Intelligent Transportation and Evacuation Planning

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A Modeling-Based Approach

Springer

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To my mother, wife and children
Arab Naser, Ph.D.

and

To my boys, Arshya & Ariya
Ali K. Kamrani, Ph.D., P.E.

"***Honesty is the best policy. If I lose mine honor, I lose myself***"
William Shakespeare (1564–1616)

Preface

For most human beings, facing threats is inevitable. While in some cases a threat can be treated or eliminated, the safest course of action in facing threats is often to evacuate the danger zone. This is especially demonstrated by natural threats, such as earthquakes, hurricanes, and fires, where the force of the threat is much greater than any possible human defense. Evacuation of the danger zone can vary in scale from individual movement to hundreds of thousands of people evacuating urban cities. Urban evacuation can be viewed as the process in which evacuees are moved from danger areas to safe zones utilizing transportation resources. This massive movement of population typically exceeds normal demands on transportation resources and thus requires careful planning and optimization. The greatest risk of a poor evacuation plan is that people may lose their lives if they are not given the chance to evacuate on time. Another less severe consequence is a massive number of people trapped for hours on the road.

Recently, evacuation planning and modeling have attracted interests among researchers as well as government officials. This is probably due to the fact that south eastern states of USA are under increasing threat of hurricane attacks every year. The catastrophic loss of human lives after hurricane Katrina, and the massive evacuation "nightmare" before hurricane Rita in 2005 have also initiated several research efforts for the development of evacuation planning strategies and techniques.

This book presents the state-of-art models and methodologies for evacuation planning. These models integrate various scientific disciplines, such as operations research, simulation, traffic engineering, and systems engineering. Simulation and operations research focus on analytical (mathematical) models and methodologies; thus, the main goal of these models is to find the best routes for evacuation. On the other hand, systems engineering applies the planning process at the top level or design phase, while considering all the following stages. Traffic engineering and intelligent transportation research provides understanding of real life characteristic and attributes for the evacuation process.

Intelligent transportation systems (ITS) are complex systems that apply communications and information systems technology in transportation infrastructure to improve the efficiency, safety, and security of the transportation system. The Research and Innovative Technology Administration of the Department of Transportation (U.S. DOT) lists several research initiatives to accomplish effective ITS. ITS improves safety and mobility of transportation systems and increases productivity of human beings by integrating technologies known for communications, vehicles, and infrastructures used in transportation. A broad range of wireless communications is involved in ITS. In late 1980s, importance of addressing life cycle operations and maintenance as part of the systems development was not known. To address these challenges, systems engineering was introduced to the ITS community. ITS include a vast array of possibilities, and to develop effective and reliable initiatives it is necessary to adopt certain proven methodologies as that presented by systems engineering theories.

Systems engineering is a discipline which deals with the development of both the methodologies and required technologies for design and engineering of complex systems. System is an integrated set of components such as equipments, information, materials, human resources, building, software, etc. which work collectively toward producing a desired outcome based on a set of requirements and specifications. For every system there will be multiple subsystems. Systems can be simply classified into static and dynamic. Many are a combination of these two categories. An example of a dynamic system is transportation systems. Usually large and complex systems are difficult to build and maintain. Systems engineering is an effective process which deals with the overall life cycle design of any system. It manages the projects by using tools and methods stage-by-stage from conception, design, manufacturing, operation, and to disposal.

Mathematical models have been developed for evacuation planning. These models range between network optimization and simulation models. Network optimization models aim at finding "*the best*" routes for evacuation. In evacuation planning, the ultimate goal is to clear and move all evacuees to safety in the minimum amount of time. In pursuing this goal these models have to simplify model complexity by adding assumption that may seem contradictory to real life observations. One of these observations is the relation between roads travel time and the number of evacuees on the road. Most network optimization models assume constant travel time whereas realistically travel time depends on traffic density. Simulation models on the other hand are unable to find the optimum routes. Instead several alternative routes and scenarios are evaluated to assist in the planning process. However, the simple structure of a simulation routine facilitates capturing complex system attributes, such as load-dependent travel time.

An integrated methodology that utilizes the advantages of both models is presented in this book. In this methodology, the goal is to find the best routes that minimize total evacuation time while allowing travel time to be a function of roads density. This book also presents state-of-the-arts models and methodologies for evacuation planning based on the systems engineering concepts.

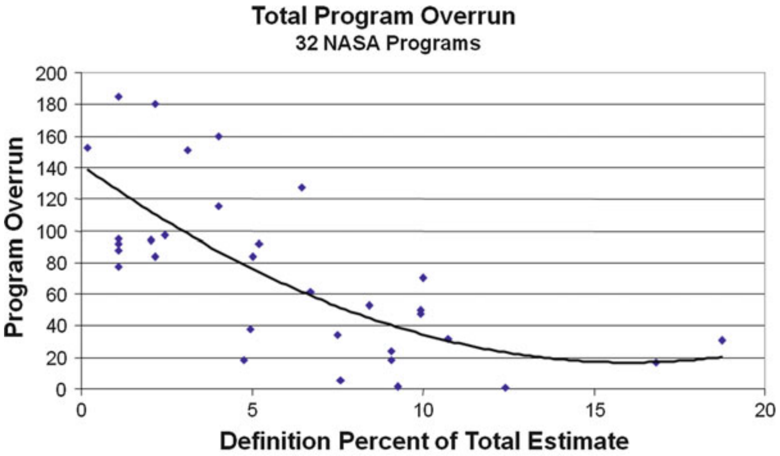

Fig. 1 Cost of project schedule overrun (Understanding the Value of Systems Engineering; Eric Honour; INCOSE 2004)

Chapter 1 presents an introduction to system engineering concept. Systems engineering (SE) is a term that was coined in the 1950s then associated with the process of developing large-scale defense systems. Per INCOSE, systems engineering is: *An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.*

This definition, while very broad, includes all aspects of a project, from development to disposal. It includes various technical and project management activities as well as design requirements analysis and risk management. In a more general sense, systems engineering is a systematic approach to providing a deliverable with minimal correction costs via detailed and synergistic planning with the development of tools that directly support project management. As shown in Fig. 1[1], systems engineering effort has a direct relationship with the project cost. Furthermore, by mitigating and correcting defects at an early stage via the implementation of the opinions of all parties involved in the project, project costs are kept within the planned range. This extensive planning and coordination effort is a critical aspect of systems engineering.

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[1] Understanding the Value of Systems Engineering; Eric Honour; INCOSE 2004.

Chapter 2 discusses the application of systems engineering in planning and developing of ITS. The systems engineering process model that is commonly emerging in developing ITS projects is the “V” model and has hence become the standard model per the DOT and FHWA.

Since its creation in the 1980s, the “V” model has taken many different forms and refinements. Namely, the wings of regional architecture(s), feasibility studies, operations and maintenance, changes and upgrades, and retirement/replacement have been added by the transportation sector as an adaptation for its use in the systems engineering of ITS projects. These additions show how project development fits within the entire ITS project life-cycle. For this particular “V” model, from left to right the “V” starts with parameters that involve initial identification of needs. These parameters include the regional ITS architecture, feasibility studies, and concept exploration. The central section of the “V” shows parameters of the systems engineering process that involve defining the project, implementing work, and lastly verifying work completed. At the far right, close-out processes include handing over the system to operations and maintenance, and from there maintaining, upgrading, and/or ultimately replacing the system. As with any infrastructure project, it is important to consider the entire life-cycle. Hence, the wings of the “V” are a key addition that brings the systems engineering of ITS projects full circle. It is clear, by moving from left to right, that the systems engineering approach starts relatively basic and generalized, then moves to highly detailed technical processes, and finally back to full spectrum validation. Further, the “V” is arranged such that quality is assured via verification and validation by linking the left and right sides of the “V” together. To properly achieve detailed design, the larger system is broken down into subsystems, and those subsystems are then decomposed into individual components. As the system is broken down into smaller and smaller pieces, the details of the design and the requirements of the individual components are clearly defined.

Thus, as the systems are broken down, a series of traceable and interlinking documents are generated that set standards for testing, verification, and validation at the system, subsystem, and component levels. These specification documents, while assuring quality, also promote project management. Another crucial component of the systems engineering approach to designing ITS projects is that by decomposing the overall system into smaller and more detailed systems, there is an inherent relationship established between all of the individual stages of the systems engineering process as well as the individual components of the system and subsystems. By documenting and establishing this interrelationship, called *traceability*, project and system requirements are developed intrinsically as part of the design. This is a critical concept of systems engineering that allows the designer to be certain that the system is delivered with the initial needs established at the beginning of the project, and throughout the design stages of the systems engineering process. For example, traceability may include relating a requirement to the subsystem or components that will implement a requirement in the overall system. This traceability ensures that a system or project need will be met through a smaller subsystem requirement.

Chapter 3 outlines the evacuation planning process and introduces the analytical representation of the evacuation models. Evacuation planning and modeling have increasingly attracted interests among researchers as well as government officials. These research efforts use the latest achievements in a number of various disciplines, such as operations research, simulation, and transportation engineering. Evacuation planning involves an iterative process to identify the best routes and to estimate the time required to evacuate the areas at risk. Methods typically used for evacuation planning includes *analytical models* to express the route choice and traffic propagation using mathematical equations and *simulation-based models* to describe the traffic conditions and pattern based on a set of rules. A state-of-the-art review for recent analytical and simulation models and methodologies for evacuation planning is also presented in this chapter.

Chapter 4 presents the proposed integrated methodology for evacuation planning. In this methodology, an optimization algorithm is integrated into a traffic simulation routine in order to determine the best routes for evacuation. Simulation models can predict travel time as a function of flow but they act merely as a tool for evaluating different scenarios and devising recommendations. The main drawback in simulation models is that they do not have the capability of identifying the "*best*" routes (optimization) and therefore a model that integrates an optimization and a simulation routine into one algorithm is proposed and used for evacuation route planning. In the proposed approach, first a traffic simulation model is developed that can propagate a flow along the arcs and predict travel time as a function of arcs load. Then an optimization model is developed to minimize total evacuation time. It is based on network optimization formulations and principles. The next step in the methodology will integrate both models. The main idea is to discretisize the time space and to solve both routines at each time step.

Finally, several sample cases using the proposed methodology are presented in Chap. 5. The purpose of this chapter is to test the premise of the presented methodology. To achieve this goal, a traffic simulator is developed that evaluates the optimum solution obtained by a constant travel time algorithm. The application considered is evacuation planning, and therefore, the selected constant travel time algorithm is for the quickest transshipment problem.

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