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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SYNTHESIS 307

Systems Engineering Processes for Developing Traffic Signal Systems

A Synthesis of Highway Practice

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A Synthesis of Highway Practice

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SUBJECT AREAS
Highway Operations, Capacity, and Traffic Control

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2003
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NCHRP SYNTHESIS 307

Project 20-5 FY 1998 (Topic 30-01)
ISSN 0547-5570
ISBN 0-309-06950-5
Library of Congress Control No. 2003100041

Price $17.00

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The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street
Washington, D.C. 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

FOREWORD

By Staff
Transportation
Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

The synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This report of the Transportation Research Board will be of interest to local, regional, state, and federal officials, as well as to other transportation professionals who work with them in the area of traffic engineering. This report presents a general discussion of the techniques employed in systems engineering, as well as techniques available to traffic systems engineers. The report identifies systems engineering methodologies used by practitioners for traffic signal systems, and gives an indication of the extent to which they are used.

Information was derived by means of a survey of state transportation agencies in combination with a literature review.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

Robert L. Gordon, Dunn Engineering Associates, was responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Bruce Abernathy, P.E., Ph.D., Vice President, Communications and Transportation Systems, Bucher, Willis, & Ratliff Corp.; Richard A. Cunard, Engineer of Traffic and Operations, Transportation Research Board; Nathan H. Gartner, Professor of Civil and Transportation Engineering, University of Massachusetts, Lowell; Stephany Hanshaw, Smart Traffic Center Facility Manager, Virginia Department of Transportation; K. Larry Head, Ph.D., Siemens Intelligent Transportation Systems; Arif Kazmi, Manager/Engineer Traffic Design, Arizona Department of Transportation; Eva Lerner-Lam, President, Palisades Consulting Group, Inc.; Robert Rupert, Federal Highway Administration; and Thomas Urbanik II, Professor, University of Tennessee.

This study was managed by Donna Vlasak, Senior Program Officer, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Stephen F. Maher and Jon Williams, Managers, Synthesis Studies. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

SYSTEMS ENGINEERING PROCESSES FOR DEVELOPING TRAFFIC SIGNAL SYSTEMS

SUMMARY

This synthesis presents a general discussion of the techniques employed in systems engineering. Systems engineering is generally considered to encompass the project life cycle, starting with problem definition and continuing through design, construction, testing, operation, and maintenance. It is an interdisciplinary approach and means to enable the realization of successful systems. Systems engineering techniques available to traffic signal systems engineers are discussed.

Key processes have been identified in the following traffic signal systems engineering areas:

- Goals and problem definition,
- Identification of constraints,
- Planning structure for identification of requirements,
- Traffic signal systems design engineering
  - Need for traffic signals,
  - Signal timing,
  - Requirements for signal coordination,
  - Selection of type of traffic signal systems control,
  - Communication systems,
  - Intersection field equipment,
  - Local intersection control strategies,
  - Preemption,
  - Transit priority,
  - Alternatives evaluation,
  - Systems procurement,
  - Operations and logistics, and
  - Project evaluation.

Systems engineering methodologies used by practitioners for traffic signal systems and an indication of the extent to which they are used are also identified. System methodologies related to the selection of objectives, alternatives evaluation, system procurement, operations, logistics, and project evaluation are described.

Summaries of existing practices are provided. These are comprised of responses to a survey questionnaire distributed to state transportation agencies to identify the system processes used by practitioners. Responses indicate that available methodologies are not used by practitioners for a significant number of functions because:

- The methodologies are not known by the practitioners or are not available in a user-friendly format.
- Organization practices and/or standard specifications limit the options available to designers. Organization practices are often designed to optimize operations for an agency. Most methodologies optimize for a particular project.
- Issues such as legacy requirements and resource constraints on operations and maintenance often limit the alternatives available to system designers.

The synthesis finishes with conclusions. A number of shortcomings in currently available traffic systems engineering methodologies are identified. Suggestions to remedy these shortcomings, as well as to better document a number of existing methodologies are provided.

CHAPTER ONE

INTRODUCTION

PURPOSE

This synthesis summarizes the systems engineering processes and methodologies, including those that have been developed and used by transportation agencies. It reports on the traffic engineering community's experience with various systems engineering approaches. The major aspects of the synthesis study are as follows:

- Definition of systems engineering and identification of the general processes, steps, and methodologies commonly used in industry.
- Relation of these processes to traffic signal systems.
- Potential requirements for traffic signal systems processes.
- Existing traffic signal systems processes and deficiencies.
- Results of a survey of transportation agencies to identify the practices currently used, the extent to which they are used, and user satisfaction with the results.
- Additional information that the survey respondents feel is required.
- Relative importance of various issues in traffic signal systems engineering.
- Recommendations for the development of additional methodologies and documentation.

BACKGROUND

Transportation agencies are developing, redesigning, or upgrading traffic signal systems using a number of different processes with varying degrees of success. Figure 1 highlights the city and county of Denver, Colorado's

FIGURE 1 The city and county of Denver (Colorado) Public Works Department maintains a website describing traffic signal upgrades using advanced technologies. (*Courtesy*: City and County of Denver Public Works Department.)

program for upgrading its signal system. Systems engineering processes have been successfully applied to the design of similar complex systems in other industries. Systems engineering logically identifies requirements and ensures that the resulting systems satisfy those requirements throughout their life cycle. Such processes can aid transportation agencies in the planning, design, operations, and maintenance of their systems in a manner that supports interoperability and growth.

Chapter two presents systems engineering approaches, definitions, and key resources. Chapter three provides an overview of various systems engineering approaches based on a review of the relevant literature and current methodologies used by state and local organizations. Chapter four reviews the current state of the practice considering the extent to which operational agencies use systems engineering. Chapter five summarizes the results of current, formal engineering practices in planning and evaluating traffic signal systems by the surveyed organizations. Chapter six presents a summary of the findings. Suggestions are offered to resolve current shortcomings and to prepare a user-friendly document for practitioners. Abbreviations used in the report are provided after the references. The appendixes provide a copy of the survey questionnaire (Appendix A) and a list of survey respondents (Appendix B), as well as examples of the Structured Analysis Process (Appendix C) and the Quality Functional Deployment Methodology (Appendix D), Interface Alternatives for Communicating with Controllers (Appendix E), and Methodology for Communication System Selection (Appendix F).