	4	6	2	5	4	6	6	6	5	4	4.8	5	6	1.3	0.6
• Detour quality	6	4	4	2	2	3	4	6	6	4	3	4	4.0	4	4	1.4	-0.8
• Working on one side of traffic	6	3	4	4	2	3	4	4	6	5	3	2	3.8	4	4	1.3	-0.6
• Working at high traffic volumes	6	6	0	2	2	3	4	6	6	5	5	2	3.9	4.5	6	2.1	-1.0
• Day shift VS night shift	0	5	0	6	2	4	4	6	6	4	3	2	3.5	4	6	2.2	-0.9
• Working toward traffic Vs	0	3	0	2	2	3	4	3	0	5	4	2	2.3	2.5	0	1.7	-0.9
• Construction activity intensity	0	2	0	2	2	3	4	3	0	3	1	3	1.9	2	3	1.4	-1.2
• Type of change	6	4	4	2	0	5	4	3	4	3	2	4	3.4	4	4	1.6	1.1
• Type of road on which change	6	6	4	4	4	5	4	3	6	4	4	4	4.5	4	4	1.0	-0.8
• Total time to evacuate accidents	0	3	0	2	0	3	4	5	6	3	0	3	2.4	3	0	2.1	-1.0

Table B-10: Accessibility Factor Ease of Measurement score

	Interview #																
	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• Reduction of number of accesses	4	4	4	4	2	4	2	3	6	1	3	3	3.3	4	4	1.3	1
• Number of forced diversions	6	4	4	2	2	4	4	4	4	4	3	3	3.7	4	4	1.1	1
• Reduction in running speed	2	3	4	2	2	4	4	4	4	4	3	4	3.3	4	4	0.9	-1
• Reduction of access points ...	6	3	4	4	2	4	4	5	2	3	2	4	3.6	4	4	1.2	0
• Reduction in parking space	0	5	4	4	2	2	4	6	6	6	3	4	3.8	4	4	1.9	0
• Additional distance from ramp	4	4	4	4	0	3	4	5	6	5	3	4	3.8	4	4	1.5	4
• Constr. congestion in front of...	2	2	2	2	2	3	4	6	2	4	2	3	2.8	2	2	1.3	3

Table B-11: Carrying Capacity Factor Ease of Measurement Score

	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• Number of cars blocked	6	3	3	0	2	3	4	5	2	2	2	4	3	3	2	1.6	0.4
• Blockage duration	2	2	2	2	2	3	4	4	2	2	2	4	2.6	2	2	0.9	-0.9

Table B-12: Schedule Performance Factor Ease of Measurement Score

	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• % Savings in duration	5	4	2	2	2	2	4	5	6	2	2	3	3.3	3	2	1.5	-1.1

Table B-13: Budget Performance Factor Ease of Measurement Score

	1	2	3	4	5	6	7	8	9	10	11	12	Av	Med	Mo	SD	K
• % Savings in cost	6	3	3	2	2	3	6	5	6	3	2	3	3.7	3	3	1.6	-1.3

APPENDIX C

BCP EVALUATION MODEL DETAILED COMPUTATION

This appendix presents the detailed of model evaluation steps and procedures. A complete application of the model is presented in Appendix E.

C.1 MODEL DETAILED STEPS

The application of the model should start after developing several BCPs. At that time, an evaluation team should be formed to conduct the evaluation. This team should include design and owner representatives. From the owner side, structural, construction, transportation and safety engineers should be present on that team. Community representative and interested contractor representative can attend the team meetings (Ref 37), if possible. Figure C-1 shows the general steps schematically, while Table C-1 lists the proposed evaluation procedures for each sub-factor. Figure C-2 shows the procedures of developing the final objective matrix.

The exact steps of the model are as follows:

Step 1: Adjust the model for project specific needs

- Add any additional evaluation factors or sub factors.
- Modify / Accept the suggested weights.

Step 2: Prepare BCP for evaluation

- Divide each plan into phases of construction.

Step 3: Factor evaluation

- Evaluate safety, accessibility sub factors. Use appropriate procedure as shown in Table C-1.
- Find the scores of safety, accessibility by substituting in equations C-2 and C-3 respectively.
- Evaluate carrying capacity factor. Use procedure #6 shown in section C.8.
- Evaluate schedule and budget performance factors as shown in procedure #7 in section C.8.

Step 4: Final score

- Evaluate the final score as in equation C-1.

C.2 MODEL EQUATIONS

The following set of equations are to be used to calculate the final BCP score.

BCP Final score (F)

$$F = w_1 * S + w_2 * A + w_3 * C + w_4 * T + w_5 * B + w_6 * Q \qquad \text{C-1}$$

Safety Score (S)

$$S = \sum_{i=1}^{i=12} w_i * SF_i \qquad \text{C-2}$$

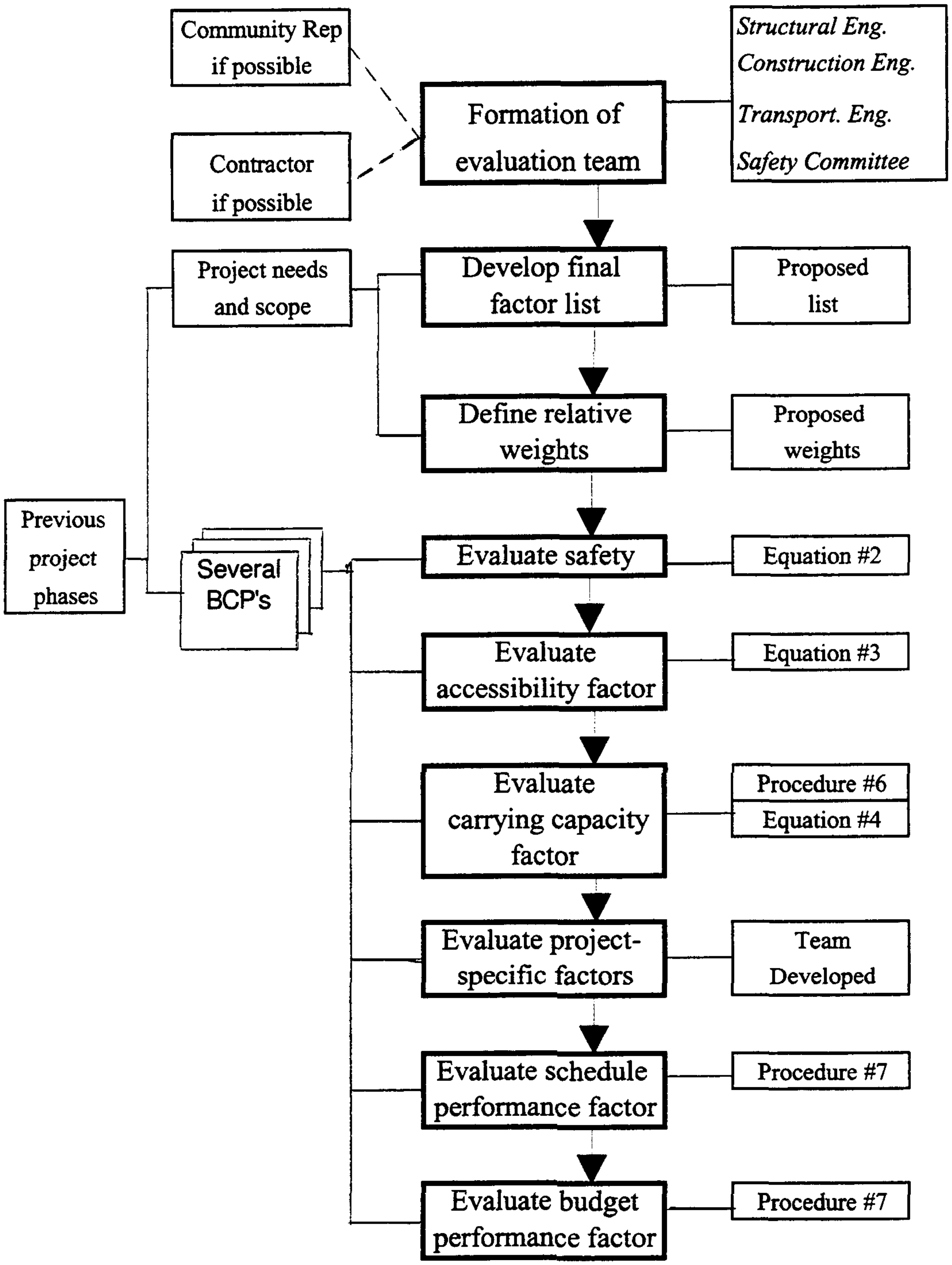


Figure C-1: Model Application Steps

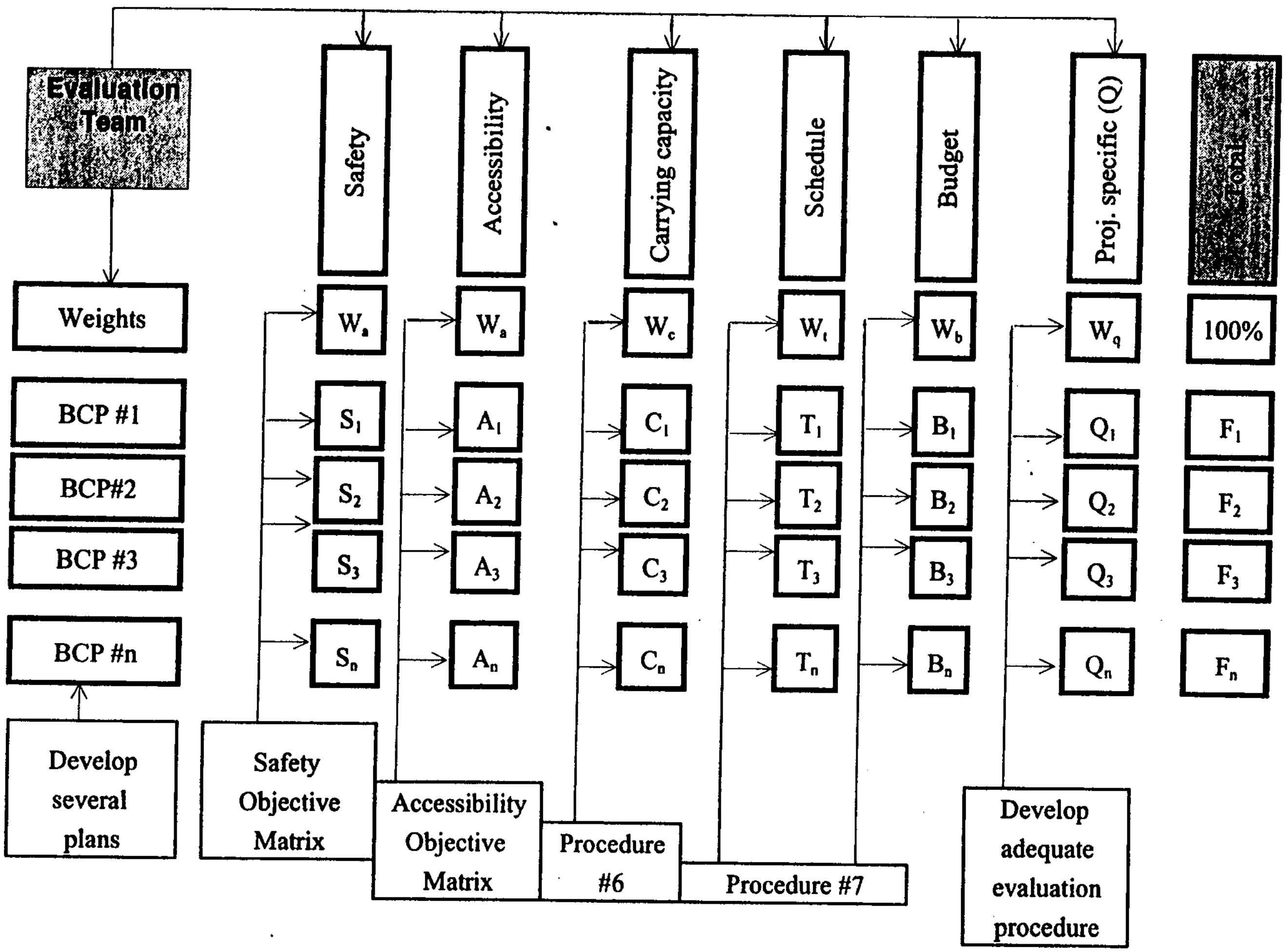


Figure C-2: Development of Final Objective Matrix

Accessibility score (A)

$$A = \sum_{i=13}^{i=19} w_i * SF_i \qquad \text{C-3}$$

Carrying capacity score (C)

$$C = \sum_{j=1}^{j=n} c_j * b_j \qquad \text{C-4}$$

Schedule score (T)
Follow scoring rule explained in section C.8.

Budget Score (B)
Follow scoring rule explained in section C.8.

Additional factors score (Q)
Any additional factor should be evaluated out of 10. A specific scoring technique has to be developed by the user for each new factor. The scoring techniques in Appendix C can be used as guide in this regard.

Where:
i: sub factor counter
n: number of blockage/delay incidents in a plan
SF: Sub factor score
C: Number of cars blocked/delayed
b: Blockage/Delay duration

C.3 SAFETY FACTOR

This evaluation factor is proposed to assess the level of safety a BCP can provide to both traveling public and construction crew above and beyond the minimum standards.

The interaction between construction activities and running traffic has a high impact on the safety of both travelers and crew. This interaction may be the direct cause of accident between construction equipment and traveling vehicles. It may also be the indirect cause of an accident between vehicles on the road because of its effect on drivers' attention or site distance.

The design and the sequence of construction activities have a direct influence on the level and duration of this interaction.

The following is a list of sub factors to assess this factor:

1. Overhanging equipment

Relates to situations in which a construction equipment is overhanging or swinging over traffic. If such condition exists frequently, this could raise the probability of an accident.

Scoring

The BCP will be credited an extra point for each overhanging condition. See procedure #1 in section C.8.

2. Adequacy of traffic barrier

Deals with how well the traffic barrier separates traffic from construction activities. Such barrier is a major device in protecting both travelers and construction crew. The higher and stiffer the barrier, the less probable an accident can take place. If a BCP sequence is such that it does not allow the installation of an adequate barrier, it is inferior to another BCP that allows so.

Scoring

The BCP will be credited an extra point for each inadequate traffic barrier condition. See procedure #1 in section C.8.

3. Traffic-Activity interaction length

Refers to the length of construction activity adjacent to traffic. The longer the length of interaction between traffic and construction, the more probable an accident will occur.

Scoring

The BCP will be credited a score commensurate with the length o traffic and construction interaction. See procedure #3 in section C.8.

4. Distance between traffic and construction activity

Refers to the cross distance between traffic and construction activity. The further the traffic is from the construction area, the safer the travelers are.

Scoring

A threshold distance of 3' has been selected to scale this parameter. BCP will be credited a point for every time a construction activity is closer than 3' to traffic without a barrier separating them. See procedure #1 in section C.8.

5. Lane width

Refers to the average lane width of the freeway and frontage road during construction. Effective lane width has a direct impact on the probability of car accidents (Zeeger 1987). The wider the lane width, the safer travelers are.

Scoring

Find the average lane width throughout the BCP then use Table C-2 to assign a score to each plan. See procedure #2 in section C.8.

6. Detour length

Measures the total detours required to perform the construction. A plan with fewer detours is relatively safer than one with more detours. This is because detours may cause confusion to travelers specially ones who are accustomed to the original road configuration. The total detour length throughout the BCP will be used to measure this item.

Scoring

Find the total detour length for each BCP. Give the BCP with the shortest detour length a score of ten; others relative to that. See procedure #3 in section C.8.

7. Detour curve quality

Measures the sharpness of horizontal and vertical curves. The quality of both horizontal and vertical curves has direct impact on roadway safety. A BCP with simple curves is safer than another one with sharp curves. Average vertical slop of all vertical curves in the BCP and average horizontal curve degree of all horizontal curves in the BCP will be used to assess this parameter.

Scoring

Calculate average vertical slop of each BCP and the average curve degree of each BCP. Use Table C-3 to give each plan a score as explained in procedure #4 in section C.8.

8. Working on one side of traffic Vs working between traffic lines

Refers to the location of crew relative to traffic. Other elements constant, a crew working between traffic lines is in a more dangerous situation.

Scoring

The BCP will be credited an extra point for each time a crew is working between traffic lines. See procedure #1 in section C.8.

9. Working at high traffic volume Vs working at low traffic volume

Deals with the intensity of traffic around construction activity. A crew working at high traffic volumes is in a much dangerous situation than a crew working at low traffic volumes.

Scoring

The BCP will be credited an extra point for each time a crew works at high traffic volumes. See procedure #1 in section C.8.

10. Day shift Vs night shift

Deals with crew visibility to traffic. Night shifts are more dangerous than day shifts.

Scoring

The BCP will be credited an extra point for each night shift. See procedure #1 in section C.8.

11. Traffic changes

Deals with the changes to traffic path. It includes changes like lane drop, traffic diversion, freeway closure. Changing the traffic path is one of the most dangerous activities to crew members. It also causes some confusion to drivers. Hence, this activity deserves special attention in the evaluation process. Because not all changes are equal in their effect on safety, the change factor (C_f) was introduce to perform this task of differentiating between the various types of change. Table C-4 presents one suggestion to the values of Cf. Furthermore, different roads in the site have variable importance and effect on the safety (A change on the freeway is more dangerous than one on the frontage road for example). The road index (T_r) was introduced to differentiate between the various roads in the project. Table C-5 presents one way of assessing this index.

Scoring
The weighted sum of all traffic changes will be used to score this factor as explained in equation C-5. See procedure # 5 in section C.8.

$$T_c = \sum_{k=1}^{k=m} (c_f * t_r)_k \qquad \text{C-5}$$

Where:
m: total number of traffic changes
C_f: Change factor
T_r: Road factor

C.4 ACCESSIBILITY FACTOR

This evaluation factor is proposed to assess the BCP effect on traffic, business, and contractor accessibility during construction. Among the major impacts of BCP are its effects on business activity and traffic flow within and around the site. Bridge construction projects usually cause major interruption to the surrounding businesses. An optimum BCP should work to reduce that. Also an optimum BCP will work to enhance the traffic accessibility in and out of site.

This factor includes the following sub factors:

12. Reduction of number of traffic accesses

Evaluates the frequency of closing highway on/off ramps. If a BCP requires the closure of several access ramps to or from the highway or closure of side street, then it is less effective than one that does not require so. This is because it is impeding the normal traffic path for the highway users.

scoring
The BCP will be credited an extra point for each access reduction condition. See procedure #1 in section C.8.

13. Number of forced diversions (to traffic)

Deals with forced diversions to traffic like diverting traffic to another road. Such diversions reduce travelers options and accessibility to several locations.

Scoring
The BCP will be credited an extra point for each forced diversion. See procedure #1 in section C.8.

14. Reduction of access points to businesses

Evaluates the frequency of closing/impeding access to businesses. A BCP may mandate the closure of several ramps or side street that lead to a business. It may also keep those ramps or streets open, but change their configuration in a way that prevents a direct access to certain businesses. Such an impedance to business access is not desirable.

Scoring
The BCP will be credited an extra point for each time an access point to businesses is closed. See procedure #1 in section C.8.

15. Reduction of parking space

Refers to the reduction in business parking space caused by construction work. A BCP may require the use of some of the parking space of a business or impede access to some of it. Such an action may affect the business activity in that location.

Scoring

The BCP will be credited points commensurate with the reduction in parking space. See procedure #1 in section C.8.

16. Additional distance from ramp (for business)

Evaluates the impact of changing ramp location on business activity. If the BCP requires the change of ramp location providing access to a business, this may cause some customers to abstain from their regular business distention to avoid traffic jams.

Scoring

The BCP will be credited a point for every additional 1000' movement of a ramp. See procedure #1 in section C.8.

17. Construction congestion in front of business

Deals with the level of work around the business that may impede access to business. The more congested the construction work around the business the more likely that business will suffer some reduction in customer turn out.

Scoring

The BCP will be credited a point for every congested construction situation that takes place in front of a business. See procedure #1 in section C.8.

18. Contractor access to work zone

Refers to the availability of access for contractor equipment like cranes or hauling equipment.

Scoring

The BCP will be credited a point for each time access of construction equipment is obstructed. See procedure #1 in section C.8.

C.5 CARRYING CAPACITY

This factor evaluates BCP impact on the carrying capacity of the freeway. BCP usually requires closing portions of the freeway. This results in more congestion on other city highways, also, an increased user cost.

A BCP should maximize the carrying capacity of the highway during construction. This can be achieved by (1) minimizing the number of lane closures, and (2) minimizing lane closure duration.

This factor will be assessed depending on the amount of cars blocked from the site due to construction. The following two sub factors are used to score this factor:

19. Number of cars blocked/delayed

The estimated number of cars blocked or delayed on the highway in each road closure or diversion.

20. Blockage/Delay duration

Total estimated time in which cars are being blocked or delayed on the highway.

Scoring

See equation C-4 and procedure #6 in section c.8.

C.6 SCHEDULE PERFORMANCE

This factor evaluates the effectiveness of BCP schedule. An optimum BCP will reduce the total project budget.

Scoring

% saving in total project duration will be used to evaluate this factor. See procedure #7 in section C.8.

C.7 BUDGET PERFORMANCE

An optimum BCP will reduce the total project budget.

Scoring

% saving in total project direct cost will be used to evaluate this factor. See procedure #7 in section C.8.

C.8 Evaluation Procedures

Table C-1: Sub Factor Evalaution Procedures

Major Factor		Sub Factor	Procedure #
Safety			
	1	Overhanging equipment	1
	2	Adequacy of traffic barrier	1
	3	Traffic-Activity interaction length	3
	4	Distance between traffic and construction	1
	5	Lane width	2
	6	Detour length	3
	7	Detour curve quality	4
	8	Working on one side of traffic Vs working between traffic lines	1
	9	Working at high traffic volumes Vs working at low traffic volum	1
	10	Day shift VS night shift	1
	11	Traffic change	5
Accessibility			
	12	Reduction of number of traffic accesses	1
	13	Number of forced diversions (to traffic)	1
	14	Reduction of access points to businesses	1
	15	Reduction in businesses parking space	1
	16	Additional distance from ramp (for	1
	17	Constr. congestion in front of business	1
	18	Contractor access to work zone	1
Carrying capacity			
	19	Number of cars blocked or delayed	6
	20	Blockage/Delay duration	
Schedule			
	21	% savings in time	7
Budget			
	22	% savings in cost	7

Procedure #1
Currently applicable to:
Safety: Overhanging equipment; adequacy of traffic barrier; Distance between traffic and construction; Working on one side of traffic vs working between traffic lines; Working at high traffic volumes vs working at low traffic volumes
Accessibility: All sub factors

The main idea of this procedure is to spot the existence of certain condition (or the violation of a sub factor) in a BCP. The evaluator can then compare the performance of different plans and assign scores accordingly. The detailed steps of this procedure are as follows (see Figure C-3):

- Spot the existence (violation) of sub factor under consideration in each phase of each BCP (n_{ij})
- Find the total number of occurrences of this sub factor in the BCP

$$n_j = \sum_{i=1}^{k} n_{ij} \quad \text{.......C-6}$$

- Find the BCP with the best performance, i.e., the one with the fewest violations.

$$n_p = min\ (n)_j \quad \text{.......C-7}$$

- Give the plan with best performance a score of ten.

$$Set\ S_p = 10 \quad \text{.......C-8}$$

- Give other plans a score relative to n_p

$$S_z = 10\ X\ \frac{n_p}{n_z} \quad \text{.......C-9}$$

- Substitute the value of (S) in the appropriate equation

Where:
n_{ij}: Number of time a sub factor (condition) exists in phase #i of BCP # j.
n_j: Total number of sub factor existence in BCP #j
n_p: Score of best BCP; set always at 10
BCP #p: BCP with best performance

Example

Suppose that in abridge project the evaluation team has (k) number of BCP options. Suppose also that the sub factor under consideration is "Adequacy of traffic barrier". As shown in Figure C-4, BCP #1 has four phases. There were 4 violations of this sub factor in phase #1, 3 violations in phase #2, no violations in phase #3, and 3 violations in phase #4.

The total number of inadequate traffic barrier conditions in BCP #1 sums up to n1=12. Similarly, BCP #2 has 7 violations, BCP #p has 5 violations, and BCP #k has 10 violations.

BCP #p has the best performance, i.e. fewest violations. BCP #p gets a score of 10. Other BCP's get 4.1, 7.1, and 5 respectively. All these scores should be substituted into equation C-2.

Procedure #2 (Lane width)

For each plan do (see Figure C-5):

- Find the average lane width of all detours, main lanes, and frontage road in the plan.
- Use the given index in Table C-2 to give each plan a score (Lw).
- Use this score in equation C-2.

Table C-2: Lane Width Score index

Average Lane Width	Score
11'+	10
10.5' - 11'	9
10' - 10.5'	7
9.5' - 10'	3
Below 9.5'	Unacceptable

Example

For the same situation in the previous example, suppose that the average lane width in phase #1 in BCP #1 is 9.5'; 10', 10', and 11' in phases 2, 3, and 4 respectively. The average lane width of BCP #1 is then: 10.12'.

Similarly, the average lane widths of BCP # 2, p, and k are 11.2', 12', and 9.7' respectively.

Looking up at Table C-2, the scores of each BCP come out as 7, 10, 10, and 3 respectively. See Figure C-6.

Procedure #3 (Detour length)

For each plan do:

- Find the total length of the detours in the plan.
- Give the best plan (BCP with the fewest detours) a score of ten. Other plans relative to that.
- Use this score in equation C-2.

Procedure #3.a (Traffic-Activity interaction length)

For each plan do:

- Find the total length of traffic -construction activity interaction in the plan.
- Give the best plan (BCP with the least interaction length) a score of ten. Other plans relative to that.
- Use this score in equation C-2.

Procedure #4 (Detour curve quality)

For each plan do (see Figure C-7):

- For each phase in the BCP, find the average vertical slope and horizontal curve degree.
- Find the overall average vertical slope and curve degree of each BCP.
- Substitute the previous values in Table C-3.
- Use the resulting score in equation C-2.

TABLE C-3: Detour Alignment Evaluation Index

Curve degree \ Vt. Slope	0-1%	2%	3%	4%	5%	6%
1	10	9	8	7	6	5
2	9	8	7	6	5	4
3	8	7	6	5	4	3
4	7	6	5	4	3	2
5	6	5	4	3	2	1
6	5	4	3	2	1	0

Example

For the same previous situation, suppose that the average slope and the curve degree of each phase of BCP #1 are as shown in Figure C-8. The overall average slope for BCP #1 is then 4%. The overall curve degree of BCP #1 is 3.75. Suppose that BCP # 2, p, and k have average slope and curve degrees as shown in Figure C-8. The final score of each plan can be found by entering these two values for each plan in table C-3.

Procedure #5 (Traffic change)

For each plan do (see Figure C-9):

- Find the number of times traffic is shifted or changed.
- For each time assess the following:
  - ◊ The relative importance of the road on which the change will take place (Tr). Use Table C-4.
  - ◊ The degree / level of change (Cf). Use Table C-5.
- Using equation C-5, find the traffic change index of each plan.
- Give the plan with the least index value a score of 10. Others relative to that.

Example

Suppose that in phase 1 of BCP #1 there were 3 traffic changes: a diversion of main lanes to frontage road, which scores a 7 regarding change type as shown in table C-4; a two lane closure (Cf = 3); and a freeway closure (Cf = 7). Consequently, the road index for the three changes comes out as 8, 6, and 8 respectively as shown in Table C-5. The traffic change indices for these three changes are, then, 32, 18, and 56 respectively. The total traffic change index for phase #1 in BCP #1 is then, 96. The total index for BCP #1 is 241 as shown in Figure C-10.

Similarly, other plan indices are 140, 100, and 175 for BCP # 2, p, and k respectively.

The scores of the BCP's are then: 4.1, 7.1, 10, and 5.7 respectively.

TABLE C-4: Road Index (Tr)

Road	Score
Main lanes	8
Frontage road	6
Overpasses	3
Secondary roads	1

TABLE C-5: Change Index (Cf)

Traffic Change	Score
Freeway closure	7
Diversion to Frontage road	4
Two lane closure	3
One lane closure	1

Procedure #6 (Carrying Capacity)

For each plan (see Figure C-11):

- Define the number of times traffic is blocked / delayed / disrupted.
- For each blockage incident find:
  - ◊ The estimated blockage duration.
  - ◊ The estimated number of cars blocked.
- Find the weighted sum of all blockage/delay conditions.
- Give the plan with the best performance a score of ten. Others, relative to that.

Example

Suppose that phase #1 in BCP #1 includes three incidents of traffic blockage/delay. Assume that the number of cars affected in each incident is estimated at 2000, 3000, and 4000 cars respectively. Assume also that the delay time associated with each of these incidents is estimated at 1, 5, and 2 hours respectively. Then the carrying capacity index of phase #1 in BCP #1 is 25,000 car.hour. See Figure C-12.

Assume that the indices of other phases are 84000, 66000, and 16000 respectively. Then the total carrying capacity of BCP #1 is 191000 car.hour.

Assume that BCP #2, p, and k have the following carrying capacity indices 250000, 170000, and 270000 car.hour respectively.

Then BCP #p gets a score of ten. BCP #1 gets a score of 8.9; BCP #2 gets a score of 6.8; and BCP #k gets a score of 6.2.

Procedure # 7 (Schedule and Budget performance)

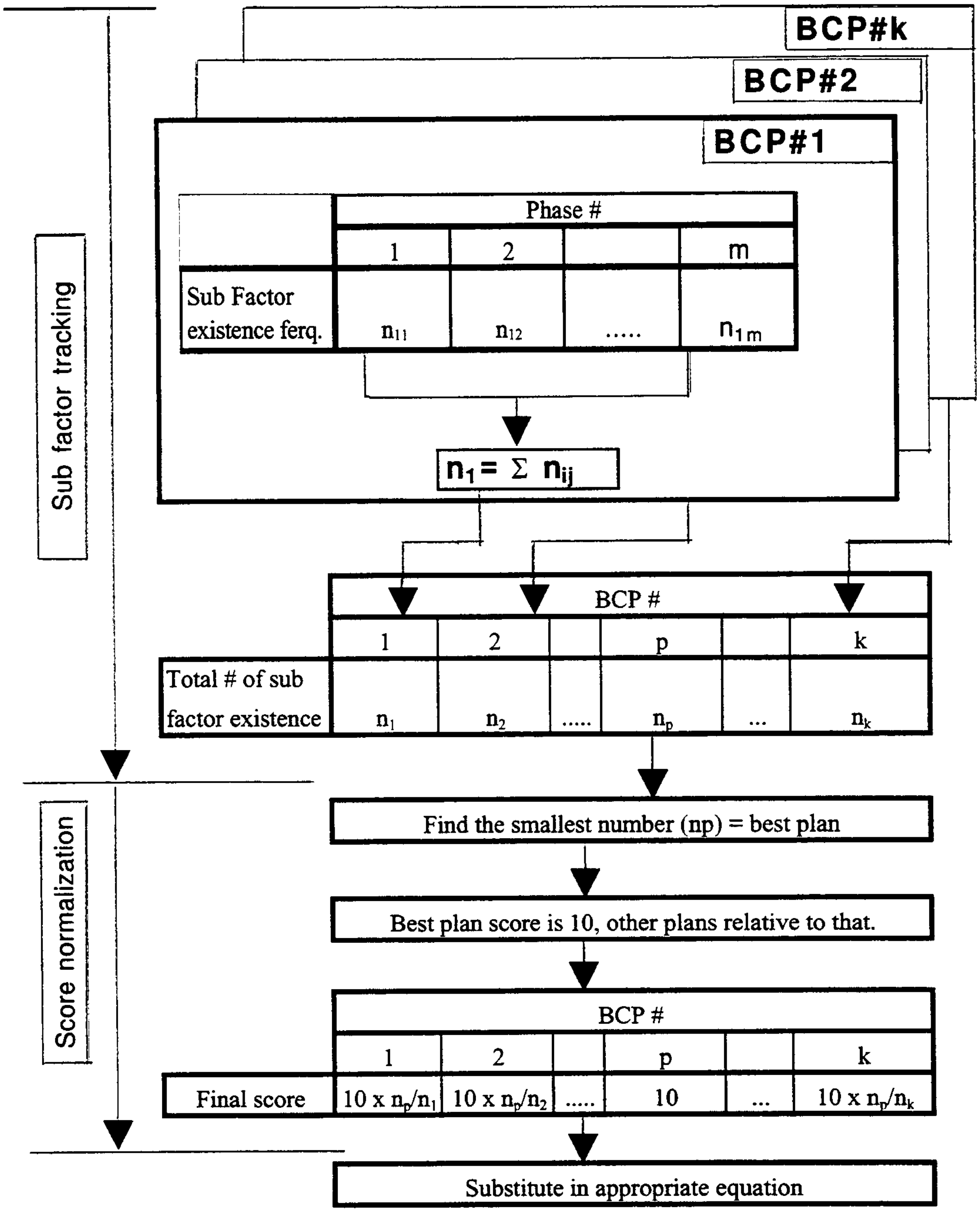
- Give the plan with the best (minimum) schedule/cost a score of ten.
- Other plans relative to that.

Example

Suppose that the evaluation team is considering three plans. The cost of BCP #1 is $10 million; BCP #2 is $9 million; and BCP #3 is $8 million. BCP #3 is the best. It gets a score of 10. BCP #1 gets a score of 8 and BCP #2 gets a score of 8.8. These values should be substituted in equation C-1 directly.

TABLE C-6: Cost (Schedule) Example

Plan	Cost	Score
Plan #1	$ 10 million	8
Plan #2	$ 9 million.	8.8
Plan #3	$ 8 million.	10



Note: nij presents the number of times the sub factor (condition) existed in phase i of BCP # j

Figure C-3: Evaluation Procedure #1

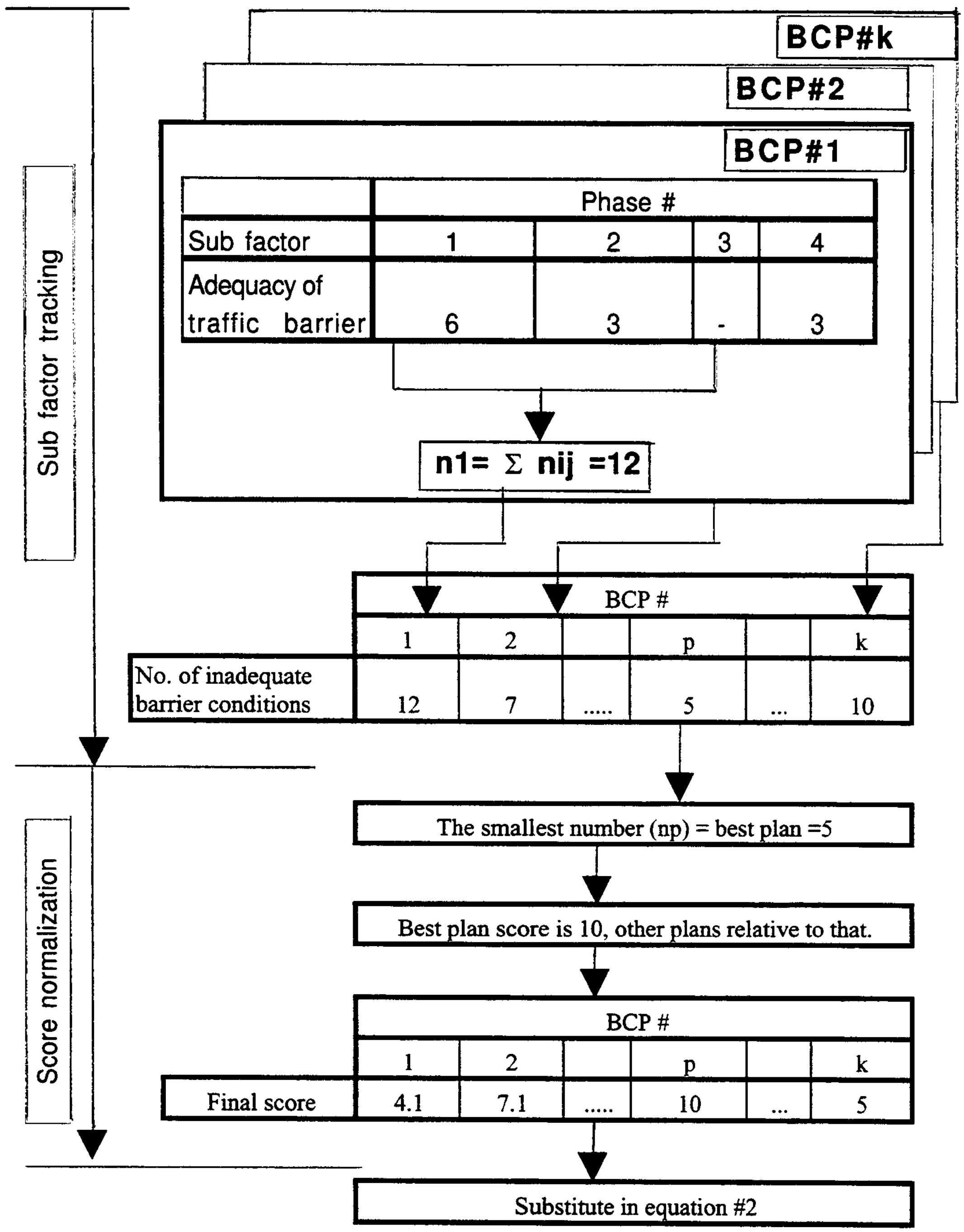
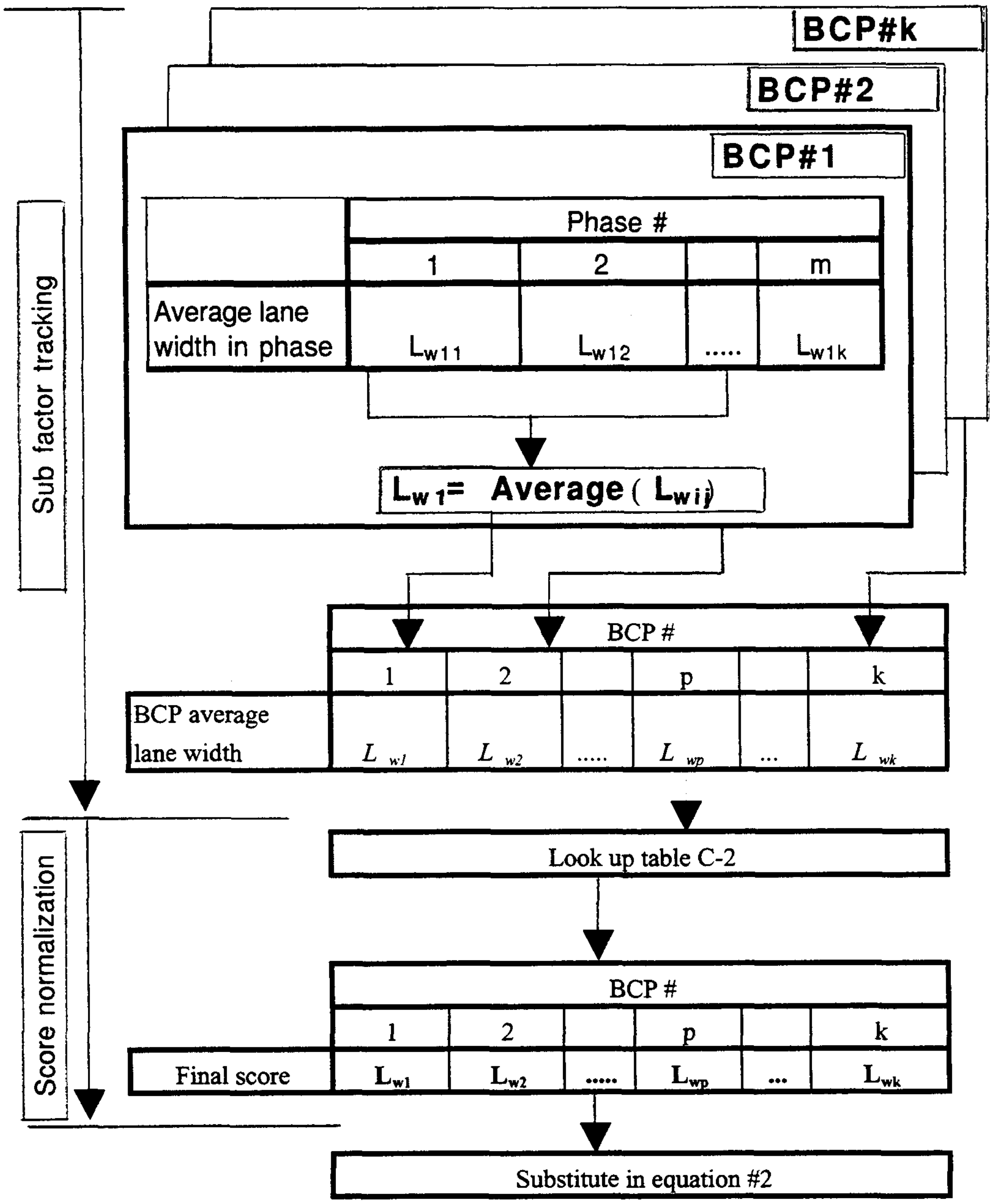


Figure C-4: Evaluation Procedure #1 - Typical Example



Note: L_{wij} presents the average lane width in phase i of BCP # j

Figure C-5: Evaluation Procedure #2 (Lane Width Evalaution)

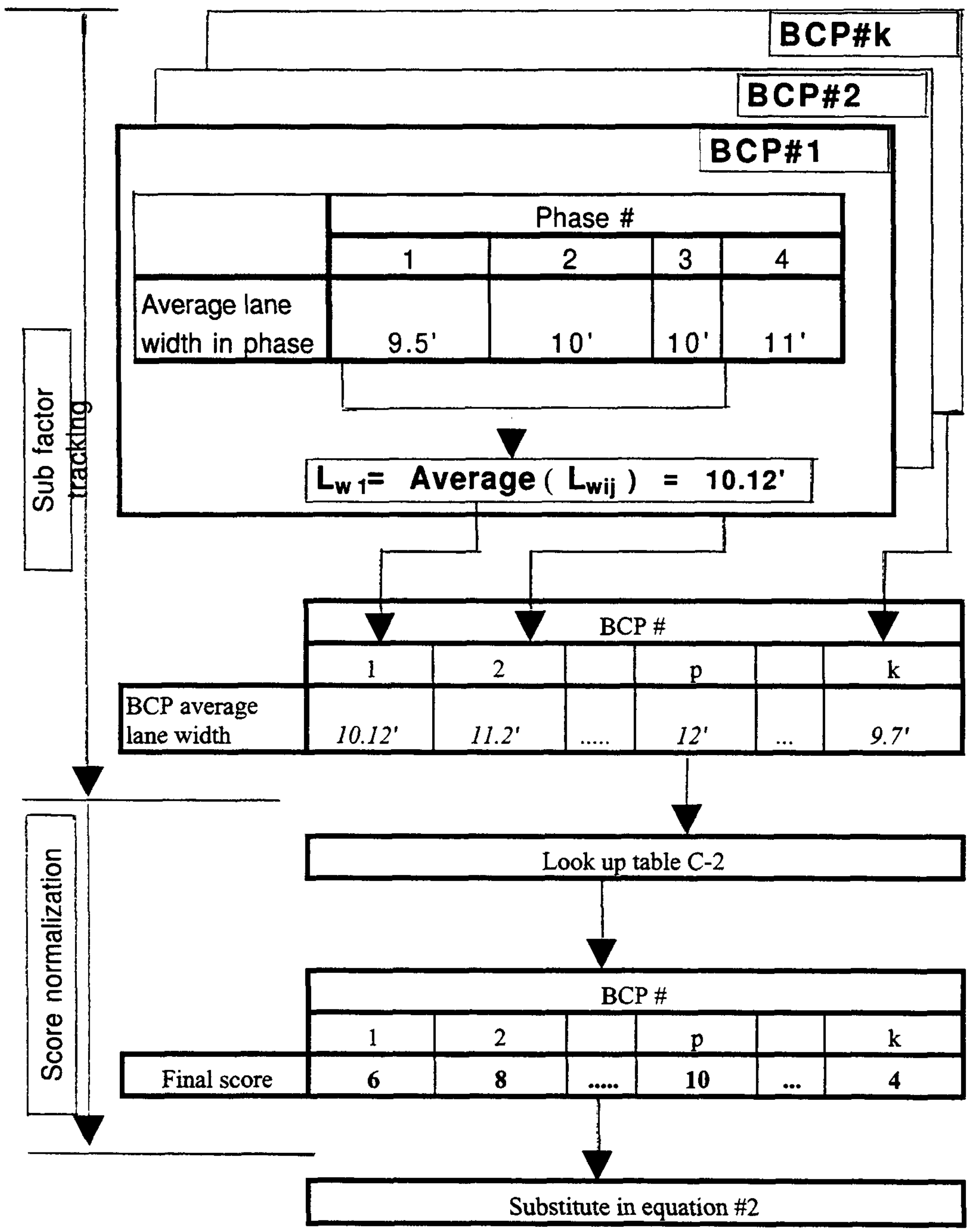
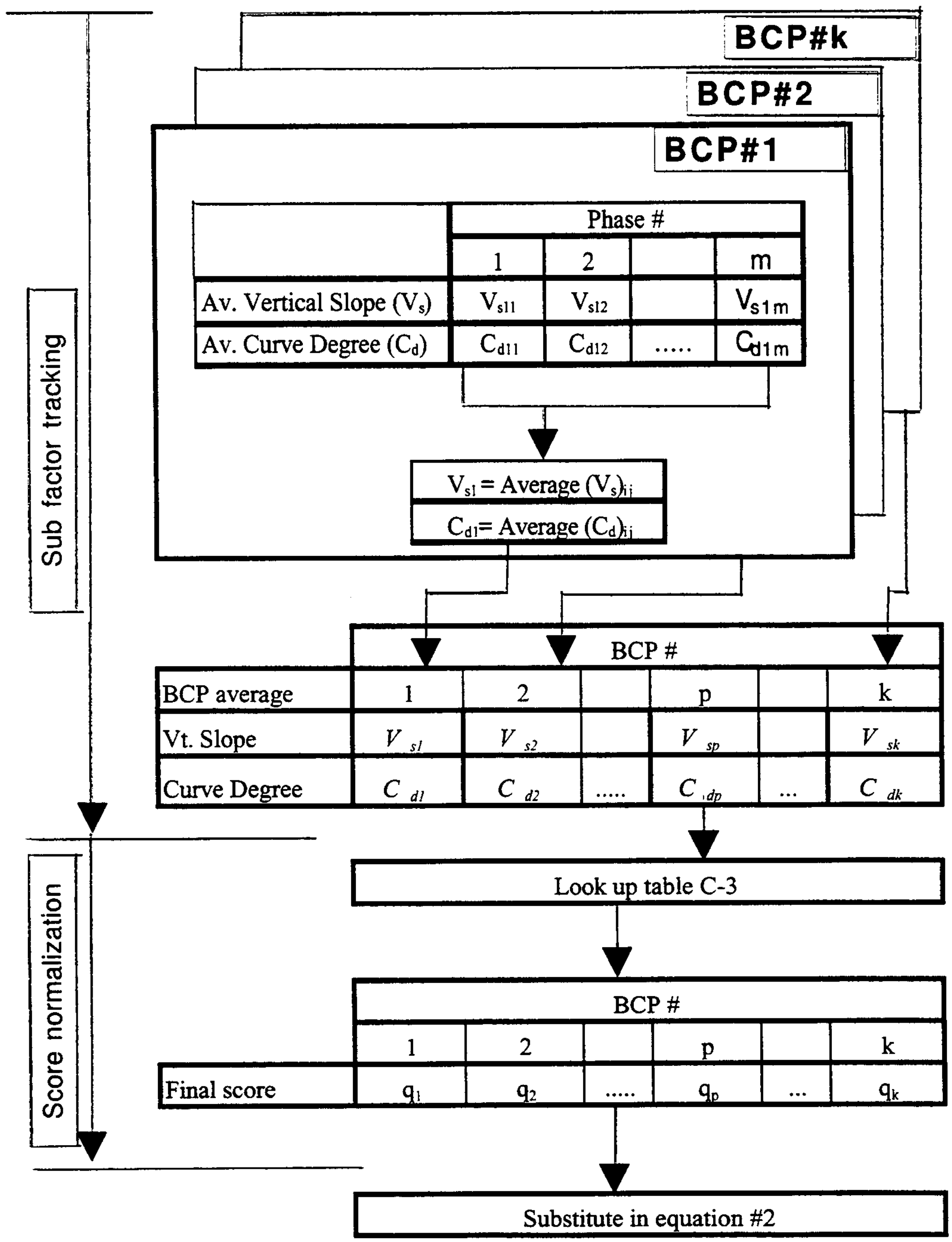


Figure C-6: Evaluation Procedure #2 - Typical Example



Note: Vsij denotes the average vertical slope of mainlanes in phase i of bCP #j
Cd_{ij} denotes the average curve degree of mainlanes in phase i of bCP #j

Figure C-7: Evaluation Procedure #4 (Detour Curve quality)

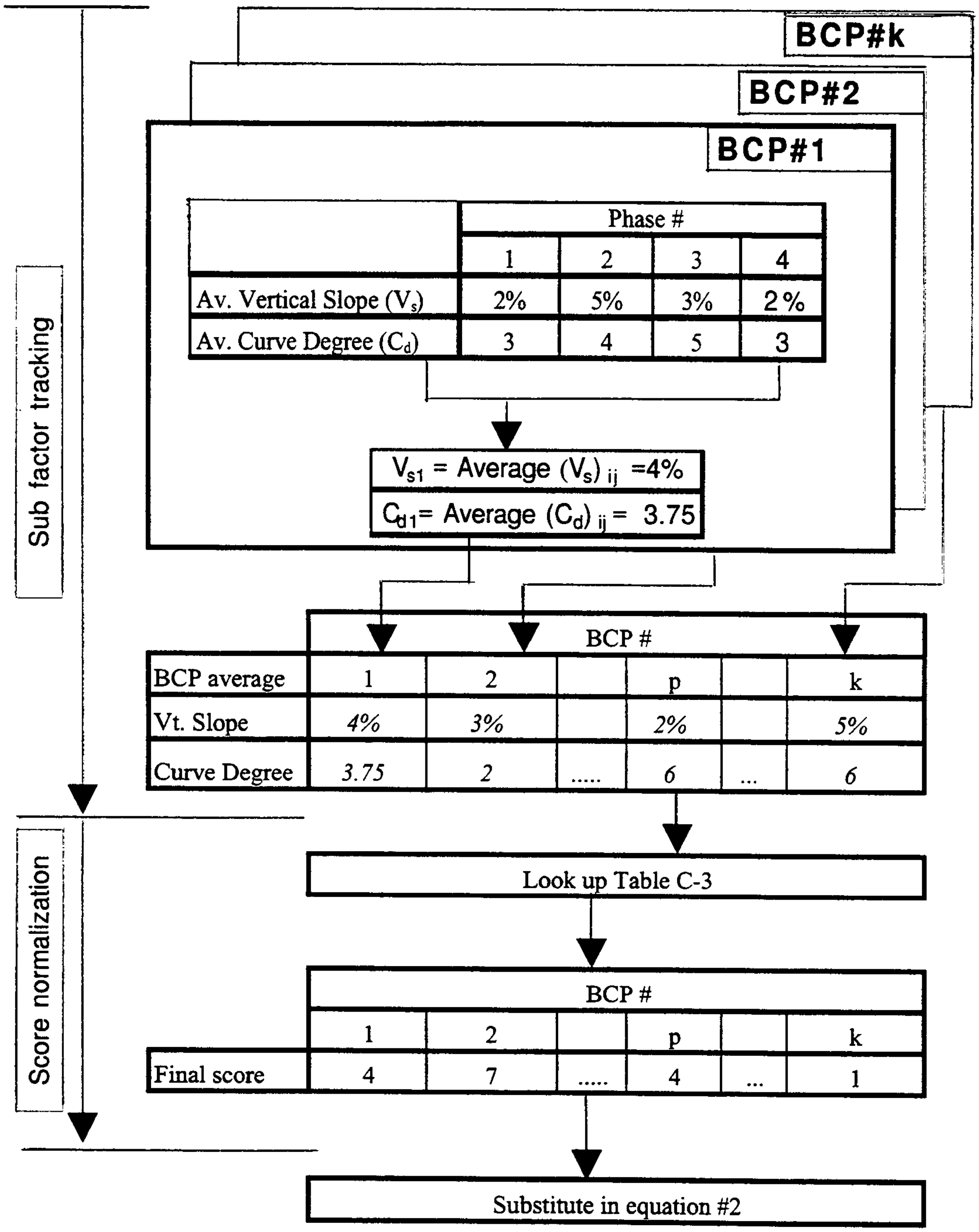


Figure C-8: Evaluation Procedure #4 - Typical Example

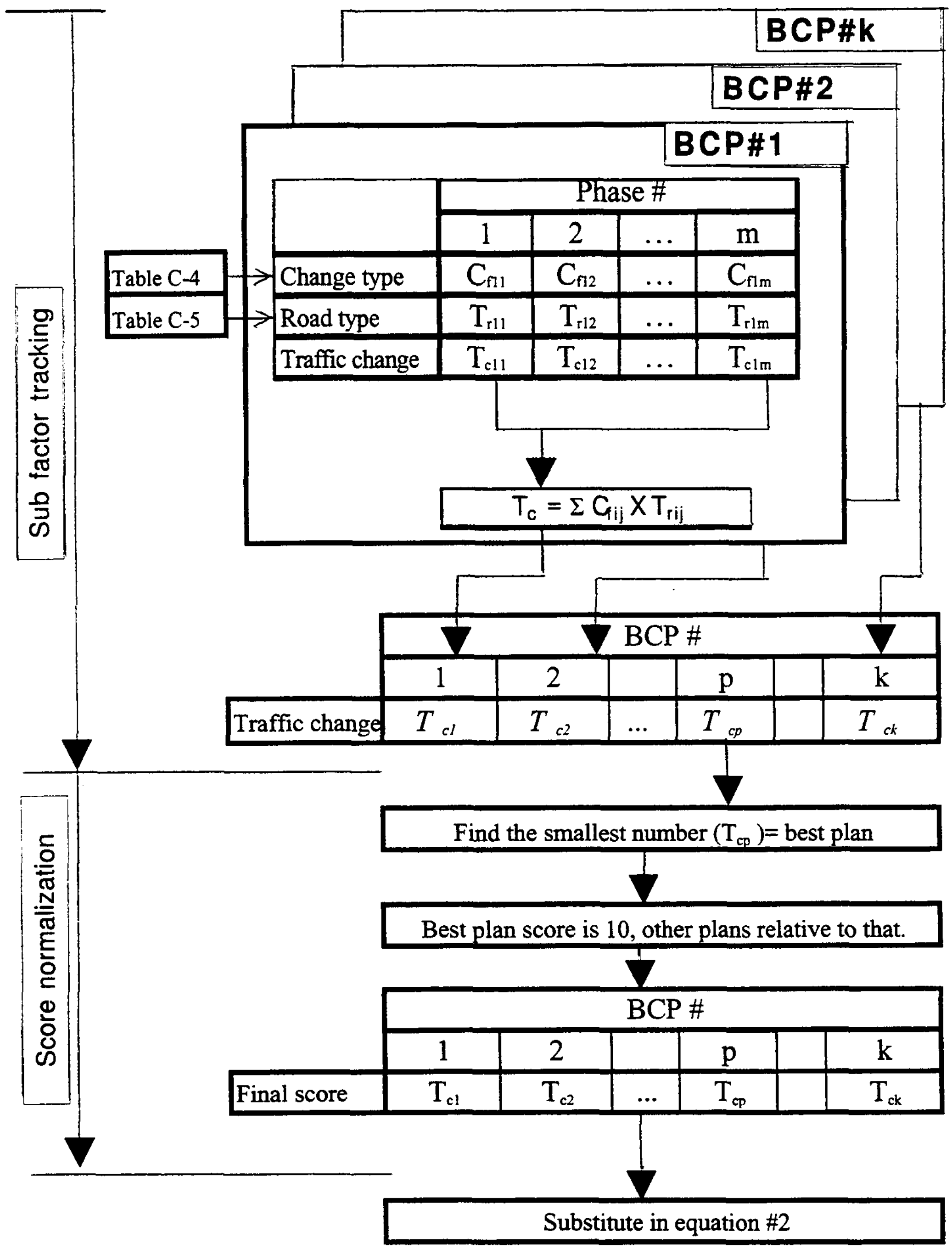


Figure C-9: Evaluation Procedure #5 (Traffic Change)

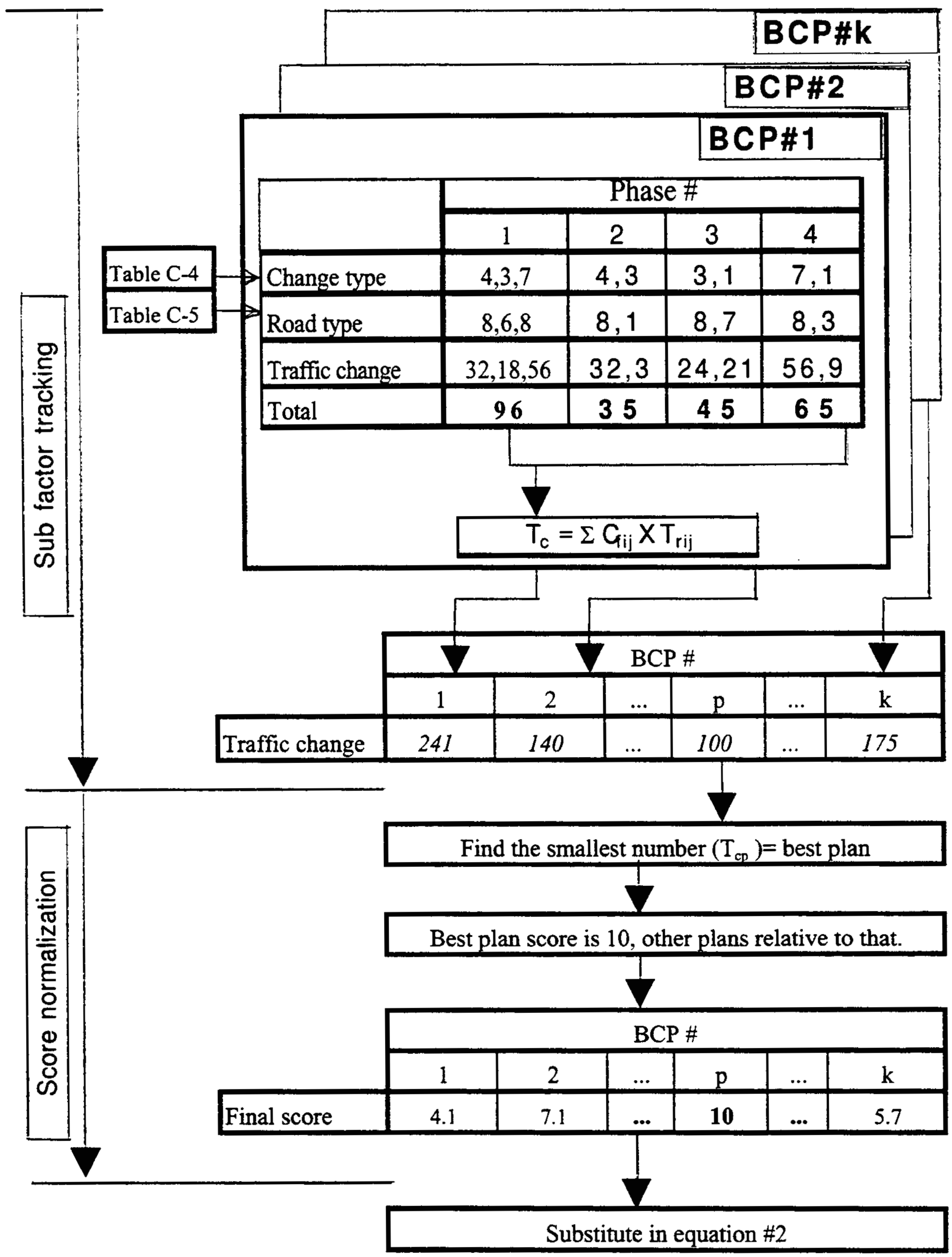


Figure C-10: Evaluation Procedure #5 - Typical Example

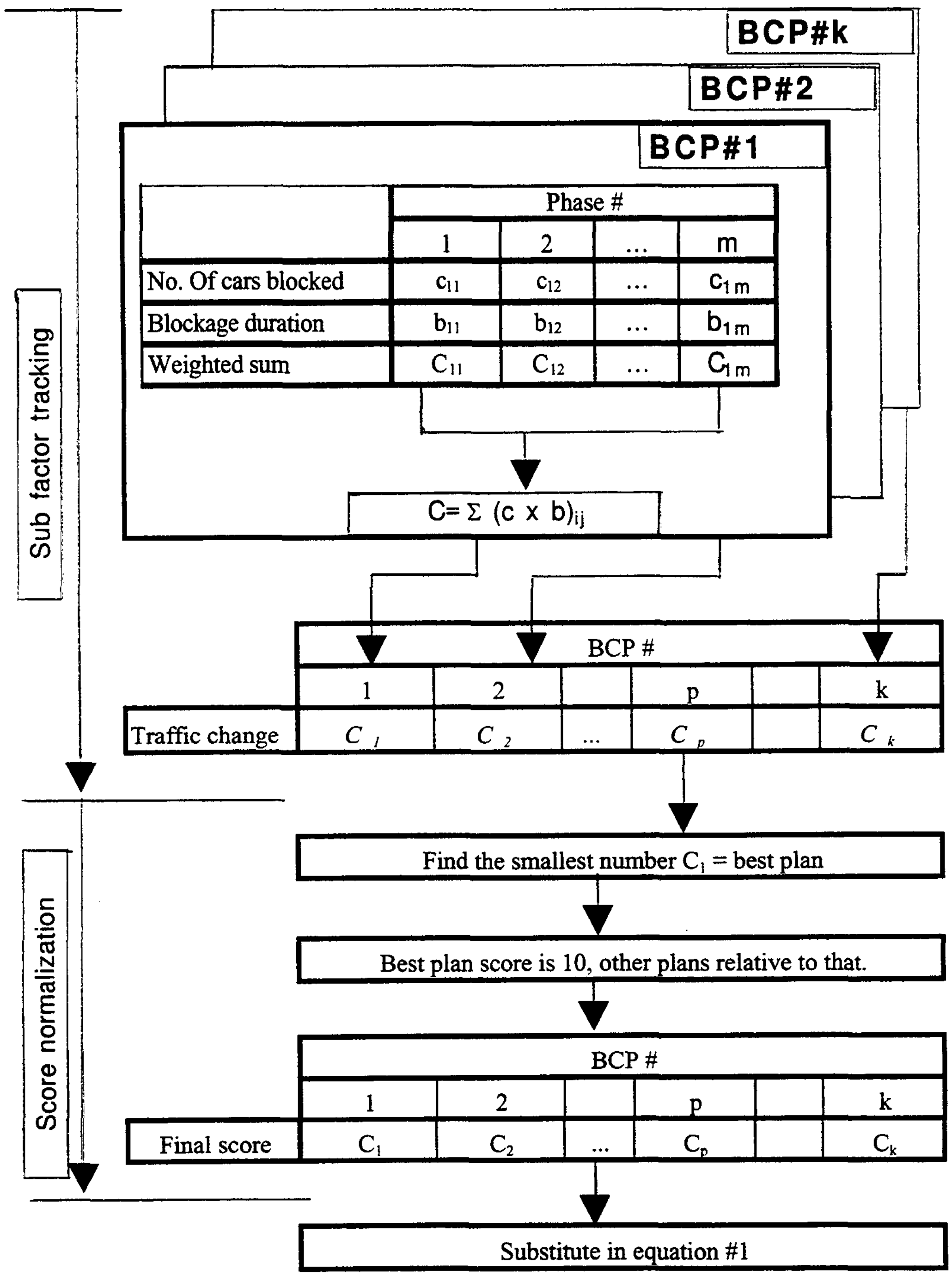
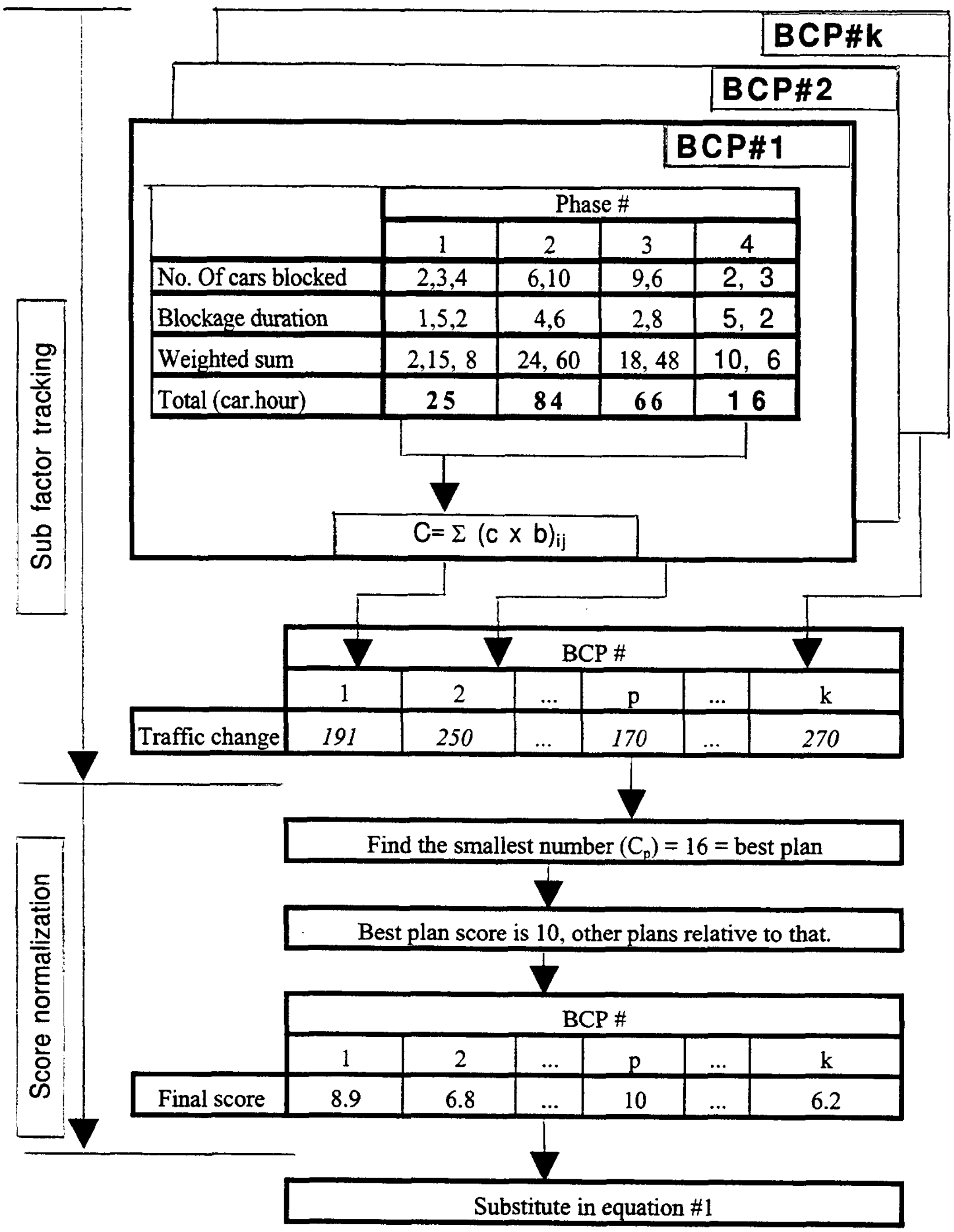


Figure C-11: Evaluation Procedure #6 (Carrying Capacity)



Note: No. of cars is in tens of thousands, blockage duration is in hours.

Figure C-12: Evaluation Procedure #6 - Typical Example

APPENDIX D

MODEL VALIDATION INTERVIEWS

Interview Guide

Interviewee Log

Interview Results

Interview # ______________________

Date: ______________________

Location: ______________________

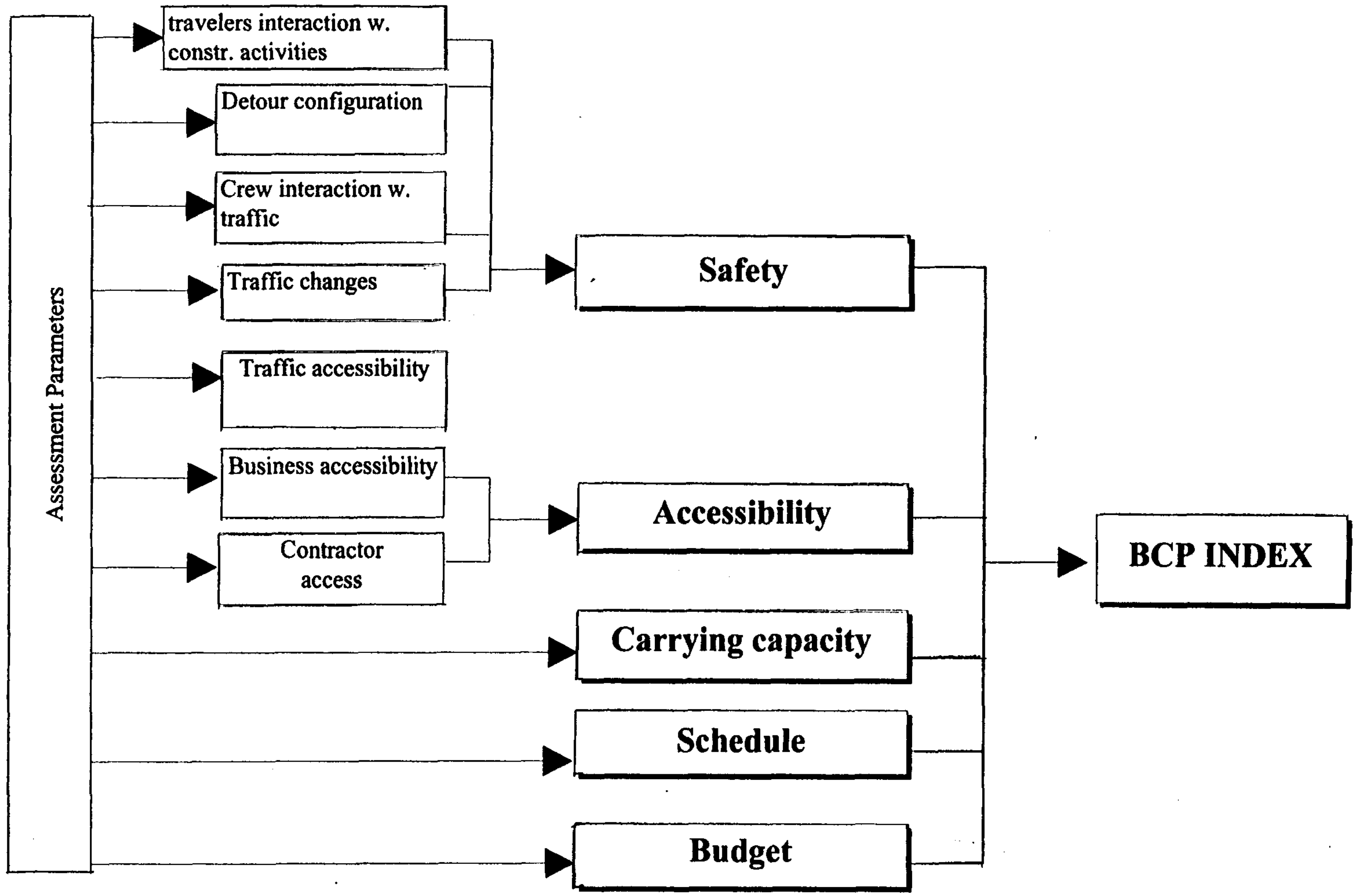
Name: ____

Organization name: ____

Title/Position: ____

Field of experience: ____

Years of experience: ____



Evaluation Model General Structure

INTERVIEW DIRECTIONS

The following parameters are proposed for evaluating the effectiveness of bridge construction plans (BCP) during the design phase. Please provide your input as regard to the following :

PART I: SUB FACTOR ASSESSMENT

Column 1: Parameter Significance.

Assess the relative significance (importance) of the parameter to the success of a BCP.
Use a scale of 1 to 6, as shown below,

Column 2: Parameter Generality

Are these parameter applicable to any bridge, i. e. can they be meaningful and applied to a generic bridge project.
Use a scale of 1 to 6, as shown below,

Column 3: Evaluation Data Availability

Is the data required for evaluating these parameters available/can be estimated during the design phase
Use Yes or No.

PART II: OVERALL ASSESSMENT

This part includes two questions regarding the overall meaningfulness/coverage of the proposed factors and the impact of applying the model.

SCORE	0	2	4	6
SIGNIFICANCE	None	Low	Considerable	Major
Note: Use 1, 3, 5 as intermediately scores.				

SAFETY FACTOR

	Significance to plan success	General/ Applicable to a generic bridge project		Data available / can be estimated during design phase	
	1 to 6	yes	no	yes	no
Travelers interaction with constr.					
Over Hanging equipment					
Adequacy of traffic barrier					
Traffic-Activity interaction length					
Distance between traffic and constr.					
Detour configuration					
Lane width					
Detour length					
Detour quality					
Crew interaction with traffic					
Working on one side of traffic Vs working between traffic lanes					
Working at high traffic volumes Vs working at low traffic volumes					
Day shift VS night shift					
Traffic changes					
Type of change					
Type of road where change takes place					

SCORE	0	2	4	6
SIGNIFICANCE	None	Low	Considerable	Major

Note: Use 1, 3, 5 as intermediately scores.

ACCESSIBILITY FACTOR

	Significance to plan success	General/ Applicable to a generic bridge project		Data available / can be estimated during design phase	
	1 to 6	yes	no	yes	no
Traffic accessibility					
Reduction of number of accesses					
Number of forced diversions					
Business accessibility					
Reduction of access points to business					
Reduction in parking space					
Additional distance from ramp					
Constr. congestion in front of business					
Contractor access					
Machine access to work zone					

SCORE	0	2	4	6
SIGNIFICANCE	None	Low	Considerable	Major

Note: Use 1, 3, 5 as intermediately scores.

CARRYING CAPACITY FACTOR

	Significance to plan success	General/ Applicable to a generic bridge project		Data available / can be estimated during design phase	
	1 to 6	yes	no	yes	no
Number of cars blocked					
Blockage duration					

SCHEDULE PERFORMANCE

	Significance to plan success	General/ Applicable to a generic bridge project		Data available / can be estimated during design phase	
	1 to 6	yes	no	yes	no
% Savings in duration					

BUDGET PERFORMANCE

	Significance to plan success	General/ Applicable to a generic bridge project		Data available / can be estimated during design phase	
	1 to 6	yes	no	yes	no
% Savings in cost					

SCORE	0	2	4	6
SIGNIFICANCE	None	Low	Considerable	Major

Note: Use 1, 3, 5 as intermediately scores.

PART II: OVERALL ASSESSMENT

How well did the proposed factors cover the major concerns regarding BCP effectiveness?

Not at all		Minimal		Good		Very good
0	1	2	3	4	5	6

Based on your experience, would the consideration of these factors be of benefit to BCP effectiveness?

No		Low		Considerable		Major
0	1	2	3	4	5	6

Table D-1: Interviewee Log

Name	Position	Organization
Gabrial Jonston, P. E.	Director, Transport. Planning, Houston Dist.	TxDOT
Steve Semmins, P. E.	Deputy District Engineer, Houston Dist.	TxDOT
Wayn Johns, P. E.	Director, Transport. Operation, Houston Dist.	TxDOT
Stephen A. Hrncir, P. E.	Project Manger	HNTB Corp.
Raymond C. Barker, P. E.	Project Manger	Brown & Root Inc.
David A. Nachman, P. E.	Project Manger	HNTB Corp.
Tommy Kelly, P. E.	Project manager	Brown & Root Inc.
Galib Sunnah, P. E.	District Design Engineer, Dallas District	TxDOT
David Jessub, P. E.	District Highway Engineer, Dallas District	TxDOT
Tamer Ahmed, P. E.	Structural Engineer	FHWA
David E. Harley, P. E.	Structural Engineer	FHWA

Table D-2: Safety Factor Significance Score

	Interview #															
	1	2	3	4	5	6	7	8	9	10	11	Av	Med	Mo	SD	K
Travelers interaction with constr.																
Over Hanging equipment	4	4	6	2	4	2	6	3	3	6	4	4.0	4	4	1.5	-1.1
Adequacy of traffic barrier	6	5	4	6	6	6	4	4	5	5	4	5.0	5	6	0.9	-1.9
Traffic-Activity interaction length	4	5	2	4	4	3	4	3	3	4	2	3.5	4	4	0.9	-0.5
Distance between traffic and..	6	6	4	4	3	6	2	3	3	2	3	3.8	3	3	1.5	-1.2
Detour configuration																
Lane width	4	4	4	6	4	4	5	5	5	5	5	4.6	5	4	0.7	-0.3
Detour length	4	5	4	6	4	3	2	3	3	5	3	3.8	4	3	1.2	-0.3
Detour quality	6	5	4	6	4	5	6	5	5	4	6	5.1	5	6	0.8	-1.5
Crew interaction with traffic																
Working on one side of traffic	6	4	2	6	3	3	4	6	6	3	4	4.3	4	6	1.5	-1.6
working between traffic lanes																
Working at high traffic volumes	4	5	3	4	3	5	4	4	4	5	5	4.2	4	4	0.8	-0.9
working at low traffic volumes																
Day shift VS night shift	4	6	4	4	3	4	6	6	6	3	4	4.5	4	4	1.2	-1.7
Traffic changes																
Type of change	4	4	6	5	6	3	6	4	4	5	5	4.7	5	4	1.0	-1.0
Type of road where change...	6	3	4	4	5	5	4	3	3	5	3	4.1	4	3	1.0	-0.9

Table D-3: Accessibility Factor Significance Score

	Interview #															
	1	2	3	4	5	6	7	8	9	10	11	Av	Med	Mo	SD	K
Traffic accessibility																
Reduction of number of accesses	3	4	4	5	5	3	4	5	5	5	5	4.4	5	5	0.81	-0.8
Number of forced diversions	5	4	6	6	5	3	4	5	5	6	6	5.0	5	5	1	-0.1
Business accessibility																
Reduction of access points to...	3	5	6	3	4	4	4	6	6	5	5	4.6	5	5	1.12	-1.2
Reduction in parking space	3	6	4	3	3	3	4	2	3	4	4	3.5	3	3	1.04	2.62
Additional distance from ramp	4	4	4	3	3	2	6	3	5	3	3	3.6	3	3	1.12	0.81
Constr. congestion in front ...	3	4	6	4	4	5	4	3	3	3	4	3.9	4	4	0.94	1.21
Contractor access																
Machine access to work zone	2	5	4	5	4	5	4	4	4	5	3	4.1	4	4	0.94	1.21

Table D-4: Carrying Capacity Factor Significance Score

	1	2	3	4	5	6	7	8	9	10	11	Av	Med	Mo	SD	K
Number of cars blocked	4	5	4	5	5	5	6	4	3	6	5	4.7	5	5	0.9	-0.1
Blockage duration	5	6	4	5	5	4	6	3	5	6	5	4.9	5	5	0.9	0.2

Table D-5: Schedule Performance Significance Score

	1	2	3	4	5	6	7	8	9	10	11	Av	Med	Mo	SD	K
% Savings in duration	6	5	4	5	6	5	4	6	6	5	5	5.2	5	5	0.75	-0.9

Table D-6: Budget Performance Significance Score

	1	2	3	4	5	6	7	8	9	10	11	Av	Med	Mo	SD	K
% Savings in cost	4	5	4	6	5	4	4	6	6	6	5	5	5	4	0.89	-1.9

Table D-7: Model Impact and Comprehensiveness Scores

	Interview #															
	1	2	3	4	5	6	7	8	9	10	11	Av	Med	Mo	SD	K
Impact	4	5	4	5	6	4	4	5	5	5	5	4.7	5	5	0.65	-0.2
Comprehensiveness	5	5	5	6	5	4	4	5	5	6	5	5	5	5	0.63	0.42

APPENDIX E

MODEL APPLICATION DEMONSTRATION

This appendix presents the details of the model application demonstration. The application was done by the researcher. The total duration of the evaluation process was 46 working hours. A good part of that time was spent in preparing plans for evaluation - especially BCP #1. A team of 3 engineers working together can finish the evaluation in less than two days. Which is a fair amount of time given the amount of work needed and the importance of the decision.

At the end of this Appendix is a summary of the most important steps in both BCP's. The details of evaluating each sub factor follow hereafter.

E.1 SAFETY FACTOR EVALUATION

Table E-1 shows the details of evaluating safety for both BCP's. It shows also the time spent for evaluating each sub factor. Table E-2 presents a sample of the step by step evaluation of these sub factors for BCP #1. Same procedures were followed for BCP #2.

Overhanging equipment

This parameter is evaluated through counting the number of times such condition exists. The number of such conditions in both BCP's is limited because of TxDOT's restrictions on such situations. Nonetheless, the evaluation process consumed a relatively long time. This may be attributed to the subjective nature of the sub factor.

Adequacy of traffic barrier

This sub factor is evaluated by counting the number of time it exits in a BCP. Again, this condition did not exist frequently in both BCP's because of TxDOT's restrictions in this regard.

Traffic-Activity interaction length

The total length of interaction between construction and traffic in all phase of BCP is the measure of this sub factor. As shown in table E-1, BCP #2 have significantly reduced the interaction between traffic and construction. This may be attributed to the fact that BCP #2 have consolidated several activities and created longer work zones throughout the site.

Distance between traffic and construction

This parameter is evaluated based on the number of times the distance between traffic and construction is less than two feet in cases where is no concrete traffic barrier (CTB). TxDOT is so restrictive for this condition. However, the research spotted 2 such conditions in BCP #1 and 3 conditions in BCP #2.

Lane width

The average lane width in all phases of each BCP is the measure for this sub factor. According to Table C-2, BCP #1 got a score of 9, while BCP #2 got a score of 10. This sub factor was easy to estimate and consumed relatively less time.

Detour length

The total length of detours in each BCP is the measure of this sub factor. This sub factor did not consume a long time in evaluation.

Detour quality

This sub factor is evaluated through the values of vertical slopes and curve degrees of all detours in a BCP -see table C-3. BCP #2 used slightly sharper curves than BCP #1.

Working on one side of traffic Vs working between traffic lines

There were 9 conditions in which crew have to work between traffic lines in BCP #1. BCP #2 has only 7 such conditions.

Working at high traffic volumes Vs working at low traffic volumes

Because of the high capacity of the highway, most of the construction activities related to foundations, columns, and beam setting required working all day long. This mandated that crews work during high traffic volumes frequently in both plans.

Day shift Vs night shift

There was 7 night shifts in BCP #1 and 4 night shifts in BCP #2. BCP #2 had a better number because it reduced the number of demolition for the old bridge to only two times.

Traffic changes

Both plans included several traffic changes to main lanes, frontage road, and overpass traffic. The weighted sum of change level and road importance was calculated for both BCP as explained in equation C-4 And Table C-5. This sub factor consumed a lesser time than expected.

E.2 ACCESSIBILITY FACTOR EVALUATION

Same evaluation procedures, as safety factor, were followed for accessibility factor. Table E-3 summarizes the evaluation details of accessibility for each BCP.

Reduction of number of traffic accesses

This parameter counts the number of obstructed access to traffic. Its evaluation was straight forward, objective and consumed little time.

Number of forced diversions (to traffic)

This parameter was also very easy to evaluate.

Reduction of access points to business

This parameter consumed a longer time period than expected. It took a longer time to categorize a construction activity as "obstructing access to business".

Reduction in parking space

The data for this item was easy to spot. However, the calculation for it consumed a relatively long time.

Additional distance from ramp (for business)

This sub factor was easy to evaluate.

Construction congestion in front of business

This sub factor is subjective in nature. It took a longer time to evaluate because of that.

Contractor access to work zone

Both plans provided adequate access to contractor. BCP #1 had three such conditions, while BCP#2 had two conditions.

E.3 Carrying Capacity Evaluation

The evaluation of this factor includes the following steps:

- Identify conditions in which there is a blockage or delay to traffic
- Estimate the number of vehicles affected by the condition
- Estimate the duration of such condition

With the help of traffic counts on the main lanes, frontage road, and overpass and the CPM of both BCP's, the researcher was able to find the data required for the evaluation of this factor. However, the process consumed a relatively long time.

BCP #1 included much interruption to traffic than BCP#2. This is because BCP #2 has a shorter duration and fewer shifts to traffic. See table E-4

E.4 Schedule and Cost Performance Factors

The cost and duration of each plan were already available through field engineers. They reported that the development of a macro CPM for both BCP's took about 9 working hours. The development of macro cost estimate of both BCP's also required a similar amount of time.

BCP #2 was better in both counts. It reduced project duration by 30%. It also reduced direct project cost by 16%.

Table E-1: Safety Sub Factors Evaluation Results

Sub factor	Units of measurement	BCP#1 Score in sub factor units	BCP#1 Time to evaluate	BCP#1 Model score	BCP#2 Score in sub factor units	BCP#2 Time to evaluate	BCP#2 Model score
Overhanging equipment	#	3	30 min	6.6	2	20	10
Adequacy of traffic barrier	#	3	20	6.6	2	15	10
Traffic-Construction interaction	Yard	4000	60	9.2	3700	60	10
Distance between traffic & Constr.	#	2	40	10	3	60	6.6
Lane width	Ft	10.5'	40	9	11.5'	40	10
Detour length	Yard	3600	30	8	2900	30	10
Detour quality	Scale	Table C-3	30	8	Table C-3	25	8
Working on one side of traffic Vs...	#	9	30	7.7	7	20	10
Working at high traffic volumes Vs...	#	21	40	10	27	30	7.7
Day shift Vs night shift	#	7	15	5.7	4	10	10
Type of traffic change	Scale	112	90	6	67	80	10

Table E-2: Sample Step-by-Step Sub Factor Evaluation (Safety in BCC #1)

	BCC Step #					
Sub factor	1	2	3	4	5	6
Overhanging equipment				Beam setting for NW corner		
Adequacy of traffic barrier		.@STA 182				.@STA 191
Traffic-Construction interaction	100 Yards	300	600	400	200	500
Distance between traffic & Constr.					.@STA 191	
Lane width*	10'	9.8'	10.5'	11'	12'	10'
Detour length	400Yard	300	300	600	200	_
Detour quality**	8	9	7	6	10	8
Working on one side of traffic Vs...	.@STA 180		.@STA 186, 189		.@STA 191, 192, 187	
Working at high traffic volumes Vs...	.@STA 180, 183, 187	.@STA 182, 190	.@STA 191, 192	.@STA 184, 186, 189		.@STA 181, 183,187,191
Day shift Vs night shift		2 Night shifts		1		2
Type of traffic change***	1 Change		2		3	2

* See Table C-2

** See Table C-3

*** See Tables C-4 and C-5

Table E-2: Sample Step-by-Step Sub Factor Evaluation (Safety in BCC #1; Cont.)

	BCC Step #					Total
Sub factor	7	8	9	10	11	
Overhanging equipment		Beam setting for SE corner		Cantilever construction		3
Adequacy of traffic barrier			.@STA 184			3
Traffic-Construction interaction	100	200	600	600	400	4000
Distance between traffic & Constr.			.@STA 184			
Lane width	10'	10.5'	10.5'	11'	11'	10.57'
Detour length	500	200	500	400	200	3600
Detour quality	8	10	9	10	10	8
Working on one side of traffic Vs...	.@STA 190	.@STA 182, 188				
Working at high traffic volumes Vs...	.@STA 182, 189,192		.@STA 188, 189	.@STA 190, 191		21
Day shift Vs night shift				2		7
Type of traffic change	3		1	1		112

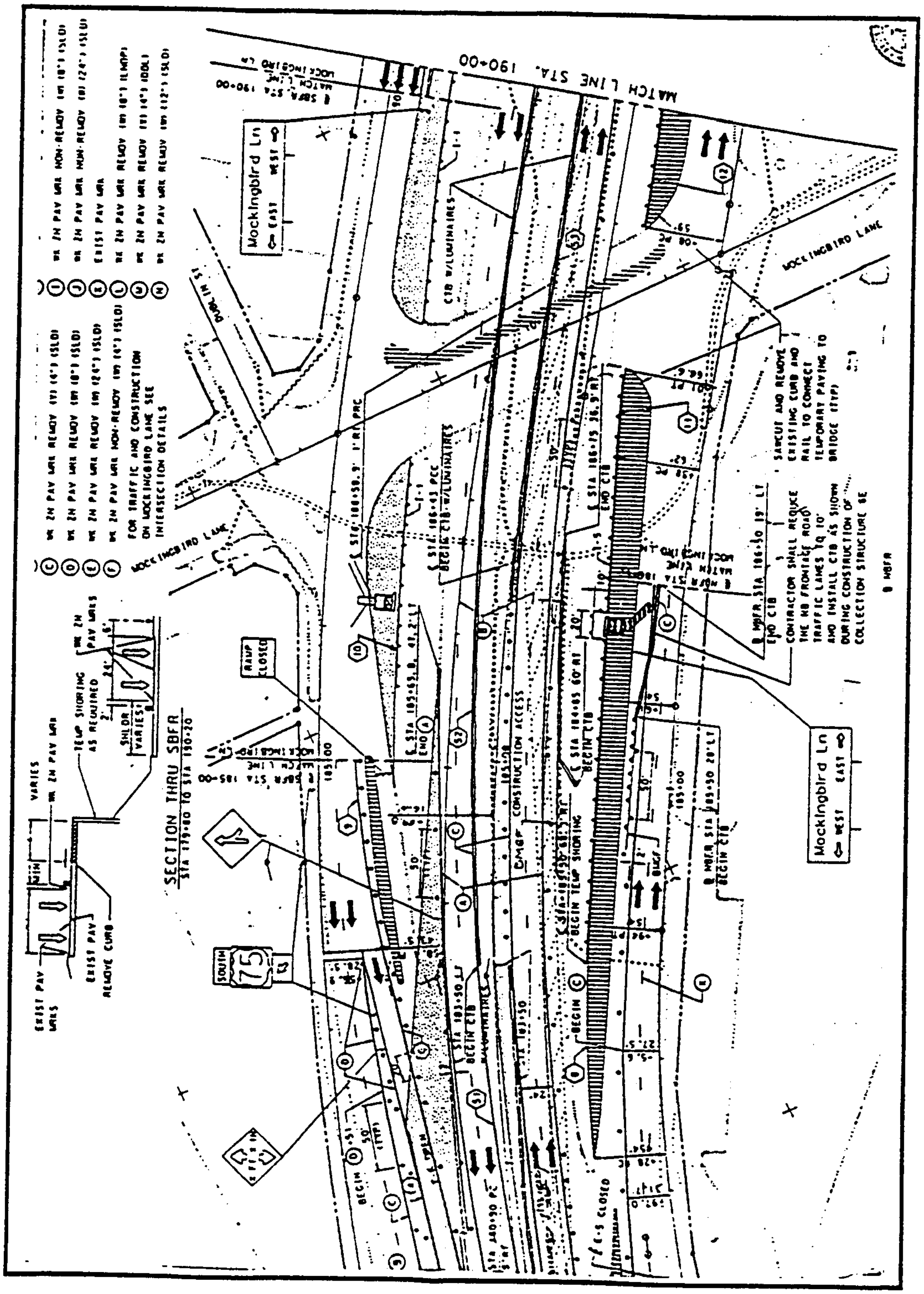
Table E-3: Accessibility Sub Factors Evaluation Results

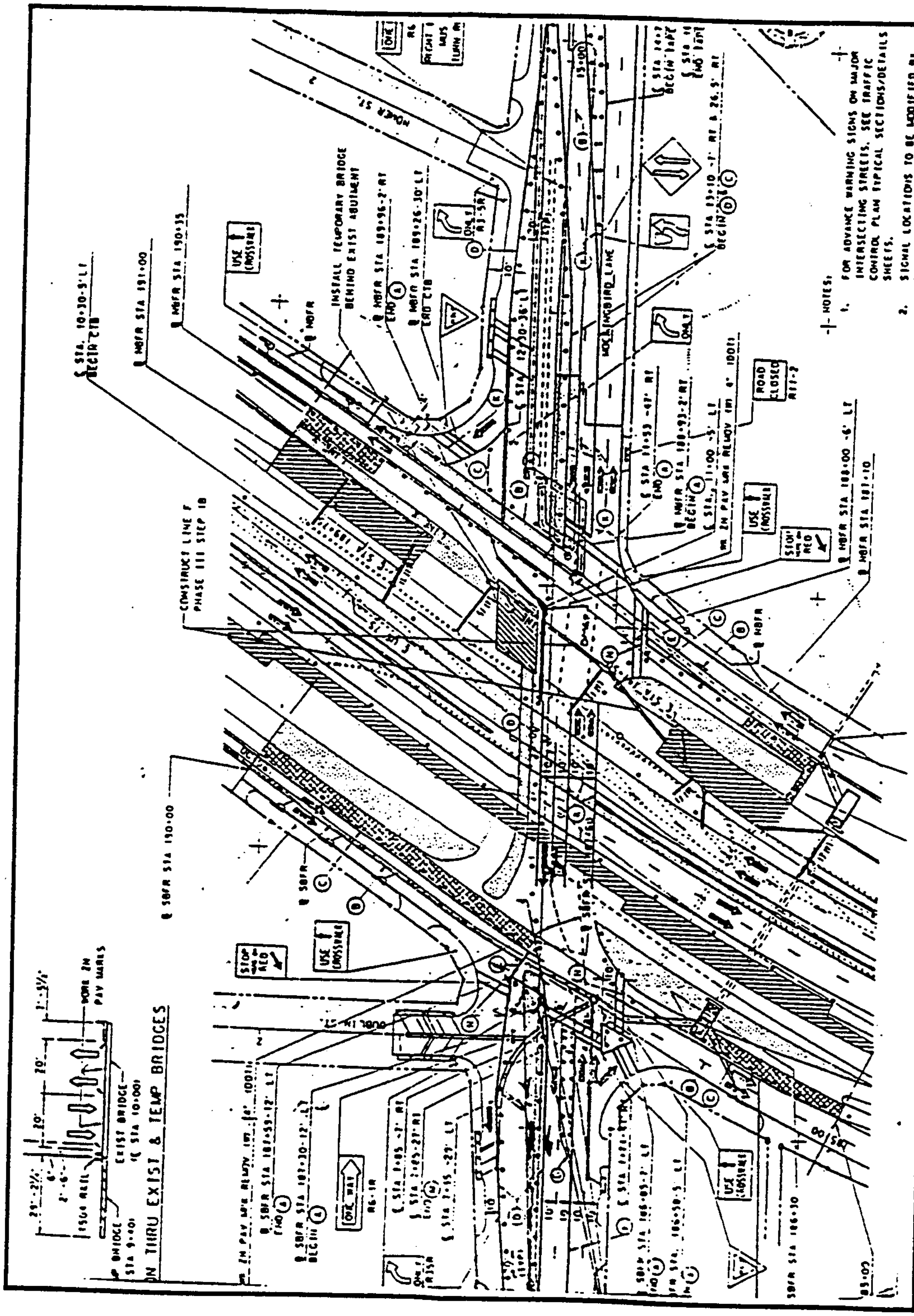
Sub factor	Units of measurement	BCP#1 Score in sub factor units	BCP#1 Time to evaluate	BCP#1 Model score	BCP#2 Score in sub factor units	BCP#2 Time to evaluate	BCP#2 Model score
Reduction of number of access	#	19	30	5.2	10	30	10
Number of forced diversions	#	7	20	5.7	4	10	10
Reduction of access points (Business)	#	21	30	7.1	15	20	10
Reduction in parking space	Sq. Yard	15000	45	8.6	13000	30	10
Additional distance from ramp	#	6	45	10	8	45	7.5
Construction congestion in front of...	#	9	90	10	13	90	7
Contractor access	#	3	30	6.6	2	40	10

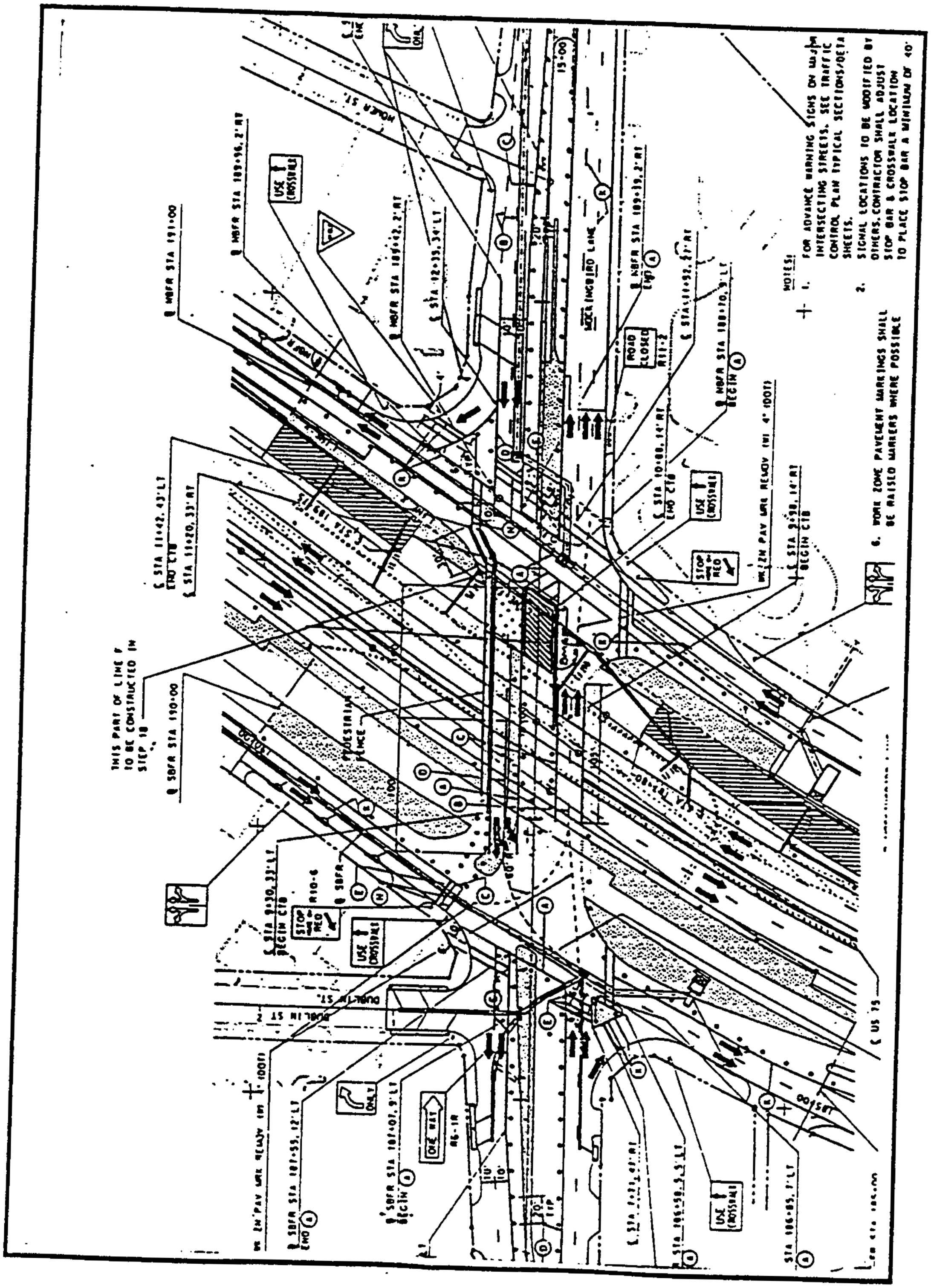
Table E-4: Details of Carrying Capacity Factor Evaluation

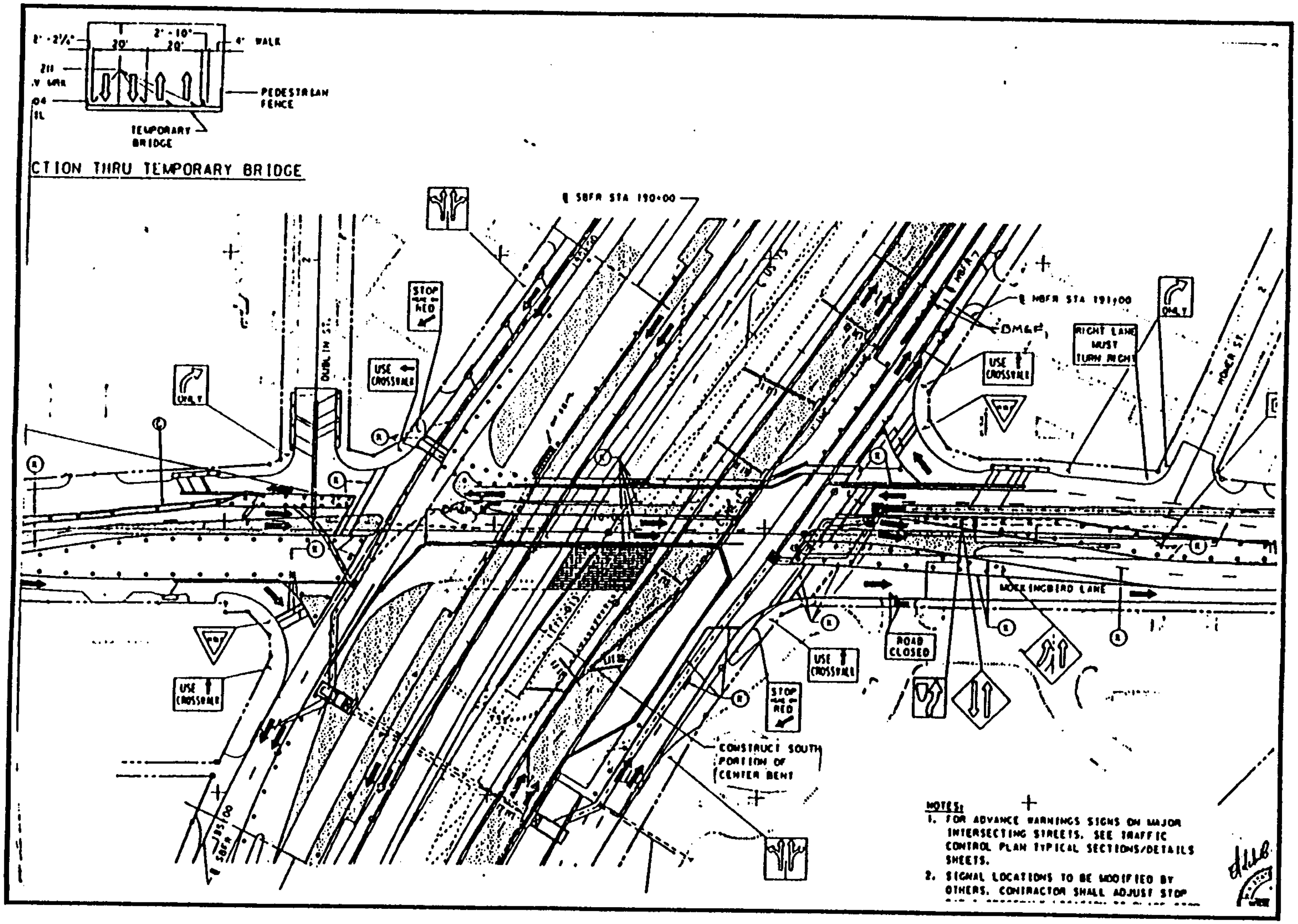
	BCP#1			BCP#2		
Incident #	# Vehicles in thousands	Duration in hours	Index thousand car.hour	# Vehicles in thousands	Duration in hours	Index thousand car.hour
1	50	4	200	50	6	300
2	75	3	225	60	4	240
3	100	3	300	75	8	600
4	100	8	800	30	10	300
5	30	6	180	100	2	200
6	50	8	400	30	6	180
7	100	5	500			
8	40	4	120			
9	30	3	80			
10	50	2	100			
Total			2915			1820

BCP #1

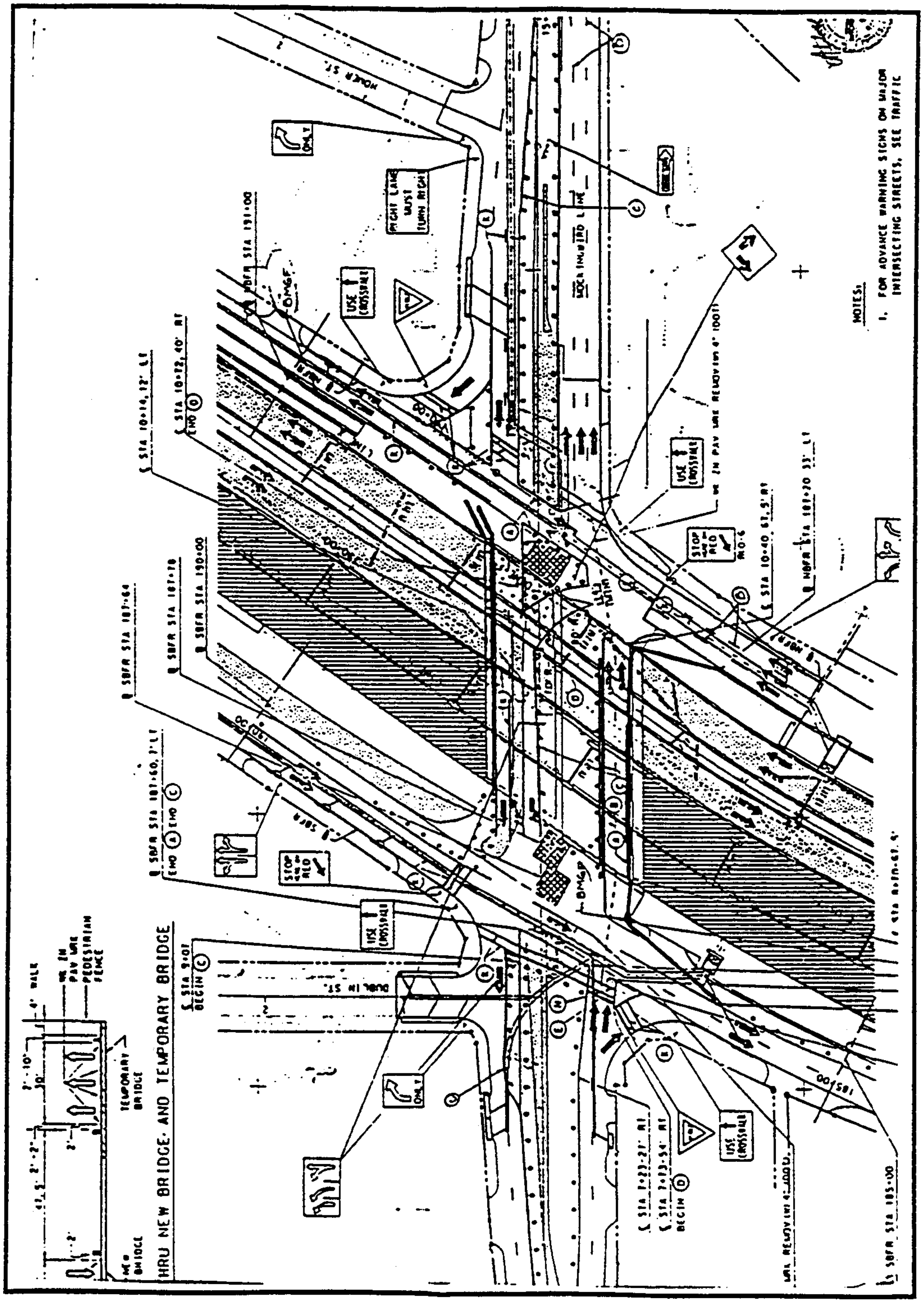

SECTION THRU SBFR
MATCH LINE STA. 190+00
Mockingbird Ln
RAMP CLOSED
MOCKINGBIRD LANE


ON THRU EXIST & TEMP BRIDGES
CONSTRUCT LINE F PHASE III STEP 1B
INSTALL TEMPORARY BRIDGE BEHIND EXIST ABUTMENT
USE CROSSWALK
ROAD CLOSED
ONE WAY
NOTES:
1. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
2. SIGNAL LOCATION(S) TO BE MODIFIED BY

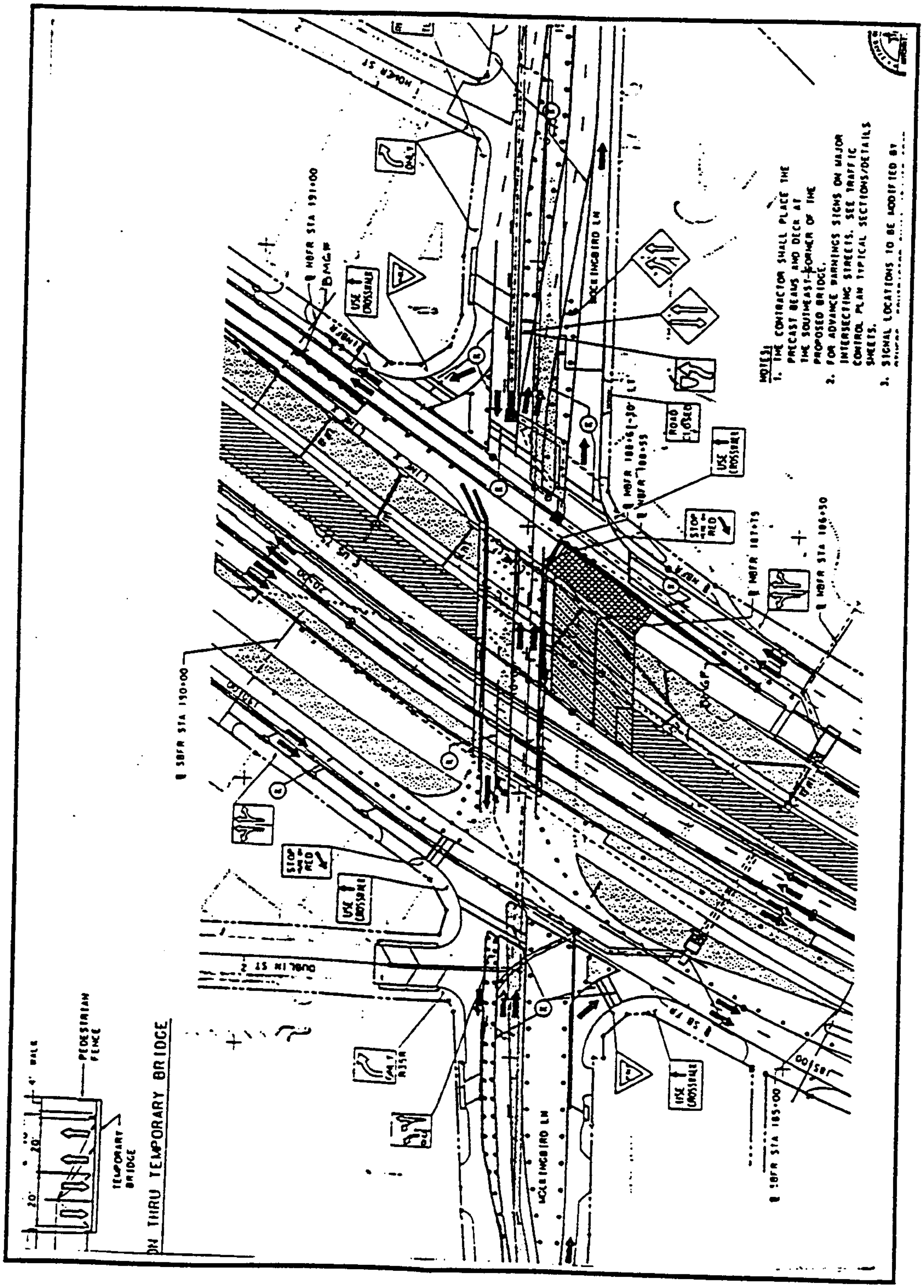

THIS PART OF LINE F TO BE CONSTRUCTED IN STEP 18
PEDESTRIAN FENCE
DUBLIN ST.
HOMER ST.
USE CROSSWALK
ROAD CLOSED
ONE WAY
STOP HERE ON RED
NOTES:
1. FOR ADVANCE WARNING SIGNS ON INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAIL SHEETS.
2. SIGNAL LOCATIONS TO BE MODIFIED BY OTHERS, CONTRACTOR SHALL ADJUST STOP BAR & CROSSWALK LOCATION TO PLACE STOP BAR A MINIMUM OF 40'
6. WORK ZONE PAVEMENT MARKINGS SHALL BE RAISED MARKERS WHERE POSSIBLE

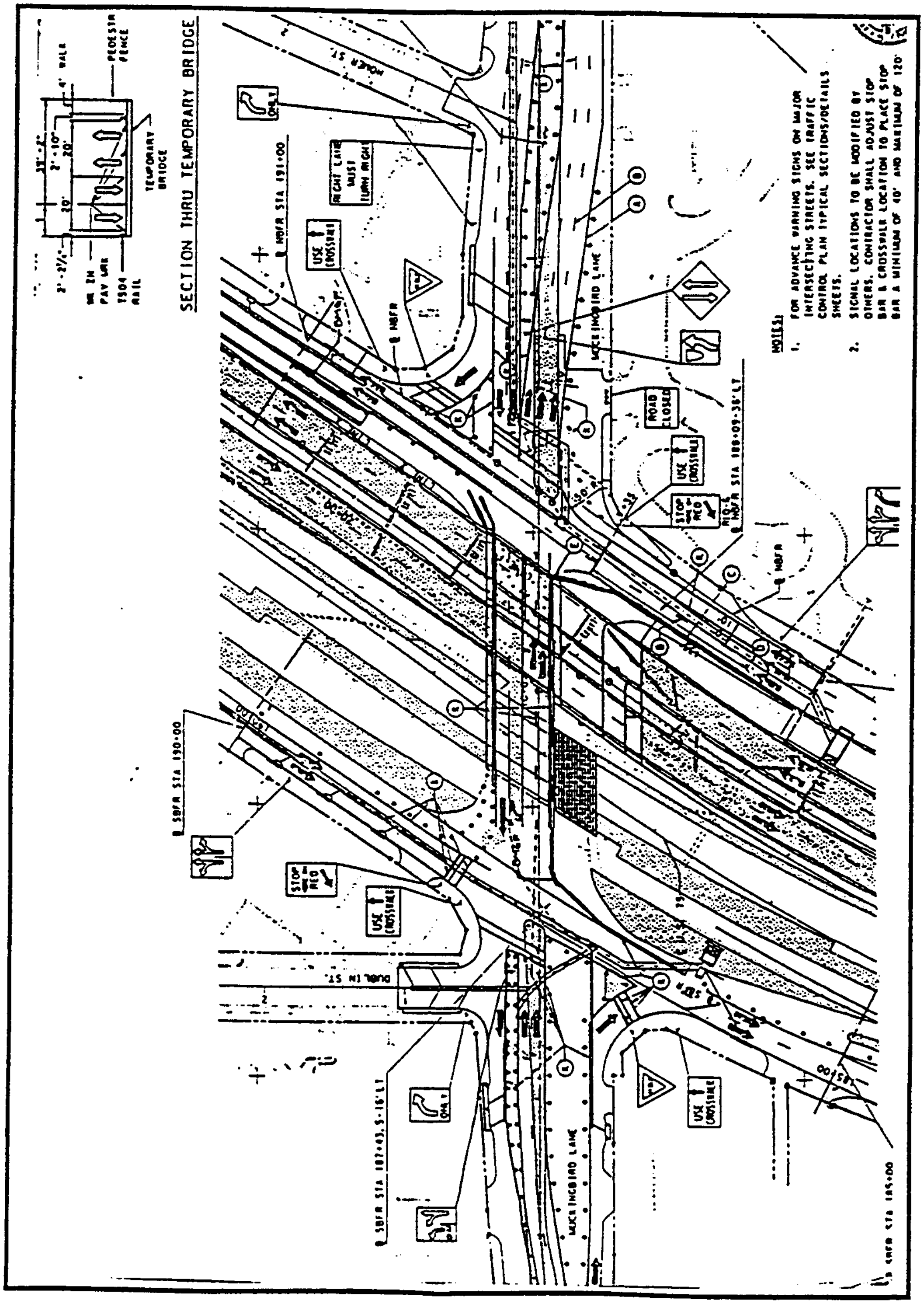


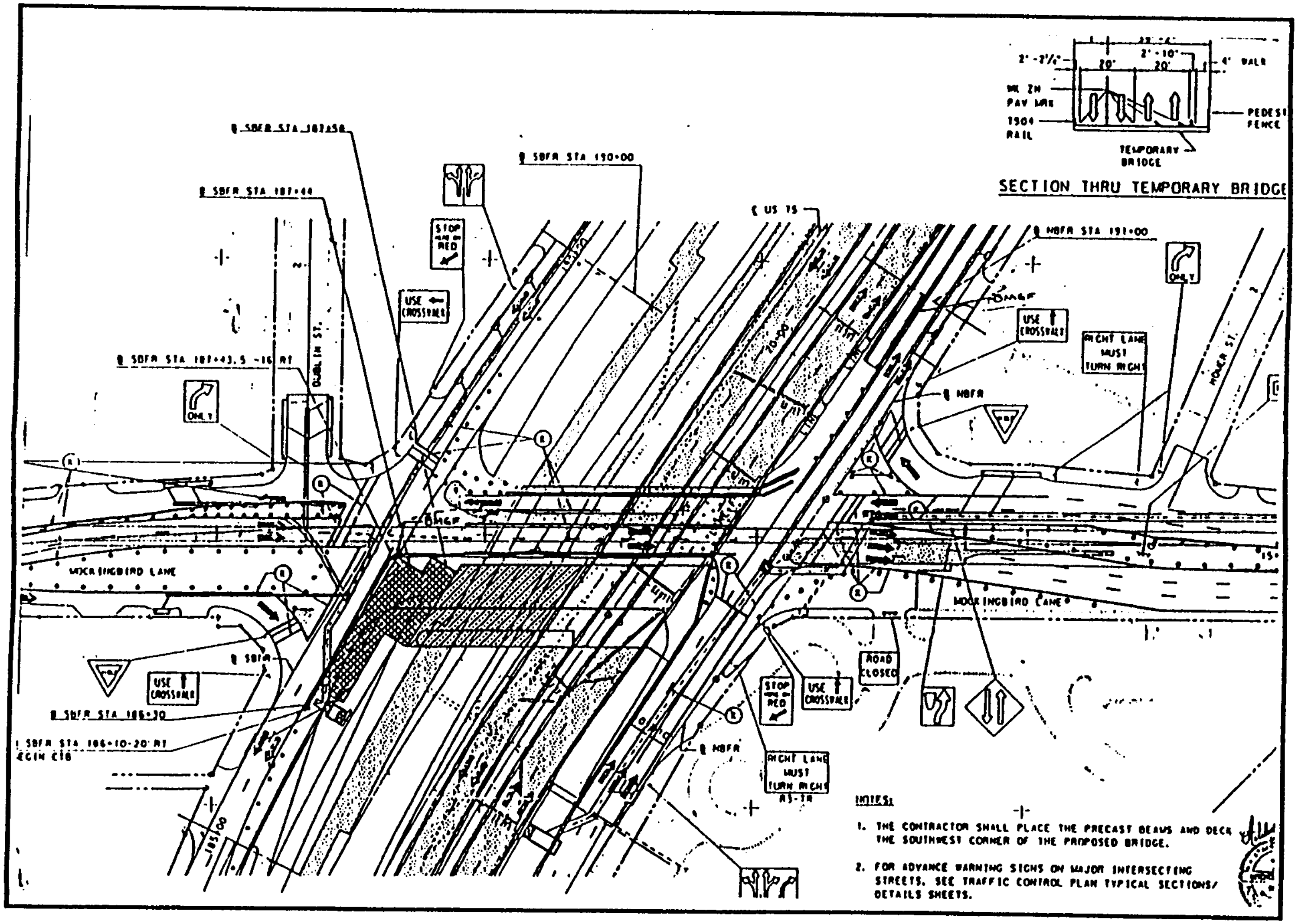
PEDESTRIAN FENCE
TEMPORARY BRIDGE
CTION THRU TEMPORARY BRIDGE
SBFR STA 190+00
NBFR STA 191+00
DUBLIN ST.
STOP HERE ON RED
USE CROSSWALK
ONLY
RIGHT LANE MUST TURN RIGHT
MOCKINGBIRD LANE
ROAD CLOSED
CONSTRUCT SOUTH PORTION OF CENTER BENT
NOTES:
1. FOR ADVANCE WARNINGS SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
2. SIGNAL LOCATIONS TO BE MODIFIED BY OTHERS. CONTRACTOR SHALL ADJUST STOP

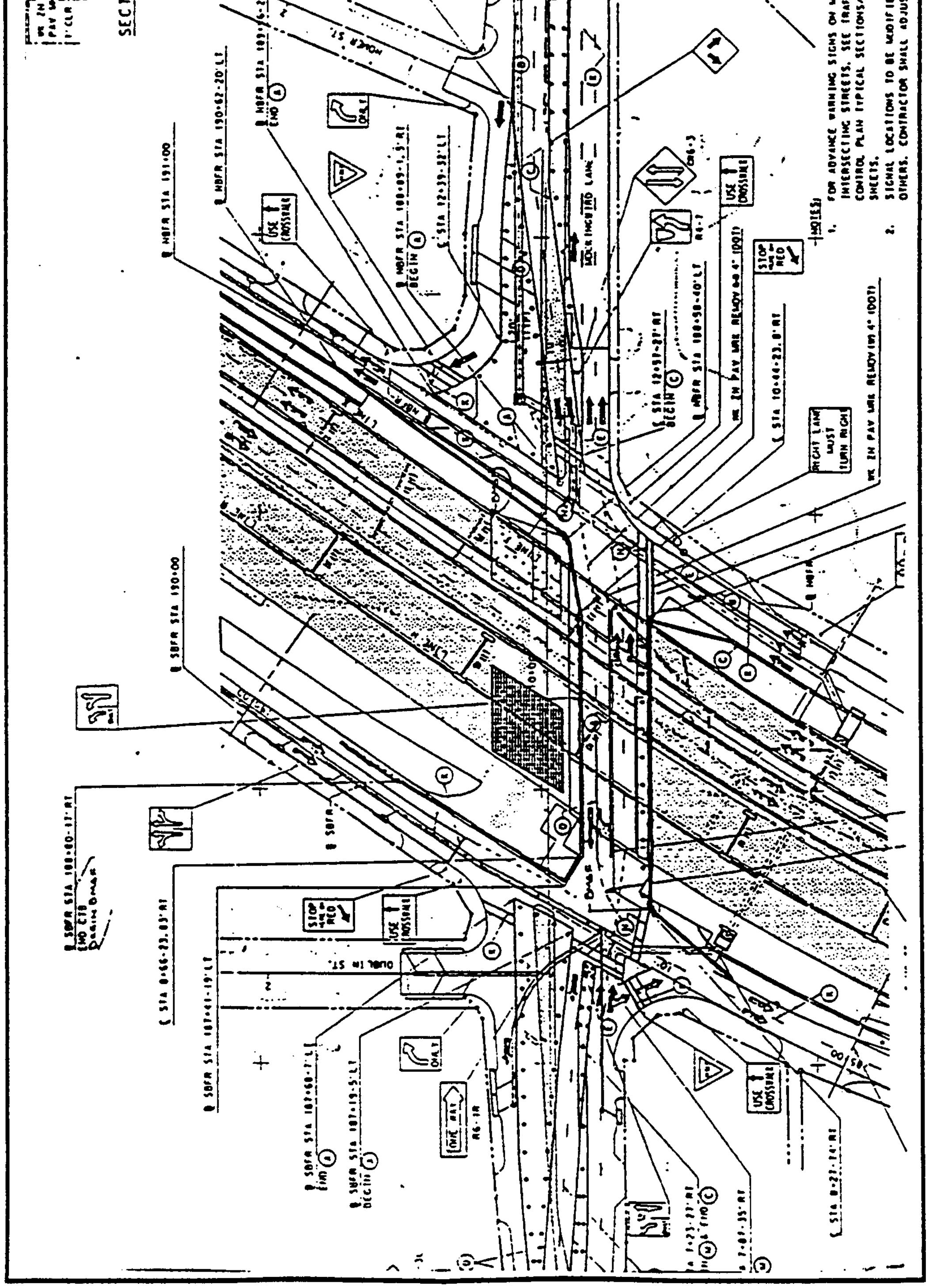


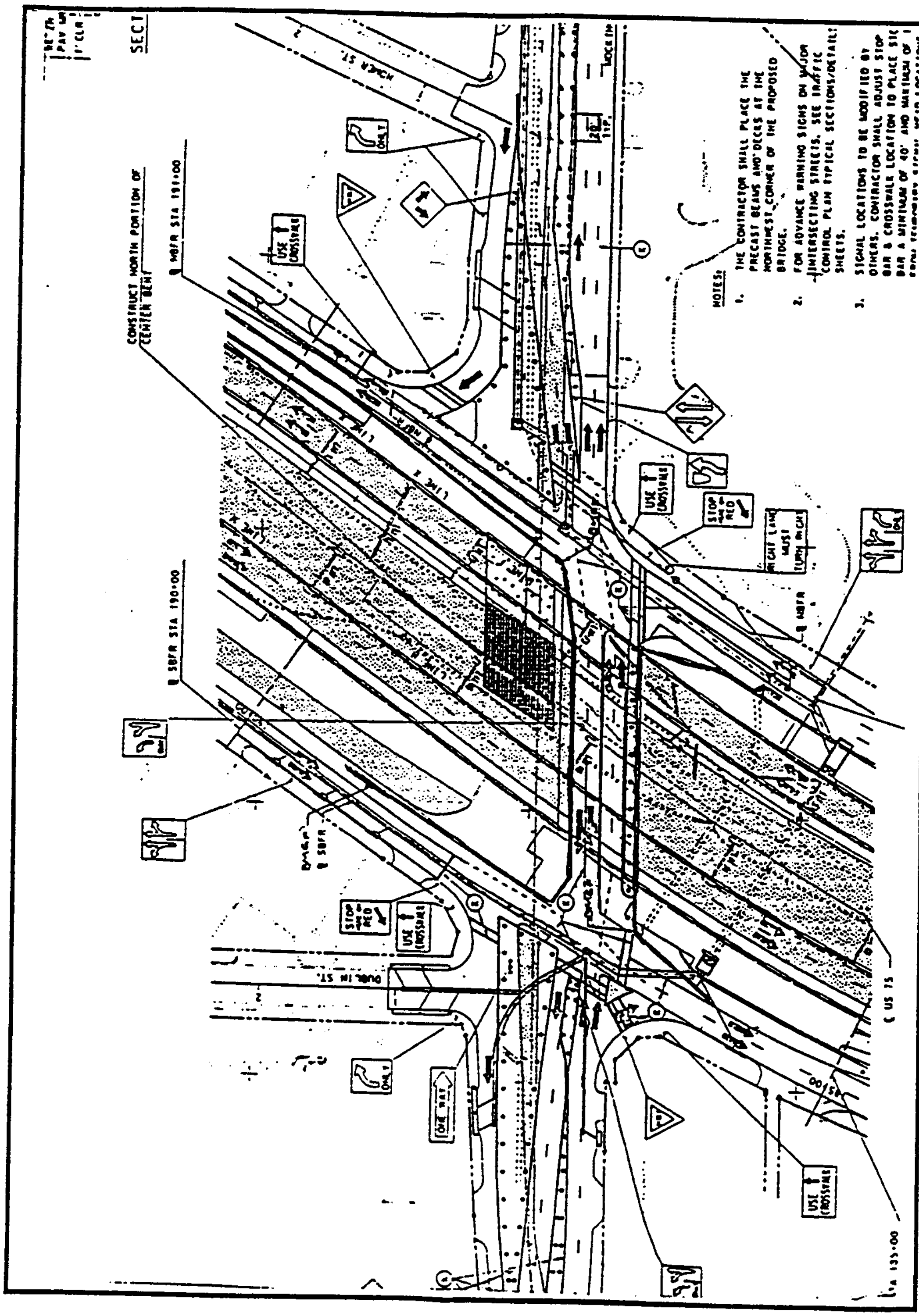
HRU NEW BRIDGE AND TEMPORARY BRIDGE
TEMPORARY BRIDGE
PEDESTRIAN FENCE
DUBLIN ST.
HOMER ST.
USE CROSSWALK
STOP HERE ON RED
RIGHT LANE MUST TURN RIGHT
ONLY
NOTES:
1. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC

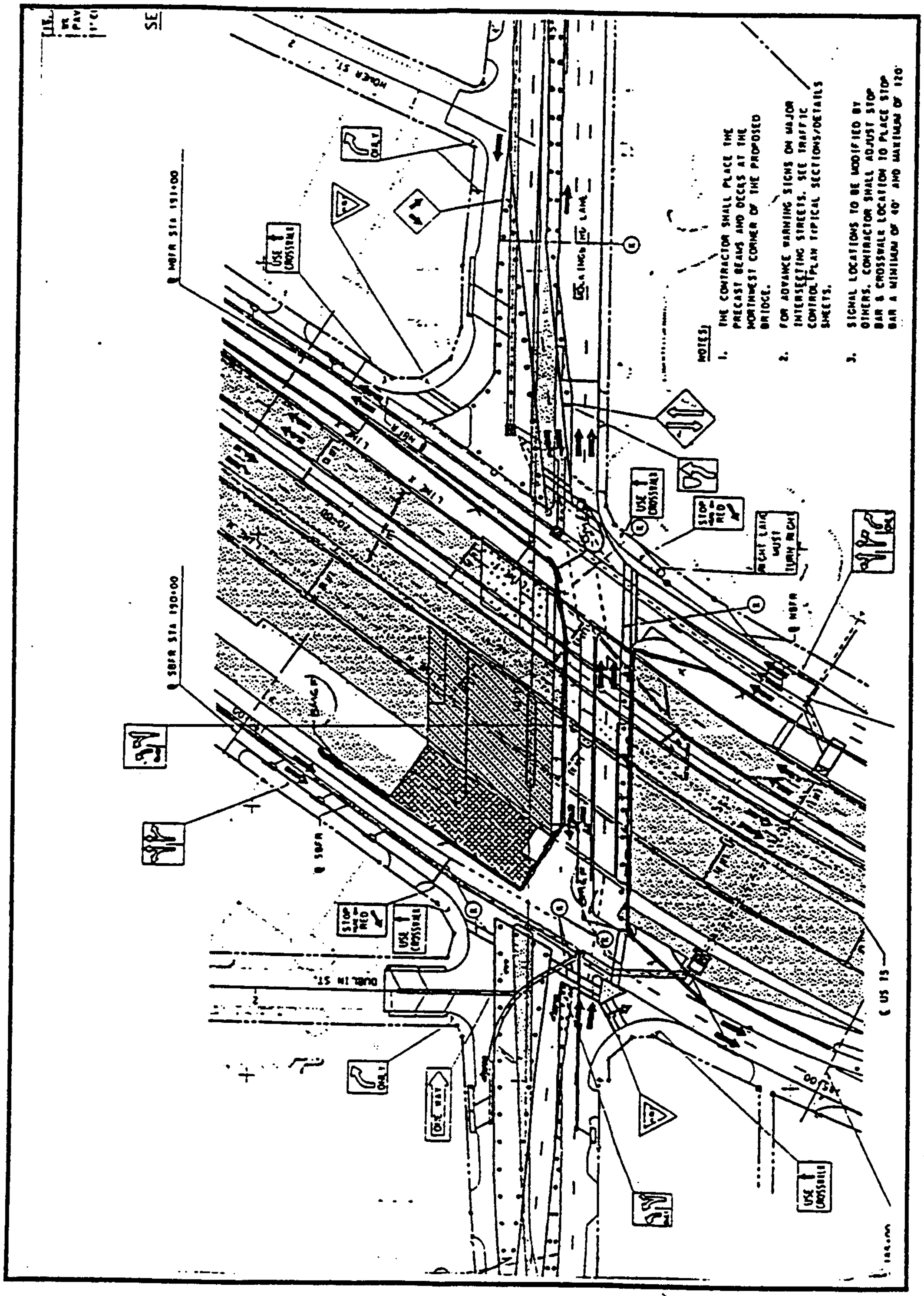

THRU TEMPORARY BRIDGE
PEDESTRIAN FENCE
TEMPORARY BRIDGE
MOCKINGBIRD LN
DUBLIN ST
USE CROSSWALK
STOP HERE ON RED
ROAD CLOSED
ONLY
NOTES:
1. THE CONTRACTOR SHALL PLACE THE PRECAST BEAMS AND DECK AT THE SOUTHEAST CORNER OF THE PROPOSED BRIDGE.
2. FOR ADVANCE WARNINGS SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
3. SIGNAL LOCATIONS TO BE MODIFIED BY

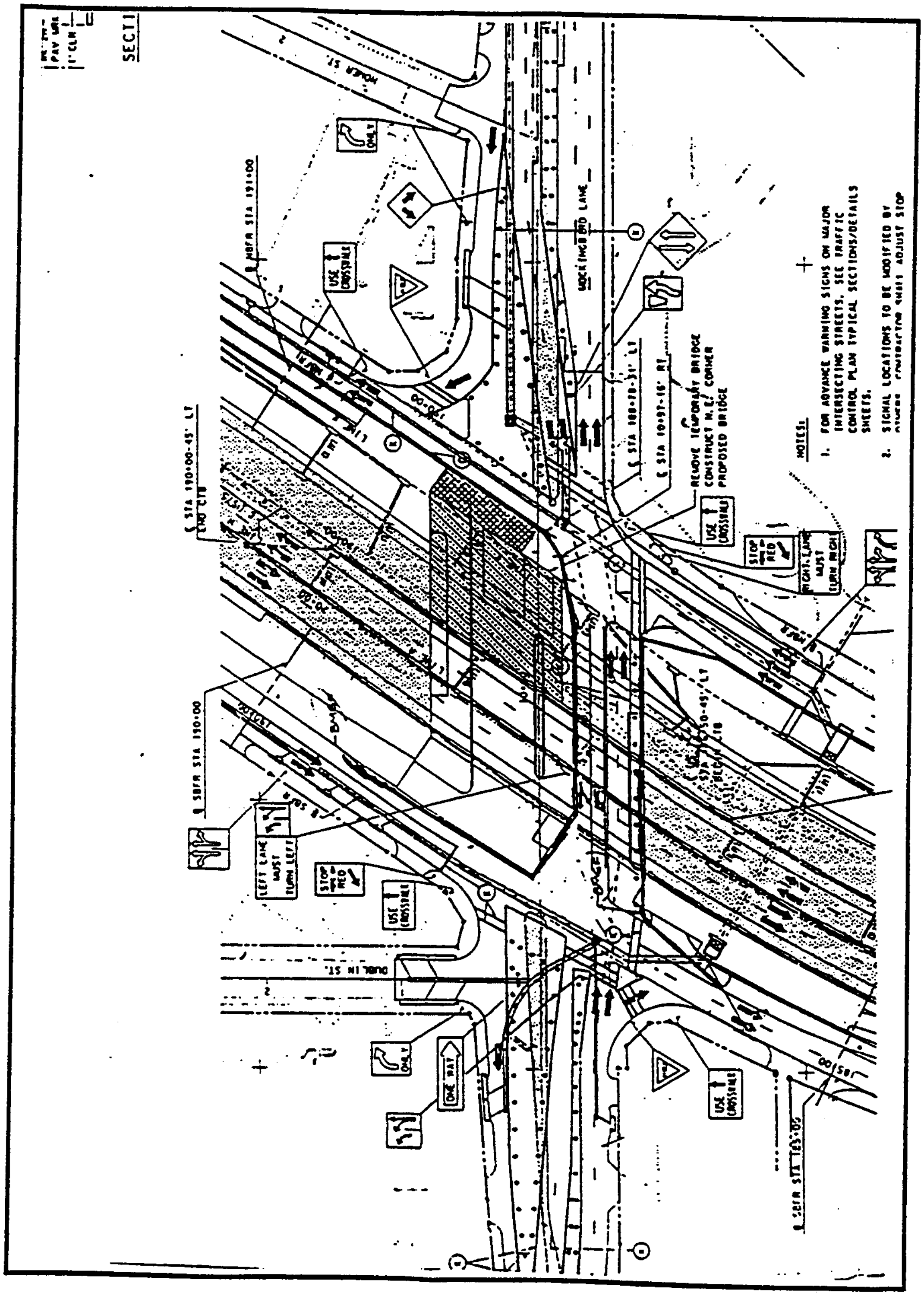

SECTION THRU TEMPORARY BRIDGE
TEMPORARY BRIDGE
MOCKINGBIRD LANE
DUBLIN ST.
ROAD CLOSED
USE CROSSWALK
ONLY
NOTES:
1. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
2. SIGNAL LOCATIONS TO BE MODIFIED BY OTHERS. CONTRACTOR SHALL ADJUST STOP BAR & CROSSWALK LOCATION TO PLACE STOP BAR A MINIMUM OF 40' AND MAXIMUM OF 120'


SECTION THRU TEMPORARY BRIDGE
TEMPORARY BRIDGE
PEDEST FENCE
USE CROSSWALK
STOP HERE ON RED
ONLY
RIGHT LANE MUST TURN RIGHT
ROAD CLOSED
MOCKINGBIRD LANE
DUBLIN ST.
MOLER ST.
US 75
NBFR
SBFR
SBFR STA 190+00
NBFR STA 191+00
SBFR STA 186+30
NOTES:
1. THE CONTRACTOR SHALL PLACE THE PRECAST BEAMS AND DECK THE SOUTHWEST CORNER OF THE PROPOSED BRIDGE.
2. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/ DETAILS SHEETS.

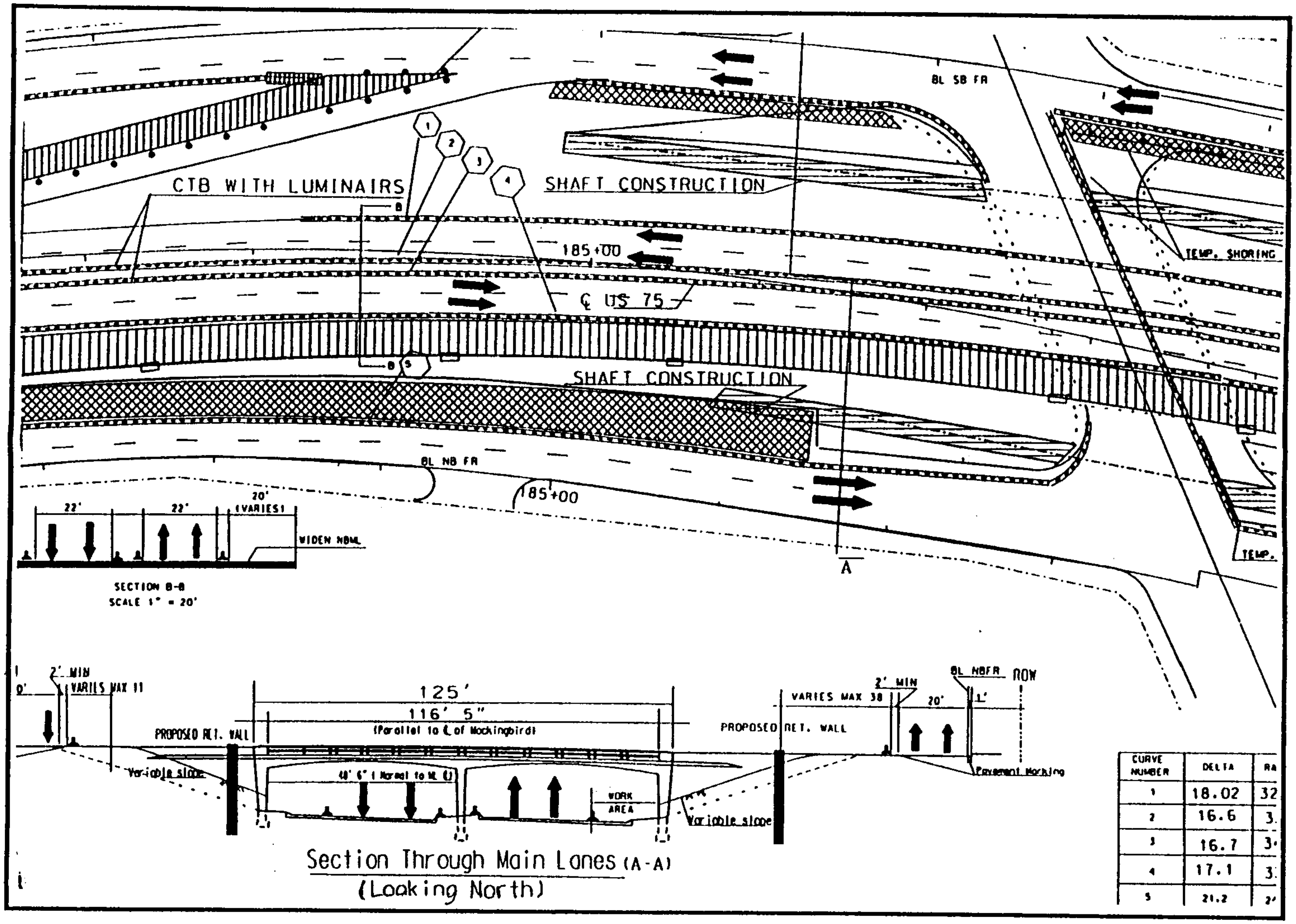


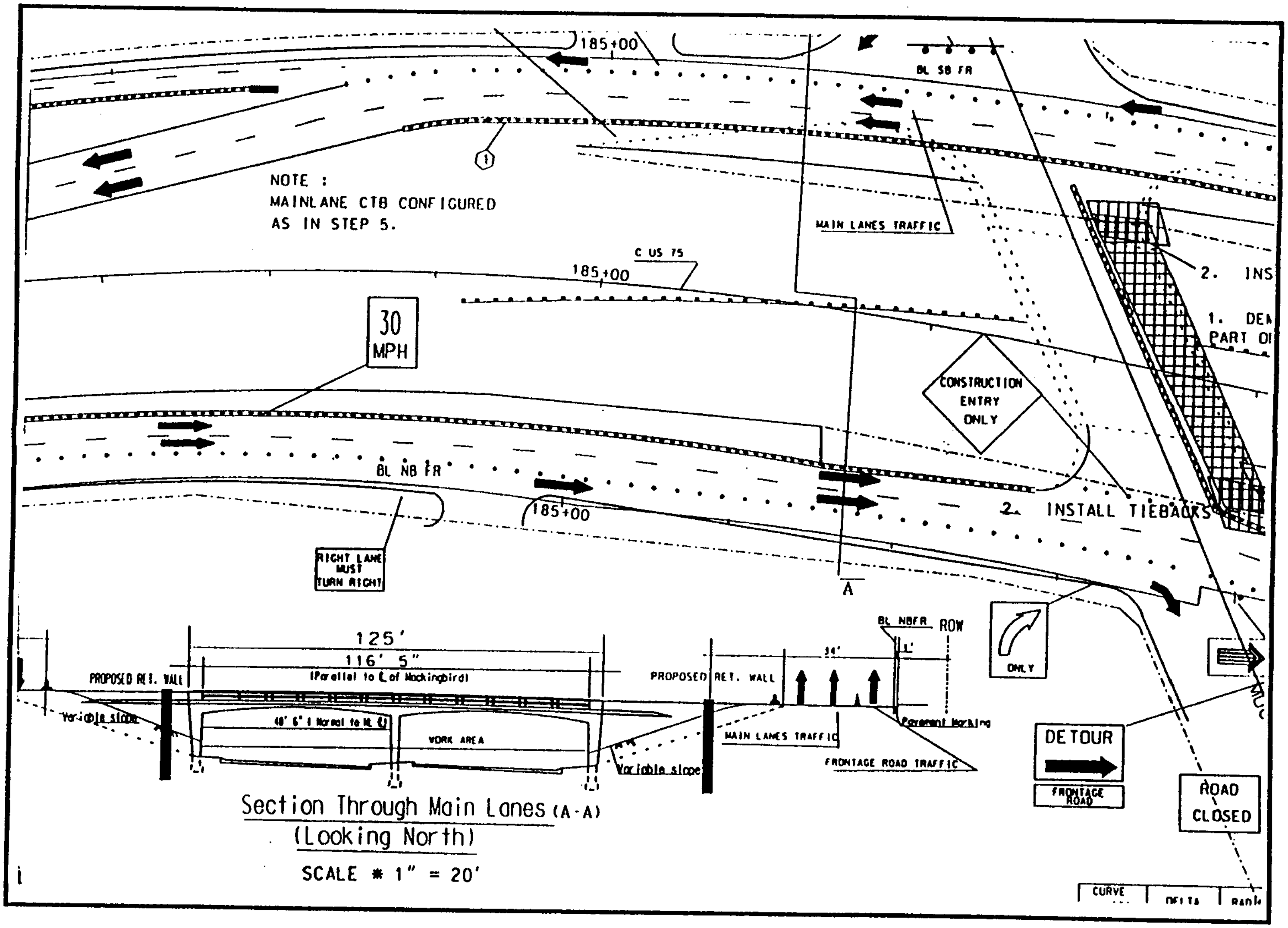

CONSTRUCT NORTH PORTION OF CENTER BENT
HOMER ST.
DUBLIN ST.
ONE WAY
USE CROSSWALK
STOP HERE ON RED
ONLY
NOTES:
1. THE CONTRACTOR SHALL PLACE THE PRECAST BEAMS AND DECKS AT THE NORTHWEST CORNER OF THE PROPOSED BRIDGE.
2. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
3. SIGNAL LOCATIONS TO BE MODIFIED BY OTHERS. CONTRACTOR SHALL ADJUST STOP BAR & CROSSWALK LOCATION TO PLACE SIG BAR A MINIMUM OF 40' AND MAXIMUM OF

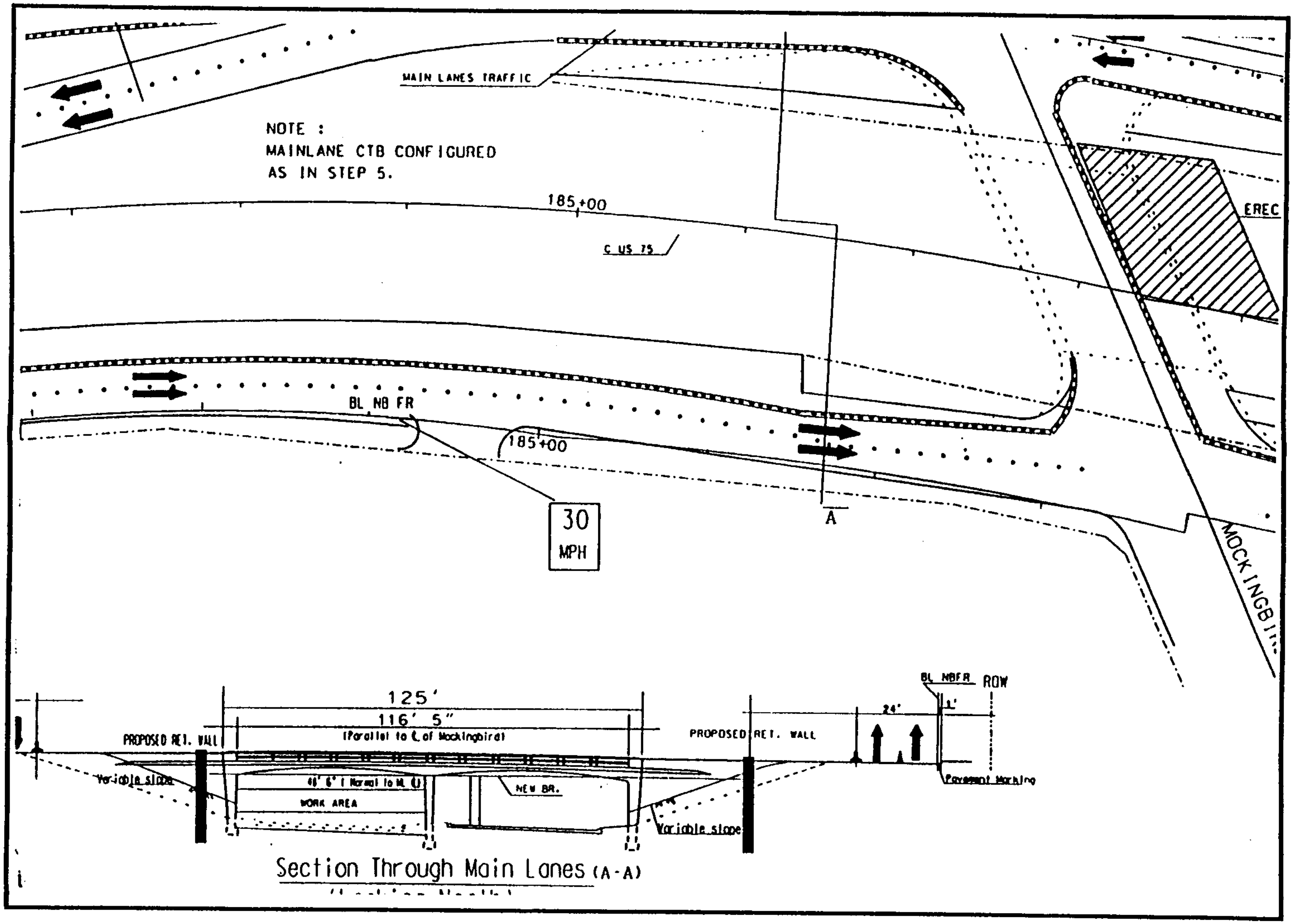

NOTES:
1. THE CONTRACTOR SHALL PLACE THE PRECAST BEAMS AND DECKS AT THE NORTHWEST CORNER OF THE PROPOSED BRIDGE.
2. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS. SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
3. SIGNAL LOCATIONS TO BE MODIFIED BY OTHERS. CONTRACTOR SHALL ADJUST STOP BAR & CROSSWALK LOCATION TO PLACE STOP BAR A MINIMUM OF 40' AND MAXIMUM OF 120'.
USE CROSSWALK
STOP HERE ON RED
RIGHT LANE MUST TURN RIGHT
ONE WAY
DUBLIN ST.
NBFR STA 131+00
SBFR STA 130+00
US 75


NOTES:
1. FOR ADVANCE WARNING SIGNS ON MAJOR INTERSECTING STREETS, SEE TRAFFIC CONTROL PLAN TYPICAL SECTIONS/DETAILS SHEETS.
2. SIGNAL LOCATIONS TO BE MODIFIED BY
USE CROSSWALK
LEFT LANE MUST TURN LEFT
STOP HERE ON RED
RIGHT LANE MUST TURN RIGHT
ONE WAY
ONLY
DUBLIN ST.
HOMER ST.
MOCKINGBIRD LANE
REMOVE TEMPORARY BRIDGE CONSTRUCT N.E. CORNER PROPOSED BRIDGE
SBFR STA 190+00
NBFR STA 191+00

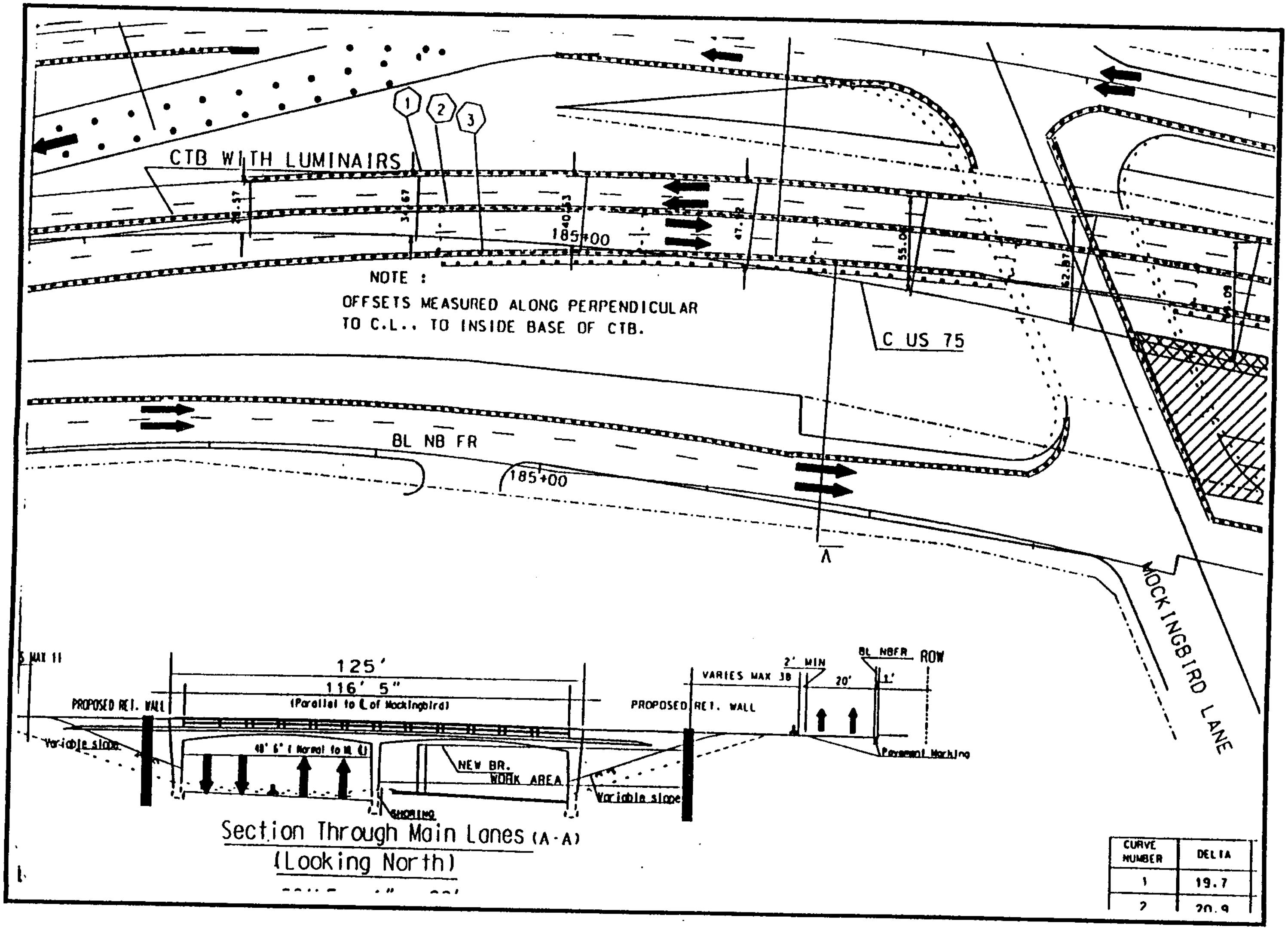
BCP #2


CTB WITH LUMINAIRS
SHAFT CONSTRUCTION
BL SB FR
TEMP. SHORING
185+00
℄ US 75
SHAFT CONSTRUCTION
BL NB FR
185+00
A
TEMP.
22'
22'
20' (VARIES)
WIDEN NBML
SECTION B-B
SCALE 1" = 20'
2' MIN
VARIES MAX 11
PROPOSED RET. WALL
Variable slope
125'
116' 5"
(Parallel to ℄ of Mockingbird)
WORK AREA
Variable slope
VARIES MAX 38
2' MIN
20'
BL NBFR
ROW
1'
PROPOSED RET. WALL
Pavement Marking
Section Through Main Lanes (A-A)
(Looking North)
CURVE NUMBER
DELTA
1
18.02
2
16.6
3
16.7
4
17.1
5
21.2

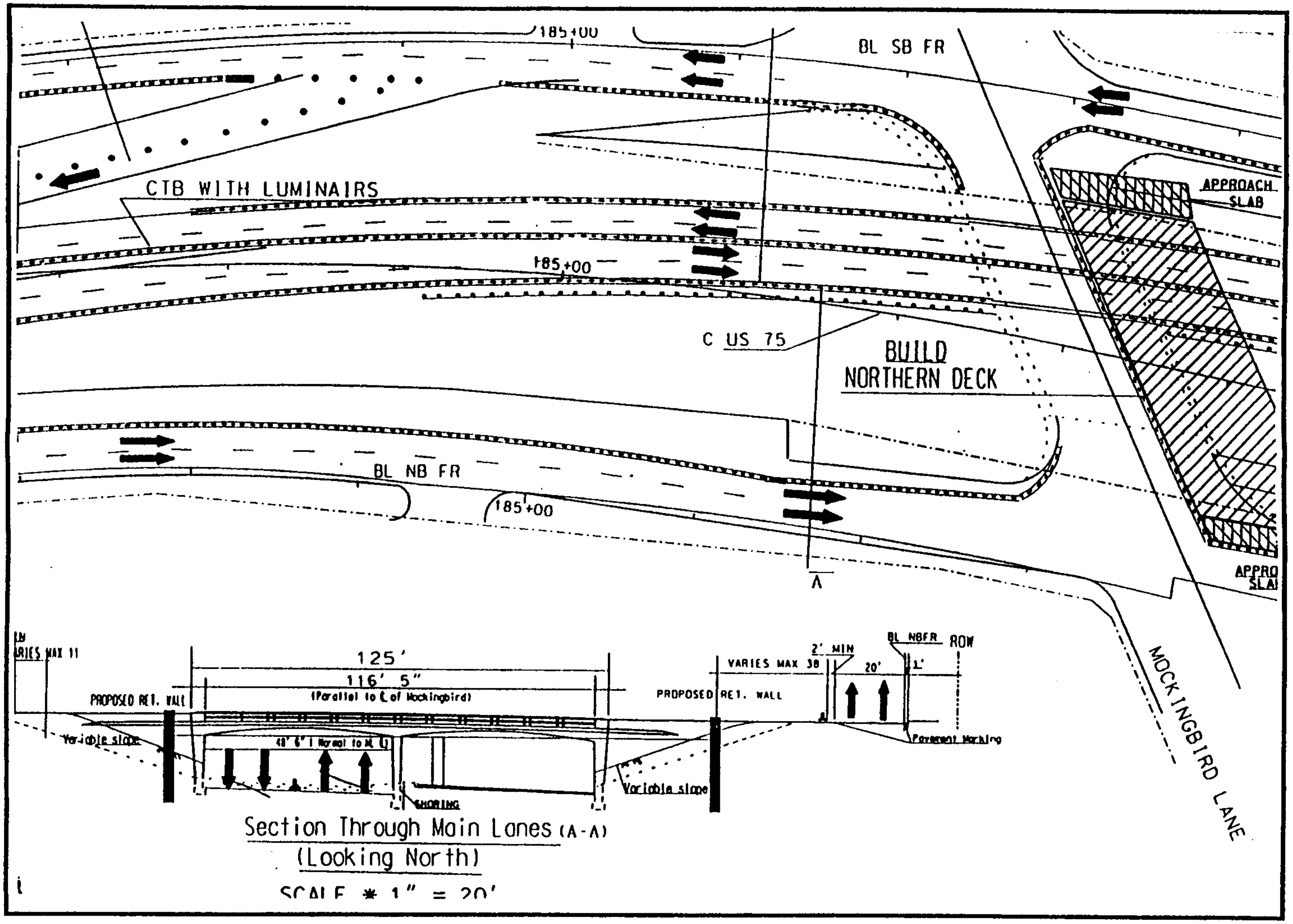

185+00
BL SB FR
NOTE :
MAINLANE CTB CONFIGURED
AS IN STEP 5.
MAIN LANES TRAFFIC
C US 75
185+00
2. INS
1. DEM
PART OF
30
MPH
CONSTRUCTION
ENTRY
ONLY
BL NB FR
185+00
2. INSTALL TIEBACKS
RIGHT LANE
MUST
TURN RIGHT
A
BL NBFR
ROW
ONLY
125'
116' 5"
(Parallel to C of Mockingbird)
PROPOSED RET. WALL
Variable slope
WORK AREA
Variable slope
PROPOSED RET. WALL
MAIN LANES TRAFFIC
Pavement Marking
FRONTAGE ROAD TRAFFIC
DETOUR
FRONTAGE ROAD
ROAD
CLOSED
Section Through Main Lanes (A-A)
(Looking North)
SCALE * 1" = 20'
CURVE



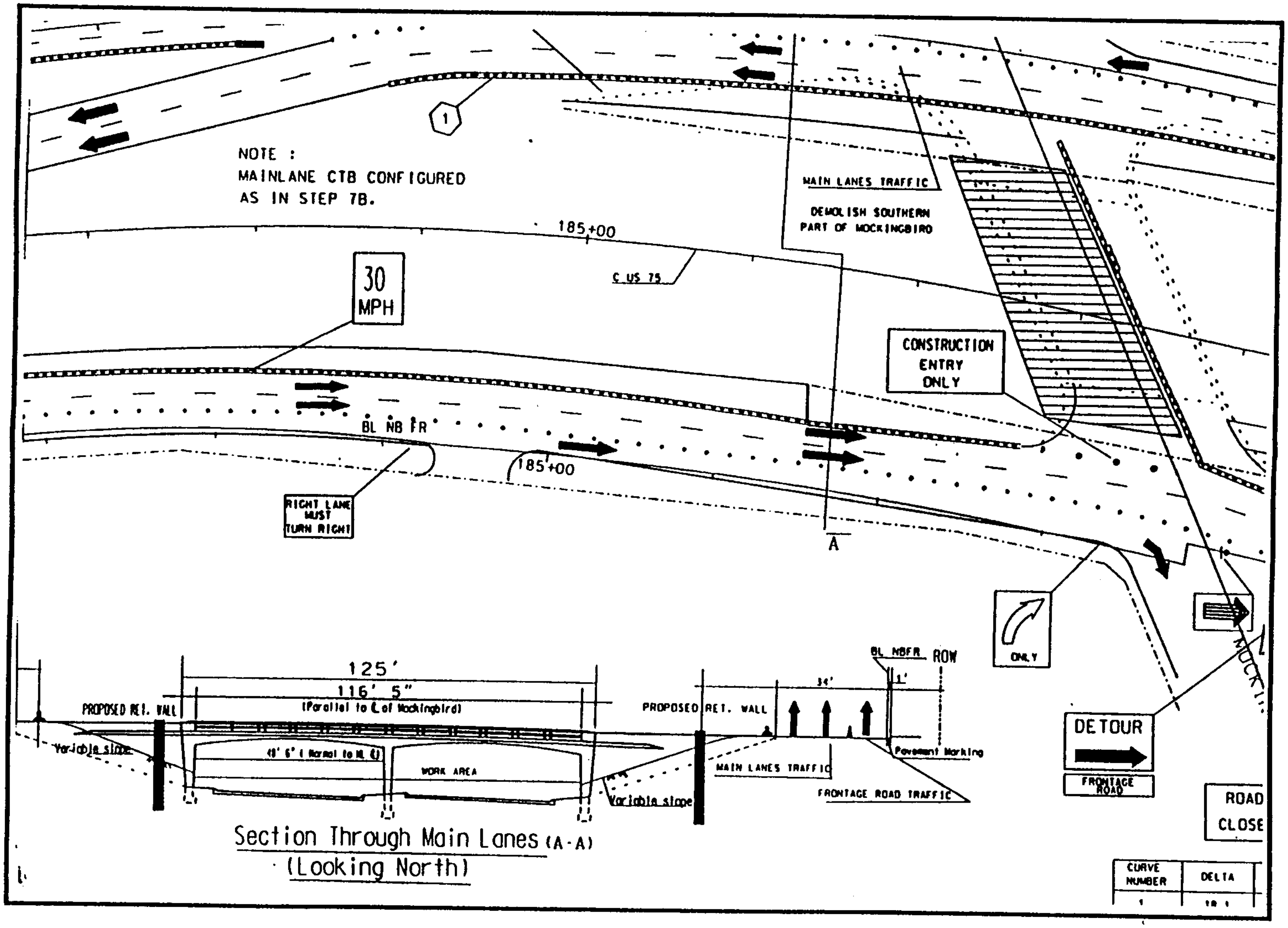
NOTE :
MAINLANE CTB CONFIGURED
AS IN STEP 5.
MAIN LANES TRAFFIC
185+00
C US 75
EREC
BL NB FR
185+00
30
MPH
A
MOCKINGBI
125'
116' 5"
(Parallel to C of Mockingbird)
PROPOSED RET. WALL
Variable slope
WORK AREA
NEW BR.
PROPOSED RET. WALL
Variable slope
BL NBFR
ROW
24'
1'
Pavement Marking
Section Through Main Lanes (A-A)

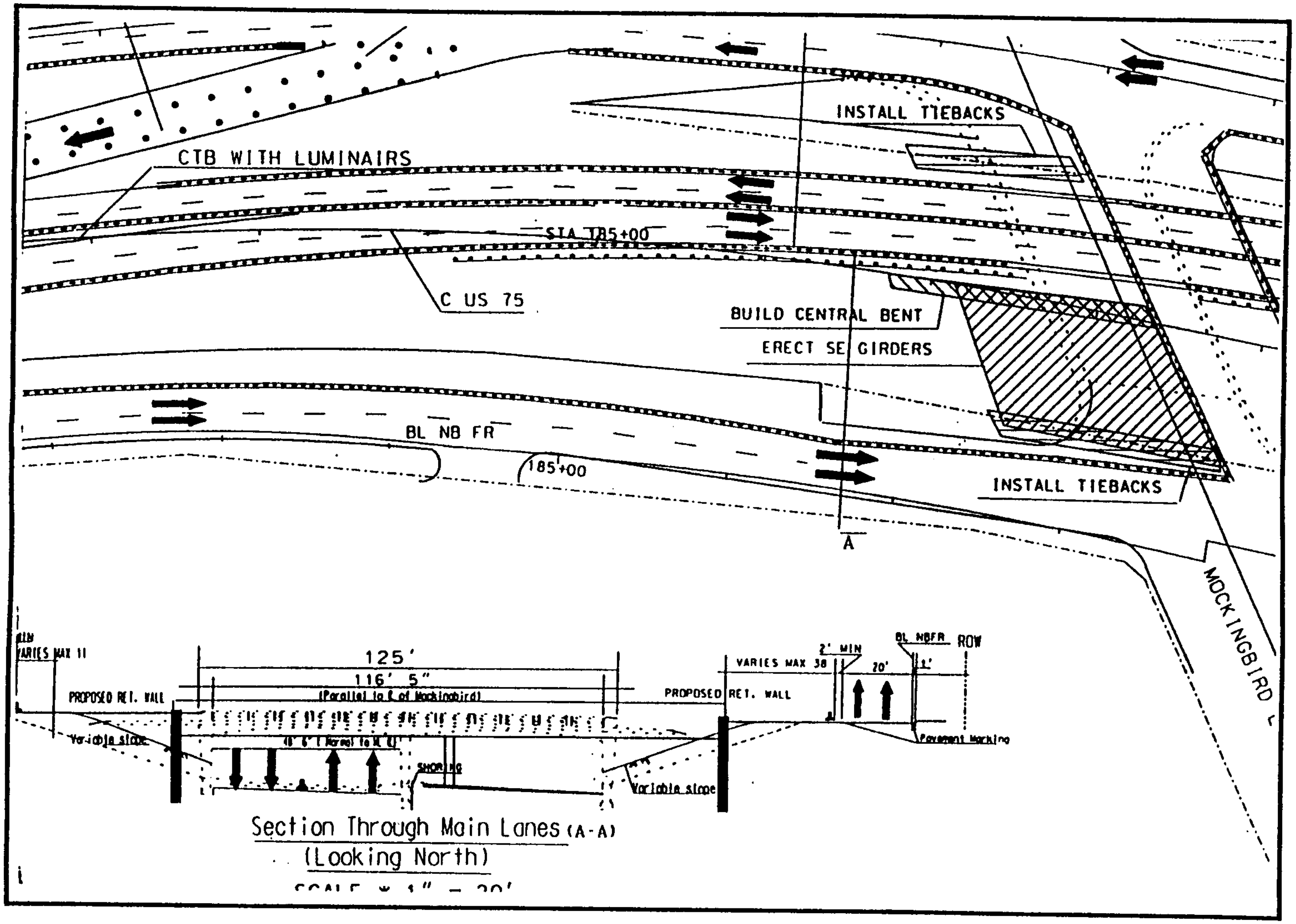


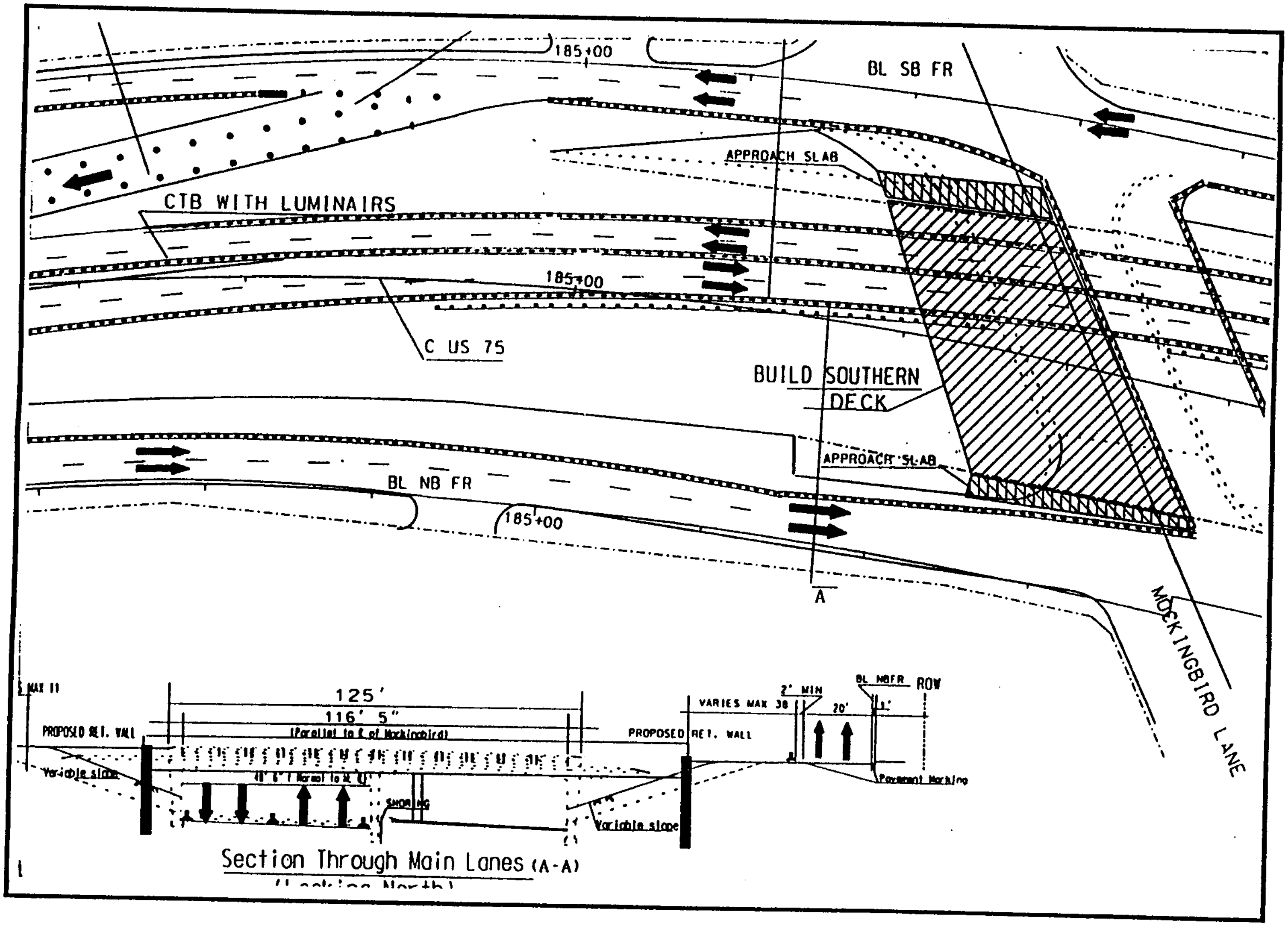
CTB WITH LUMINAIRS
1
2
3
185+00
NOTE :
OFFSETS MEASURED ALONG PERPENDICULAR TO C.L.. TO INSIDE BASE OF CTB.
C US 75
BL NB FR
185+00
A
MOCKINGBIRD LANE
125'
116' 5"
(Parallel to ℄ of Mockingbird)
PROPOSED RET. WALL
Variable slope
NEW BR. WORK AREA
SHORING
Variable slope
PROPOSED RET. WALL
VARIES MAX 38
2' MIN
20'
BL NBFR
ROW
Pavement Marking
Section Through Main Lanes (A-A)
(Looking North)
CURVE NUMBER
DELTA
1
19.7
2
20.9



Section Through Main Lanes (A-A)
(Looking North)
SCALE * 1" = 20'


NOTE :
MAINLANE CTB CONFIGURED
AS IN STEP 7B.
1
185+00
C US 75
30
MPH
MAIN LANES TRAFFIC
DEMOLISH SOUTHERN
PART OF MOCKINGBIRD
CONSTRUCTION
ENTRY
ONLY
BL NB FR
185+00
RIGHT LANE
MUST
TURN RIGHT
A
ONLY
DETOUR
FRONTAGE
ROAD
ROAD
CLOSE
125'
116' 5"
(Parallel to C of Mockingbird)
PROPOSED RET. WALL
Variable slope
WORK AREA
PROPOSED RET. WALL
MAIN LANES TRAFFIC
FRONTAGE ROAD TRAFFIC
Variable slope
BL NBFR
ROW
34'
1'
Pavement Marking
Section Through Main Lanes (A-A)
(Looking North)
CURVE
NUMBER
DELTA
1


CTB WITH LUMINAIRS
INSTALL TIEBACKS
STA 185+00
C US 75
BUILD CENTRAL BENT
ERECT SE GIRDERS
BL NB FR
185+00
INSTALL TIEBACKS
A
MOCKINGBIRD
VARIES MAX 11
PROPOSED RET. WALL
Variable slope
125'
116' 5"
(Parallel to C of Mockingbird)
SHORING
Variable slope
PROPOSED RET. WALL
VARIES MAX 38
2' MIN
20'
1'
BL NBFR
ROW
Pavement Marking
Section Through Main Lanes (A-A)
(Looking North)



Section Through Main Lanes (A-A)
(Looking North)