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# Simulation studies of traffic management strategies for a long tunnel

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ABSTRACT

The Hsueh-Shan Tunnel, the fifth long tunnel in the world, has a total distance of 12.9 km. After the opening of the tunnel, traffic demand between Taipei and I-Lan increased dramatically. However, efficient traffic management strategies for the Hsueh-Shan Tunnel need to be developed and evaluated accordingly in order to alleviate traffic congestion due to high demand and/or possible incidents. The research aims to evaluate possible traffic management strategies based on available control devices through simulation-assignment techniques. Possible traffic management strategies, including access control (ramp metering), lane control and route guidance, are proposed and examined through numerical experiments. In order to analyze traffic management strategies based on simulation, DynaTAIWAN, a simulation-assignment model, is developed to simulate traffic control strategies and reflect driver's response to route guidance. Several indexes, including vehicle queue length, average density and average speed, are used in the comparisons. The results show that ramp control provides the best benefits compared to other strategies and can reduce the average queue length by about 18%.



## 1. Introduction

Taiwan is a mountainous island, and tunnels play an important role in developing new freeways. The length of the freeway connecting Taipei and I-Lan in the northern part of Taiwan is about 55 km, and 25% of the freeway is tunnel. The Hsueh-Shan Tunnel, the fifth longest tunnel in the world, has a total distance of 12.9 km. The design speed is 80 km/h, and there are two lanes for each direction. The Tunnel opened on June 16, 2006. After the opening of the tunnel, traffic demand between Taipei and I-Lan increased dramatically and average daily demand has reached 50,000–60,000 passenger car units (PCU) (TANFB, http://www.freeway.gov.tw/). Several methods have been proposed to ensure safety in road tunnels, and these methods are classified into two categories (Mashimo, 2002), namely, reduction of the probability of an incident and reduction of the consequence of events such as accidents and fires. The latter is achieved though a highly automated surveillance and control system. However, how to utilize new traffic control devices for traffic management is a critical issue.

Traffic accidents in tunnels have been extensively studied. Ma et al. (in press) conducted a study of traffic accidents based on police-reports from four tunnels and summarized temporal and spatial distribution characteristics of traffic accidents. The analysis showed that most of the problems are speeding and the failure to maintain a safe distance to the vehicle in front. Bari and Naser (2005) presented simulation studies of smoke from a burning vehicle in a tunnel and the time-averaged equations for velocity, pressure, temperature, and mass fraction of emission are solved. Their simulation results showed that the emissions released from the vehicles in the jam posed a threat to human health and quick evacuation of the passengers is essential in the event of a fire in the tunnel.

Under Intelligent Transportation Systems (ITS), traffic management strategies can be developed based on new detection technologies and traffic control devices. Real-time traffic conditions could be observed through traffic data, such as flow, speed, and occupancy, from monitoring and surveillance systems. Thus, real-time traffic operations or traffic management strategies could respond to real-time traffic conditions to avoid and/or relieve traffic congestions.

In order to avoid possible loss and delay due to special characteristics, tunnel operation and management needs to be carefully developed and planned in advance in case of any possible incidents. Since there is no prior experience in managing long tunnels in Taiwan, especially under very high demand, advanced traffic management strategies for long tunnels need to be evaluated accordingly in order to alleviate traffic congestion due to high demand and/or possible incidents (Jha et al., 1999; Ben-Akiva et al., 2001, 2003).

Main traffic management devices in the Hsueh-Shan Tunnel include Variable Message Signs (VMS), Lane Control Signal (LCS), and

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Changeable Speed Limit Signs (CSLS). Traffic management strategies can be developed and evaluated based on these basic devices. Evaluation studies can broadly be classified into two categories: field observations and simulations. Field evaluation is time-consuming, prohibitively expensive and often not practical. Simulation-based evaluation is an essential complement to field studies. Although simulation models can be used to simulate temporal and spatial vehicular flow distribution in traffic networks based on a wide range of alternatives, evaluation of traffic management strategies requires a realistic representation of traffic flow, control systems, and drivers' response behavior to the control devices.

Prior research studies based on simulation techniques focus on freeway control, especially ramp metering control, Integrated Corridor Management (ICM), evacuation management, and emergency management. Papageorgiou et al. (1991) used METANET macroscopic traffic simulator to test Asservissement Linéaire d'Entrée Autoroutière (ALINEA) and METALINE control strategies in simulation studies and the results showed that ALIENA provides better performance than other ramp metering techniques. Stephanedes and Chang (1993) used TRAF simulation software on the I-94 freeway corridor in St. Paul, Minneapolis to test optimal control approaches for ramp metering. Hellinga and Van Aerde (1995) simulated ramp metering using INTEGRATION. Matson and Daniel (1998) used microscopic simulator in the evaluation of a time-of-day, fixed time metering strategy on the I-75 northbound corridor in the Atlanta metropolitan area. Ben-Akiva et al. (2003) presented an evaluation of freeway traffic control based on a microscopic simulation, MITSIM. The simulation studies were performed for access, route, lane, and integrated control, and the results show that a system design for integrated traffic control needs to be developed. Balakrishna et al. (2008) presented a simulation-based framework for the modeling of transportation network performance under emergency conditions, and DynaMIT is applied to illustrate the benefits of network management strategies. Shelton et al. (2008) presented the evaluation of managed lane strategies applied to freeway ramps under incident and congestion management based on DYNASMART-P (DYnamic Network Assignment-Simulation Model for Advanced Road Telematics for Planning).

These research papers and projects provide simulation studies for modeling vehicular flows in freeway systems under fixed demands, especially for ramp metering control strategies. However, drivers might choose different routes when facing congestion and drivers might follow route guidance information provided by traffic management centers (TMC). In order to evaluate route guidance strategies, driver en-route decisions need to be developed and incorporated with traffic simulation models.

In summary, many of the existing simulation studies of freeway traffic control use macroscopic traffic models; however, these models may not be sufficient for evaluating possible traffic management strategies, such as lane control and route guidance. Also, these models are not able to reflect driver decisions in the network when facing travel information. Microscopic simulation can capture vehicles' movements in detail; however, these models may be too detailed for network-level studies. The computational requirements, such as memory and computation time, for network-level studies based on microscopic simulation models are very high, thus these models cannot be applied for large networks and cannot be performed under real-time considerations. Also, in order to analyze traffic management strategies based on simulation, several important functions are essential: simulation of traffic control strategies and the ability to reflect driver's response for route guidance.

The research aims to evaluate possible traffic management strategies for the Hsueh-Shan Tunnel in Taiwan. The evaluation is achieved through DynaTAIWAN, a mesoscopic simulation-assignment model (Hu et al., 2007). DynaTAIWAN is employed to evaluate traffic management strategies, including access control, lane control and VMS, for freeway systems with long tunnels. Different traffic management scenarios are proposed and evaluated through simulation experiments. Measure of Effectiveness (MOE) indexes, including vehicle queue length, average density and average speed, are used to make appropriate comparisons.

A brief review about the Hsueh-Shan Tunnel is given in the next section. The proposed framework, DynaTAIWAN and control strategies are described in Section 3. Simulation experiments based on empirical data and numerical results, are discussed in Section 4, followed by concluding comments.

## 2. The Hsueh-Shan Tunnel

The Hsueh-Shan Tunnel is the longest tunnel in South-East Asia (TANFB, http://www.freeway.gov.tw/; Lin, 2005). The Hsueh-Shan Traffic Management Center is operated to minimize the recurrent and non-recurrent congestion in the Hsueh-Shan Tunnel. Possible traffic management operations include road user's information display, mainline speed limit control, tunnel Lane Control Signal, and Ramp Metering Signal. Several basic facilities, as illustrated in Fig. 1, are described as follows:

(1) Data collection:
   - Vehicle detector (VD): vehicle detectors (VD) are installed every 350 m.
   - Meteorological conditions monitoring (fog and rainfall) – Rain Detector
   - Closed Circuit Television (CCTV): CCTV are installed for every 175 m.
   - Emergency Telephone (ET): ET are installed for every 175 m.

(2) Information display and dynamic control signs
   - Changeable Message Sign (CMS): CMS are installed for every 1400 m, with a total of 16.
   - Lane Control Sign (LCS): LCS are installed for every 350 m. The green arrow ↓ indicates "pass". The red "X" indicates that the lane needs to be closed.
   - Changeable Speed Limited Sign (CSLS): CSLS are installed for every 350 m.
   - Ramp Metering Signal
   - Fog Sign

(3) Other equipment:
   - FM radio
   - Loudspeaker Equipment

## 3. Methodologies

### 3.1. Research framework

The research establishes a formal procedure for evaluating traffic management strategies and focuses on how to alleviate congestion for the Hsueh-Shan Tunnel during traffic incident conditions. The research framework is illustrated in Fig. 2. Within the simulation framework based on DynaTAIWAN, three basic data sets include network structure, traffic control, and time-dependent origin–destination information to clarify trip demand. Incidents can be simulated through the reduction of road capacity. When the traffic network is experiencing congestion due to incidents, the traffic management center needs to implement appropriate strategies, such as information display and route guidance via VMS, ramp closure, ramp metering, and open shoulder-lane. Traffic flow distributions depend on traffic management strategies as well as tripmaker's response. Evaluation of traffic management strategies