Monte Carlo Simulation-Based Benefit-Cost Analysis to Support ITS Investment with Consideration of Connected Vehicle Technology

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INTRODUCTION

- Decisions to invest in alternative ITS technologies is expected to increase in complexity, particularly with the introduction of the connected vehicles (CV) and automated vehicles (AV) in the coming years.
- Traditional alternative analyses based on deterministic return on investment analysis are unable of capturing the risks and uncertainties associated with the investment problems.
- In addition, these methods can not account for parameters that can not be converted to dollar values.
- This study utilizes a combination of a stochastic return on investment and a multi-criteria decision analysis (MCDA) method referred to as the Analytical Hierarchy Process (AHP) to select between ITS deployment alternatives, considering emerging technologies.
- The approach is applied to the selection between CV-based and legacy detection (point detector) technology to support the freeway traffic data collection and monitoring services, which includes incident detection and travel time estimation.

METHODOLOGY

- A four level decision making hierarchy according to the AHP method is defined for the purpose of alternative selection in the coming years.
- The four objectives specified in the AHP analysis are:
  - providing the required functions
  - providing the required performance
  - minimizing the risks and constraints, and
  - maximizing the return on investment.
- The monetizable measures are assessed in the stochastic net present value (NPV) analysis using Monte Carlo simulation and the NPV results are included as a criterion in the AHP analysis. The non-monetizable measures are included as additional measures in the AHP analysis.

Traffic Data Collection and Monitoring

Benefits

- Faster incident detection that results in lower delays:

$$Incident\ Detection\ Benefit_i = (TD_{base} - TD_{alternative}) * VOT * IF_i$$

where, TD_{base} is total delay of the base alternative in veh-hr, $TD_{alternative}$ is total delay of the alternative in veh-hr, VOT is the value of time in dollars, and IF_i is total number of incidents for the i[th] year. (Base alternative: no detection technology)

- More accurate traveler time estimation that results in better diversion decisions.

$$SPDE_{CV} = 25.15 - 19.81 * \cos\left(\frac{V}{C}\right) - 0.75 * \log(MP) - 11.56 * \frac{V}{C}$$

where, $SPDE_{CV}$ is the standard deviation of percentage error based on CV data, V is volume (vph), C is capacity (vph) and MP is the CV proportion.

Costs

- CV deployment costs:
costs were extracted from the Federal Highway Administration (FHWA) tool.

- Point detector costs:
This cost includes capital, replacement, calibration, maintenance, design, and mobilization costs and were taken from FDOT District 6 database.

Monte Carlo Simulation

Abovementioned equations include several stochastic variables that result in uncertainty in the results of the cost benefit analysis. The incident rate, CV market penetration, traffic demand, etc. were varied in the Monte Carlo analysis by expressing these variables as distributions rather than point estimates.

NPV distribution

Criteria ratings by decision makers

AHP Analysis

Alternative Selection

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GOAL

- This Study aims to develop methods to assess the use of connected vehicle data, combined with new algorithms for use as part of a framework to support agencies in the ITS investment decisions.

LITERETURE REVIEW

Widely used MCDA methods

Method	Author/Year
Simple Additive Weighting (SAW	Fishburn , 1697
Technique for Order Preference Similarity to Ideal Solution (TOPSIS)	Hwang et al., 1981
Analytic Hierarchy Process (AHP)	Saaty, 1980

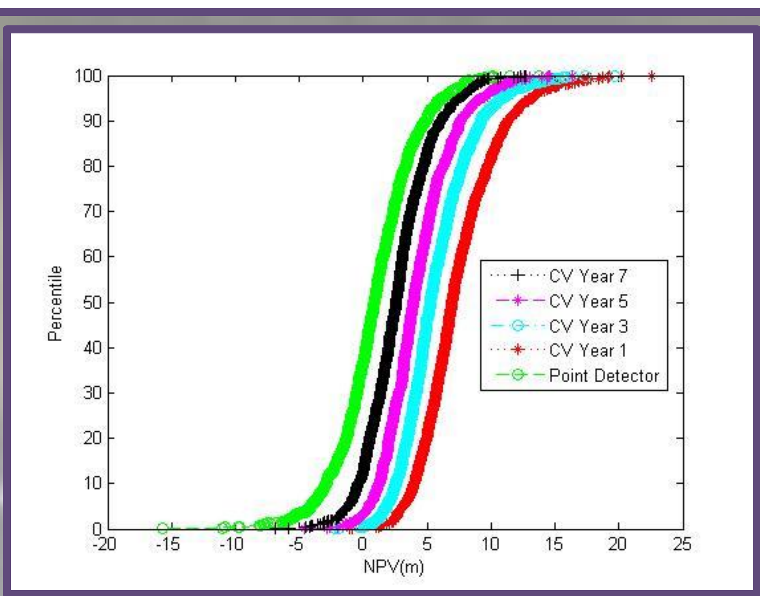
Techniques for incorporating uncertainty into the return on investment analysis

Method	Author/Year
Black Scholes	Black, 1979
binomial lattice	Cox et al., 1979
Monte Carlo Simulation	Boyle, 1977

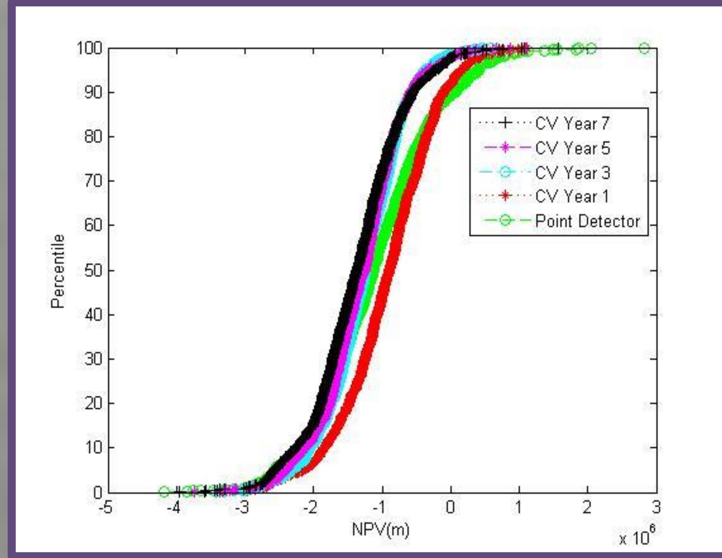
CASE STUDY AND RESULTS

- The case study addresses an investment decision for a 15 mile segment of a freeway corridors in Southeast Florida with two investigated volume demand levels: moderate and light traffic (V/C ratio=0.8 and V/C ratio = 0.4).

Monte Carlo Simulation Results : NPV Distributions



V/C=0.8



V/C=0.4

AHP Application Results : Alternative Selection (CV or Point Detector?)

CV deployment start from year 1						
		Provision of the required functions	Achieving the required performance	Minimizing the risks and constraints	Maximizing the return on investment based on NPV	Final Score
CV	V/C=0.8	0.58	0.60	0.23	0.85	0.56
Point Detector		0.42	0.40	0.86	0.15	0.47
CV	V/C=0.4	0.58	0.55	0.23	0.54	0.45
Point Detector		0.42	0.45	0.86	0.46	0.58

CV deployment start from year 5						
		Provision of the required functions	Achieving the required performance	Minimizing the risks and constraints	Maximizing the return on investment based on NPV	Final Score
CV	V/C=0.8	0.58	0.73	0.37	0.75	0.59
Point Detector		0.42	0.27	0.72	0.25	0.44
CV	V/C=0.4	0.58	0.64	0.37	0.45	0.48
Point Detector		0.42	0.36	0.72	0.55	0.55

CONCLUSIONS

- Utilizing CV data for freeway segments is significantly more cost-effective than using point detectors in detecting incidents and providing travel time estimates about one year after the CV technology becomes mandated on all new vehicles, for corridors with moderate to heavy traffic.
- However, for corridors with light traffic (V/C=0.4), there is a probability of the CV deployment being not effective in the first few years of the CV deployment due to low measurement reliability of travel time and high latency of incident detection, associated with smaller sample size of the collected data.
- The AHP analysis results indicate that the scores of the evaluated alternatives vary depending on stakeholder priorities.