

ABSTRACT

In this report, we describe our work in developing models, methodologies and simulations for network optimization problems in the planning, analyzing and optimizing of large scale (air) transportation networks with time window constrained routing and scheduling. Our research is motivated by certain problems encountered in the United States military's strategic mobility analysis, in general, and specifically in Mobility Analysis Support System (MASS) of the USAF's Air Mobility Command (AMC).

This work is performed within the framework of Semantic Control paradigm, a three-layer supervisory hierarchical structure. In this context a new mathematical programming model, called Network Optimization Mobility Analysis (NETO), for the mobility analysis system is formulated as a pickup-delivery vehicle routing and scheduling problem with time-window constraints (PDPTW). In order to cope with the computational complexity inherent in the PDPTW formulation, we have developed and implemented a novel algorithm called SP-CGCE (set-partitioning formulation, column generation and column elimination). The computational results indicate a promising and robust performance by this solution algorithm. The problems tested/solved here involve many more nodes than similar problems previously attempted. The test results indicate that the SP-CGCE algorithm is at least twice as fast as currently available column generation-branch and bound schemes; this increase in speed is due to the effectiveness of the column elimination process used after the completion of the linear programming phase to obtain integer solutions.

In particular, the focus of this report is the optimal *requirement studies* problem, where the following question is addressed: "How many of what types of transportation assets are necessary to move cargo to the specified destinations, satisfying a particular desired closure schedule?"

1. INTRODUCTION

The Center for Optimization and Semantic Control at Washington University in St. Louis has been conducting research jointly with the Air Mobility Command of the United States Air Force with respect to the Mobility Analysis Support System. In the past, we have solved several large-scale, time-dependent, mixed variable, uncertain and complex problems encountered in aerospace and decision support domains [1-5,8,9] using the Semantic Control paradigm (see below). The Center researchers approach the solution of such problems using a judicious combination of classical mathematical methodologies (mathematical programming, computational geometry, control theory, game theory, stochastic, etc.), together with Artificial Intelligence paradigms such as Planning, Search, Fuzzy System Theory, Neural Networks, Rule Based Systems, and Logic Programming [8-9]. Our approach is based on the Semantic Control paradigm—a three-level hierarchical structure (Figure 1-1) consisting of:

- an Identifier, which processes the list of requirements, known as the time-phased force deployment data/document (TPFDDs³), and interprets the available information;
- a Goal Selector, which generates and evaluates several plans; and
- an Adapter, which implements the optimal plan.

For example, the Identifier module consists of neural networks for processing, pattern recognition and optimization of TPFDDs. Once trained, neural networks identify requirements and consequently recommends assignment and allocation of aircraft in order to deliver those requirements. Currently, given a requirement containing:

- i) a commodity code (such as outsize, oversize, bulk, passengers),
- ii) an onload-offload region, and
- iii) the percent of the total requirement to be moved,

the neural network recommends the appropriate assignment and allocation of aircraft to deliver that requirement.⁴ The neural network module serves as a "pattern recognizer" in order to reduce the complexity; in addition to this, we are currently developing a "fuzzy model" of the air transportation which incorporates leeways in the constraints and goal. This should prove very useful since several quantities such as MOG (maximum on

Modeling and Optimization of Mobility Analysis: Optimal Requirement Studies¹

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MODELING AND OPTIMIZATION OF MOBILITY ANALYSIS

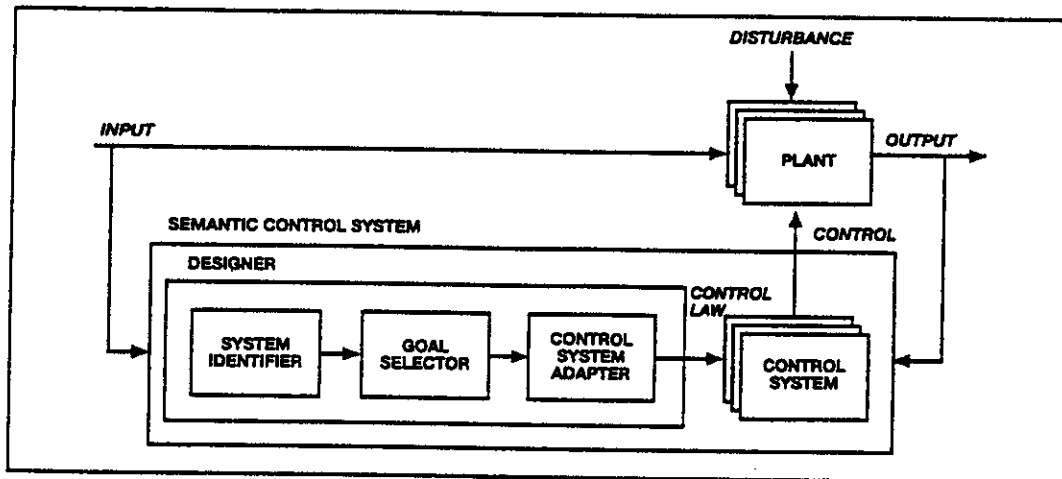


Figure 1-1: A semantic control system consists of a System Identifier, a Goal Selector, a Control System Adapter, and one or more control systems/laws.

ground) are not crisp variables. This approach admits such uncertainties as part of the model, thus reducing labor-intensive post-optimality sensitivity analysis. These issues will not be discussed further in this report. We refer the interested reader to [8,9]. This report deals mainly with algorithm development and simulation of exact mathematical programming and optimization methodologies (cf. [6] and [10]) for the Goal Selector module of the Semantic Controller. More specifically our objectives in this report are:

- 1) reviewing existing mobility analysis models and addressing their various limitations,
- 2) presenting the new mobility analysis model NETO formulated as a PDPTW problem,
- 3) discussing our solution algorithm (SP-CGCE) and comparing its performance to other published results,
- 4) providing a brief overview of the system implementation and related issues,
- 5) giving an example of the optimal requirements studies problem, and
- 6) concluding with a discussion of other relevant problems addressed by this approach as well as related open problems.

This report is divided into six sections:

- Section 1 and subsections 1.1 through 1.3 present background information on the strategic mobility analysis and limitations of current simulation and mathematical models.
- Section 2 discusses the system architecture and the components of our model NETO.
- Section 3 focuses on the mathematical formulation, algorithmic details, and performance analysis. The mathematical model for our formulation is given in more detail in Appendix B.
- Section 4 presents system implementation and gives an example of the optimal requirements studies problem.
- Section 5 discusses other related problems and defines future work.
- Section 6 concludes with a brief summary.

1.1. STRATEGIC MOBILITY ANALYSIS: BACKGROUND [7]

Various objectives of strategic mobility analysis are grouped into three broad planning categories:

- Resource Planning: long-range deployment planning and programming.