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PROCEDURES AND GUIDELINES FOR REHABILITATION OF EXISTING FREEWAY-ARTERIAL HIGHWAY INTERCHANGES

Vol. I. Executive Summary

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Final Report

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PREFACE

Efforts throughout this project were guided by a steering committee of design and traffic operations engineers from State highway agencies and consulting firms throughout the United States. The members of this committee were Mr. Andrew J. Gazda, Illinois Department of Transportation; Mr. C. William Gray, Ohio Department of Transportation; Mr. Parker Hall, California Department of Transportation; Mr. Ronald E. Magahey and Mr. Aage G. Schroder III, Florida Department of Transportation; and Mr. Bernard Rottinghaus, Howard, Needles, Tammen, and Bergendoff. The overall guidance and specific suggestions provided by this committee have contributed immeasurably to the results of this project. We also acknowledge the efforts of Mr. Kenneth E. Robertson, Michigan Department of Transportation, who coordinated our data collection activities in their respective states. Finally, we wish to express our gratitude to the many individuals in each transportation agency, at both headquarters and local levels, who assisted in the data collection efforts.

This is the Executive Summary volume of the four-volume final report. This volume is intended for readers who want a brief overview of the project objectives and results. The other volumes of the set are Volume II, entitled, "Design Procedures for Rehabilitation of Freeway-Arterial Interchanges," which presents the procedures and guidelines recommended for use in interchange rehabilitation projects; Volume III, entitled, "Evaluation of Interchange Rehabilitation Projects," which presents evaluations of 40 interchange rehabilitation projects recently constructed by highway agencies; and, Volume IV, the research report, which reviews and summarizes all activities by MRI during the contract.

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I. INTRODUCTION

Midwest Research Institute, under contract to the Federal Highway Administration, conducted a multi-year study of procedures and guidelines for rehabilitation of existing freeway-arterial highway interchanges. The study included the evaluation of recent interchange rehabilitation projects constructed by several State highway agencies and the recommendation of design procedures for interchange rehabilitation projects.

Freeways are the safest and most efficient portion of the highway system primarily because of the complete exclusion of driveways and at-grade intersections. Access from the conventional highway system to the freeway system is provided at freeway-arterial interchanges. Because of the conflicting demands of entering, exiting and through traffic, most operational and safety problems of the freeway system are concentrated at interchanges.

Redesign of inadequate interchanges can result in increased capacity, reduced delay and increased safety. However, the cost to remedy all existing traffic operational and safety problems far exceeds the funds available for improvements, and improvement needs are sure to grow. Therefore, the use of cost-effectiveness techniques is vital to assure that the limited funds available are invested optimally.

The overall objective of the current study was to develop cost, safety and operationally effective geometric design procedures and guidelines by quantifying the cost, safety and operational trade-offs for the improvement of existing freeway-arterial highway interchanges. The intent of these procedures and guidelines was to accommodate an increase in traffic volumes, maximize safety benefits and minimize costs.

The scope of the study was limited to consideration of freeway-arterial interchanges in urban and suburban areas. Throughout the study, the term "freeway-arterial interchange" has been interpreted as referring to all interchanges between a freeway and a street or highway with no control or partial control of access. Freeway-freeway interchanges and rural interchanges were specifically excluded from the project scope. However, it is recognized that many of the project results are applicable to freeway-freeway interchanges as well as freeway-arterial interchanges, and to rural interchanges as well as urban and suburban interchanges.

The final results of the contract include traffic operational and safety evaluations of 40 recent interchange rehabilitation projects, including general findings concerning their safety effectiveness. The contract also developed design procedures for each step in the interchange rehabilitation process from identification of interchanges with operational and safety problems through the evaluation of completed interchange rehabilitation projects.

The final report is presented in four volumes, of which this Executive Summary is the first. Volume II presents the recommended design procedures for interchange rehabilitation projects that were developed during the contract. The evaluation of interchange rehabilitation projects is presented in Volume III. Volume IV is the final research report which documents all activities during the contract, including the development of the recommended procedures. The remainder of this Executive Summary is organized in three sections, with one section devoted to each of the remaining volumes of the final report.

II. VOLUME II--DESIGN PROCEDURES FOR REHABILITATION OF FREEWAY-ARTERIAL INTERCHANGES

Volume II of the final report presents recommended design procedures for freeway-arterial interchanges that were developed during the contract. This volume provides guidance to engineers responsible for identification of problem interchanges and the design of interchange rehabilitation projects. The recommended procedures in Volume II could form the basis for an implementation package on interchange rehabilitation. The organization of the recommended design procedures is based on the interchange rehabilitation process, which consists of six steps. These are:

- Identify interchanges with operational and/or safety problems;
- Study problem locations and identify specific deficiencies;
- Identify improvement alternatives;
- Quantify effects of improvement alternatives;
- Evaluate alternatives and select the best; and
- Implement improvement and evaluate effectiveness.

The recommended procedures for each step in the interchange rehabilitation process are briefly described in the following sections.

A. Identify Interchange with Operational and/or Safety Problems

The first step of the interchange rehabilitation process is to identify interchanges that have traffic operational or safety problems that are potentially correctable. The recommended approach is not a formal procedure, but does provide guidance for the use of accident surveillance systems and operational data to prepare a list of candidate interchanges for further study.

The recommended operational review procedures rely on field reviews of operational conditions, traffic volume counts, capacity analyses and citizen complaints.

Greater emphasis is placed on a formal surveillance system for identifying safety problems than for operational problems, because safety problems are often more subtle and difficult to detect. Recommendations on accident surveillance procedures are based on a review of the systems employed by several state highway agencies. An appropriate organization for a surveillance system is presented in Figure 1. The effective use of an accident surveillance system for interchanges requires complete accident data for all portions of each interchange (freeway, crossroad and ramps); a location reference system to identify the portion of the interchange where each accident occurs; estimates of the expected accident rates for an entire interchange or for specific portions of an interchange; and, statistical criteria for comparison of the actual and expected accident rates.

B. Study Problem Locations and Identify Specific Deficiencies

Engineering studies for identifying specific deficiencies at problem locations are presented. A set of basic studies including physical inventories, on-site observation, traffic volume counting, accident tabulations and summaries, and collision diagrams are recommended for each problem location. Supplementary engineering studies, suitable for investigating specific types of operational and safety problems, are also discussed. These include studies of capacity, travel time and delay, speed, traffic conflicts and erratic maneuvers, traffic signals, sight distance, turning radius, and skid resistance. The recommendations identify both the objective of each type of engineering study and the sources that can be consulted for detailed procedures.

C. Identify Improvement Alternatives

A critical step in the interchange rehabilitation process is the identification of alternative solutions. It is important that all feasible alternative solutions be considered by the engineer, lest the best alternative be missed. A series of charts has been developed to relate identified operational and safety problems to potential solutions. An example of one of the charts--for interchanges with delays and accidents on off-ramps--is

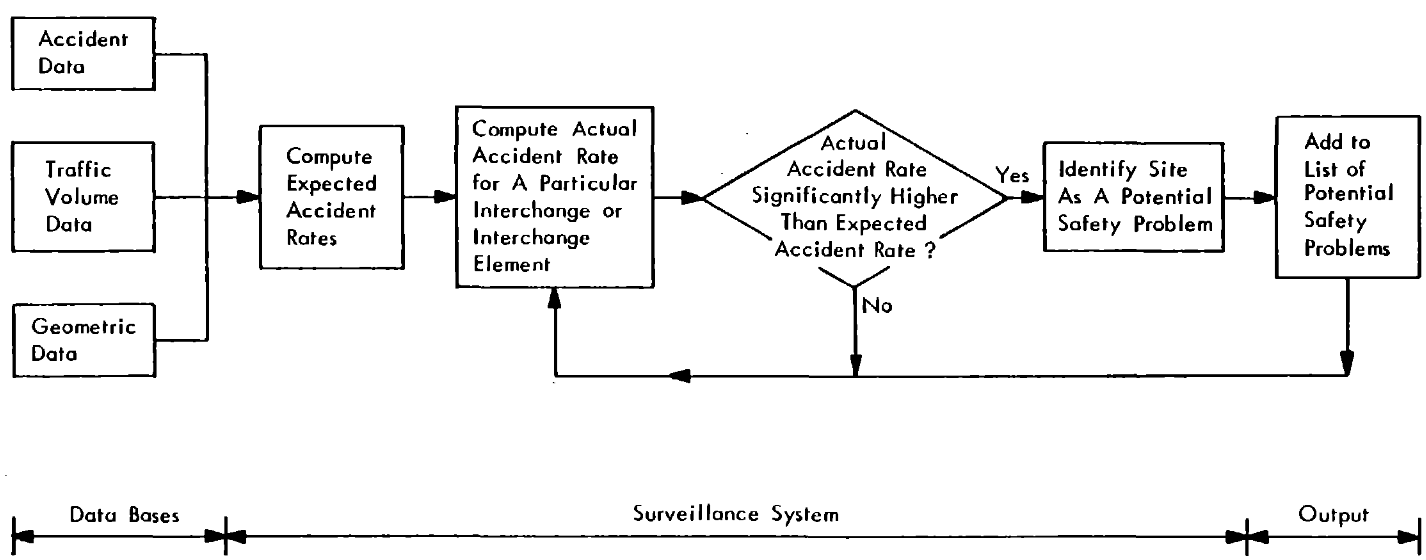


Figure 1 - Flow-Chart of an Accident Surveillance System

presented in Table 1. Using the charts, an engineer can quickly identify a set of solutions that are potentially applicable to the particular interchange configuration and problem under consideration. Additional solutions developed by the engineer should also be considered.

D. Quantify Effects of Improvement Alternatives

Procedures are provided to quantify the effects of improvement alternatives on travel time, vehicle operating costs and accidents. Travel time and vehicle operating costs are quantified through the procedures of the AASHTO Manual on User Benefit Analysis for Highway and Bus Transit Improvements - 1977, which have been adapted to specifically address the analysis of interchanges. The AAHSTO procedures provide measures of both delay and vehicle running costs (including energy consumption) for most, but not all, interchange rehabilitation situations. In particular, the procedures do not address vehicle speeds and delays in weaving areas, either within an interchange or between adjacent interchanges. Also, delay measures for Level of Service F conditions on roadway sections and at intersections are not provided by the procedures and must be obtained from field studies or queueing analyses.

Safety effectiveness estimates are based on five alternative evaluation approaches. These are:

- Estimate safety effectiveness based on the agency's own experience in similar projects;
- Estimate safety effectiveness based on reported experience in similar projects;
- Estimate safety effectiveness based on engineering judgment;

TABLE 1

DELAYS AND ACCIDENTS ON OFF-RAMPS

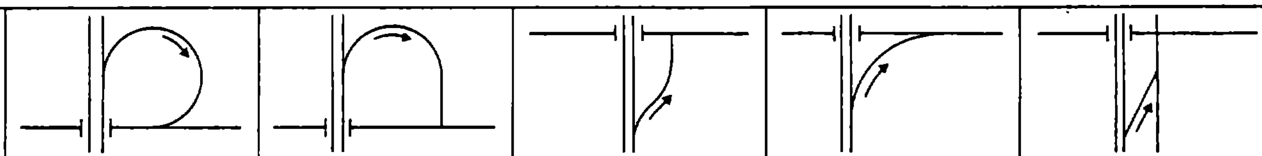
PROBLEMS

- Excessive delay on off-ramp
- Vehicle queues on off-ramp and/or freeway
- Rear-end accidents on off-ramp and/or freeway

FUNCTIONAL OBJECTIVES OF SOLUTIONS

- Increase capacity of crossroad ramp terminal and/or arterial
- Increase space available for vehicle storage off of mainline freeway lanes
- Reduce traffic volume on ramp

LIST OF POTENTIAL SOLUTIONS



<table>
<tr><th></th><th>Free-Flow Loop</th><th>Controlled-Flow Loop</th><th>Diamond Ramp</th><th>Outer Connection Ramp</th><th>Frontage Road Slip Ramp</th></tr>
<tr><td rowspan="4">Interchange</td><td>Add C-D roadway</td><td colspan="2"></td><td>Add C-D roadway</td><td></td></tr>
<tr><td colspan="2"></td><td>Add loop off-ramp</td><td colspan="2"></td></tr>
<tr><td></td><td>Add outer connection off-ramp</td><td colspan="3"></td></tr>
<tr><td>Add directional off-ramp</td><td colspan="4"></td></tr>
<tr><td rowspan="3">Freeway</td><td colspan="5">Divert demand by improving accessibility on some other route</td></tr>
<tr><td colspan="5">Lengthen upstream weaving area or deceleration lane</td></tr>
<tr><td></td><td colspan="4">Add upstream auxiliary lane</td></tr>
<tr><td rowspan="5">Ramp</td><td colspan="5">Eliminate ramp</td></tr>
<tr><td></td><td colspan="4">Add lanes to ramp</td></tr>
<tr><td></td><td colspan="2">Channelize turning movements</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="3">Lengthen ramp</td></tr>
<tr><td colspan="4"></td><td>Move ramp upstream</td></tr>
<tr><td rowspan="11">Arterial</td><td></td><td colspan="2">Optimize existing signal</td><td></td><td>Optimize existing signal</td></tr>
<tr><td></td><td colspan="2">Install signal</td><td></td><td>Install signal</td></tr>
<tr><td colspan="5">Lengthen acceleration lane on arterial</td></tr>
<tr><td colspan="5">Add auxiliary lane on arterial</td></tr>
<tr><td></td><td colspan="4">Close or move access point to major generator</td></tr>
<tr><td colspan="5">Make arterial one-way</td></tr>
<tr><td colspan="5">Other improvements to increase capacity of arterial (see table 6 for details)</td></tr>
<tr><td colspan="4"></td><td>Make frontage road one-way</td></tr>
<tr><td colspan="4"></td><td>Connect ramp directly to crossroad</td></tr>
<tr><td colspan="4"></td><td>Discontinue frontage road</td></tr>
<tr><td colspan="4"></td><td>Channelize frontage road to prevent weaving</td></tr>
</table>

- Assume that the improvement will reduce accident rate to the statewide average determined by the agency; and

- Assume that the improvement will reduce the accident rate to an average accident rate determined from the literature.

Each of these approaches has merit and could be the most suitable approach in a particular situation. Therefore, all five approaches have been retained and the choice of the most suitable approach in any particular situation is left to the user.

The potential importance of air pollution and noise analyses to some interchange rehabilitation decisions is stressed in the recommended procedures and it is recognized that other factors, which cannot be quantified, will also influence interchange rehabilitation decisions.

E. Evaluate Alternatives and Select the Best

The guidelines for evaluation of alternatives encourage the use of analytical techniques to compare alternatives, although they recognize that the choice between alternatives rests heavily on the engineer's judgment. The net return method--a conventional engineering economic analysis technique--is recommended to examine trade-offs between factors that can be quantified in monetary terms. Factors included in the net return analysis are: construction costs, travel time (delay) costs, vehicle operating costs, accident costs, and other costs. Nonmonetary factors are considered on the basis of engineering judgment. The engineer is urged to record the advantages and disadvantages of each alternative design in a formal report or memorandum to document the selection of an alternative.

F. Implement Improvement and Evaluate Effectiveness

The final step of the interchange rehabilitation process is to implement the selected improvement project and, subsequently, to evaluate its effectiveness. The objective of an effectiveness evaluation is to compare the actual effects of the project with its predicted effects. Techniques for both operational and safety effectiveness evaluations are recommended. Two simple statistical procedures for safety effectiveness evaluations are recommended: a graphical procedure based on the Chi-Square test and an analytical procedure based on the two-sample t-test. Feedback from the evaluation of completed projects will enable the anticipated effects of planned projects to be more accurately quantified in the future.

III. VOLUME III - EVALUATION OF INTERCHANGE REHABILITATION PROJECTS

Volume III presents evaluations of 40 freeway-arterial interchange rehabilitation projects recently completed by state highway agencies. The interchange rehabilitation project evaluations were useful to the study because they: (a) illustrate the broad range of operational and geometric conditions under which interchange rehabilitation projects are considered; (b) provide measures of operational and safety effectiveness that can be used to estimate the effectiveness of similar projects; and (c) provide practical insight into the problems and data limitations encountered by highway agencies in considering interchange rehabilitation decisions. For these same reasons, they are of interest to highway agency engineers involved in the design of interchange rehabilitation projects.

A. Selection of Interchange Rehabilitation Projects

Operational and safety data were collected concerning 40 selected interchange rehabilitation projects in five states. The cooperating state highway agencies were chosen on the basis of: (1) extensive urban freeway systems that were likely to include an adequate sample of interchange rehabilitation projects; (2) geographical distribution between major regions of the U.S.; and (3) interest in the goals and objectives of this contract. Five States agreed to cooperate in the data collection. These were: California, Florida, Illinois, Michigan and New York.

Forty (40) improvement projects at freeway-arterial interchanges in these five states were selected for detailed study. The projects were selected to span a range from minor geometric improvements (such as increasing the length of speed-change lanes, widening ramps, etc.) to major geometric improvements (such as installation of collector-distributor roads or some other change in the basis interchange configuration). It was found that the vast majority of rehabilitation projects (34 out of 40) at freeway-arterial interchanges involve modification of the crossroad ramp terminals. The crossroad ramp terminals appear to be the major source of operational and safety problems at freeway-arterial interchanges. Almost as many projects also involved modifications to the arterial crossroad or to individual ramps. Very few interchange rehabilitation projects involved modification of the freeway ramp terminals or the mainline freeway itself.

B. Data Collection

Physical, operational, safety and cost data were collected on 40 interchange rehabilitation projects in these States. Two forms of data were collected: (1) office documents concerning each interchange and its associated improvement projects, and (2) field data at each interchange site. Physical and project-related data obtained from office documents included construction plans showing geometrics before and after improvement; project reports and/or file memoranda justifying the improvement; documentation of improvement alternatives considered by the highway agency; and starting and completion dates of improvement construction. Operational data included ADTs; hourly traffic counts; turning movement counts; capacity analyses from before and after the improvement; and a description of the traffic operational problems at the interchange that brought about the highways agency's decision to rehabilitate that location. Safety data included a description of safety problems that led to the improvement project and detailed accident data from the agency's computerized accident records system. Cost data included the total construction cost of the interchange rehabilitation project. Field data collected at the study interchanges included site photographs, daytime observations, nighttime observations and operational studies.

C. Operational Analyses

An evaluation of the effect of each interchange rehabilitation project on traffic service was conducted. In each case, the operational evaluation focused on the portion of the interchange that was improved. Whenever possible, explicit use was made of traffic volume data obtained from the cooperating highway agencies to evaluate peak hour Levels of Service before and after improvement. Estimates of missing data were made in some cases where a reasonable basis for judgment was available.

The most frequent kind of operational improvement involved crossroad ramp terminals. In most cases, detailed signal phasing and timing data were not available to apply the Level of Service evaluation procedures of the Highway Capacity Manual. Therefore, operational evaluations of crossroad ramp terminals were based on critical movement analysis. Operational evaluations of mainline freeway segments and weaving areas were conducted using the Highway Capacity Manual procedures.

The results of the operational analyses are presented in case study evaluations of each interchange rehabilitation project. No attempt has been made to summarize the operational effects of the 40 interchange rehabilitation projects taken as a whole, because these results are only meaningful in relation to the geometric and traffic conditions and the nature of the improvement project at the specific interchange under study.

D. Safety Analyses

An accident data analysis was performed to evaluate the safety effectiveness of each of the 40 interchange improvement projects. A detailed description of each accident at each study interchange was obtained from computerized records systems for at least one year (and, preferably, three years) before and after each improvement project. Collision diagrams were prepared to compare accident patterns before and after each project. The percent reduction (or increase) in accident rate was determined for each project and statistical tests, including the t-test and analysis of variance, were used to determine whether the reduction (or increase) in accident rate was statistically significant.

Sufficient accident data to perform a statistical analysis were available for 37 of the 40 interchange rehabilitation projects. These analyses found 13 projects ranging in accident rate reduction from 36.2% to 78.2% that were statistically significant. The improvement projects were also grouped into two categories--major geometric modifications and minor ramp and/or crossroad modifications. The average major geometric modification project resulted in a 23.7% reduction in accident rate for the entire interchange. The average minor ramp and/or crossroad modification project resulted in a 16.3% reduction in accident rate for the portion of the interchange modified by the project. Thus, the minor rehabilitation projects not only had a smaller percentage accident rate reduction, but also affected a smaller portion of the interchange. The average accident rate reduction for all projects was 18.7%. These results were found to be statistically significant at the 95% confidence level.

E. Evaluation Format

A standard format was established to present the results of the 40 interchange rehabilitation project evaluations. These evaluations have been presented in case study form to familiarize the reader with the original interchange geometrics, the operational or safety problems that led to the improvement, and the type of improvement constructed. The case study of each project has five sections entitled: Background, Operational and Safety Problems, Alternatives Considered, Evaluation and Conclusions. The objectives and content of each section are described below.

1. Background: The Background section of each case study evaluation presents information necessary to understand the operational and safety problems at the interchange. This section usually describes the original interchange configuration, the general character of the freeway and arterial crossroad, and the traffic control devices at the interchange. A plan view of each interchange is presented to illustrate the text description. Aerial photographs are included for 21 of the 40 interchanges to illustrate both the interchange configuration and the surrounding development.

2. Operational and Safety Problems: The Operational and Safety Problems section identifies the specific problems that prompted the State to undertake a rehabilitation project at a particular interchange. We have described the problems in our own words, but closely follow the views expressed by the State in project reports, file memoranda and informal discussions with the project staff.

3. Alternatives Considered: The case study alternative solutions considered by the State as countermeasures to the existing operational and safety problems are described in this section. The greatest emphasis is placed on the description of the alternative actually implemented, explaining the improvement that was made and why it was expected to alleviate the observed problems. When documentation identified other alternatives considered by the State, these alternatives are described and the reasons cited for their rejection are presented. Thus, the Operational and Safety Problems and the Alternatives sections, taken together, constitute a short history of the project and the decision-making process. This history is more complete for some locations than for others because of variations in the amount of documentation available.

4. Evaluation: The Evaluation section presents the results of the operational and safety evaluations conducted by MRI. The procedures used for these evaluations are discussed above. The evaluation results represent MRI's findings and do not necessarily reflect the views of FHWA or the appropriate State agency.

5. Conclusions: The final section of each case study briefly summarizes the effectiveness of each interchange rehabilitation project, based on the operational and safety evaluations.

IV. VOLUME IV - RESEARCH REPORT

Volume IV documents all activities performed as part of this contract. The research report summarizes both the recommended design procedures for interchange rehabilitation projects presented in Volume II and the interchange rehabilitation project evaluations presented in Volume III. Other material presented in the research report includes a review of relevant literature; a review of current highway agency practice for design of interchange rehabilitation projects; a brief description of the development of the recommended procedures and guidelines; and, an annotated bibliography of the literature reviewed during the contract.