Effects of Mobility, Safety and Emissions on Signal Timing Optimization

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Background and Objectives

INTRODUCTION

The optimization of signal timings has been traditionally based on mobility, with limited consideration of other measures. The goal of this study is to develop a optimization method that can consider mobility, safety, and emissions simultaneously.

OBJECTIVES

- Develop or select from relevant research a set of equations that can be used to predict crashes as a function of intersection and signal control characteristics.
- Develop a methodology for incorporating safety (crashes), emissions and mobility (delay) measures into a single objective optimization function for signal control.
- Implement the proposed method in the Highway Capacity Software module Streets.
- Conduct a sensitivity analysis to gain an understanding of the practical influence and tradeoffs of 22 variables on safety, mobility, and emissions.

Model Components

MOBILITY MODEL

Highway Capacity Manual 6th Edition method for urban arterials

CRASH PREDICTION MODEL

Turner (2012)

$$A_j = b_0 x_1^{b_1} x_2^{b_2} \dots x_n^{b_n}$$

- A is the predicted rate for type j crashes in a 5-year period
- b_0 is a local adjustment factor
- b_i are model coefficients
- x_i are the independent variables

Table 1. Safety model coefficients and details

Factors x_i	Right angle	Left-turn against	Rear-end			Loss-of-control	Other
			small	medium	large		
Through traffic	$x^{0.311}$		$x^{0.447}$	$x^{.496}$	$x^{0.985}$	$x^{0.541}$	$x^{0.262}$
Conflicting crossing traffic	$x^{0.362}$						
Left-turning traffic		$x^{0.155}$					
Degree of saturation		$x^{0.397}$				$x^{0.447}$	
Total number of lanes	$e^{(.356x)}$			$e^{(.243x)}$	$e^{(.459x)}$	$e^{(.144x)}$	
Number of through lanes		$e^{(0.352x)}$					
Total width							$x^{0.027}$
Left-turn storage length		$(1+x)^{-0.124}$	$(1+x)^{-0.259}$		$(1+x)^{-1.142}$		
Presence of shared-turns	1.19						1.26
Shared left-turn		0.72					
Exclusive right-turn lane			1.585				
Intersection depth (m)	$x^{0.602}$						
High speed (> 35 mph)				1.449	0.985	1.57	1.98
Cycle time (sec)	$x^{0.037}$	$x^{-0.683}$				$x^{-0.704}$	$x^{0.354}$
All-red (sec)	$x^{-0.636}$						
Free right turn on red				1.442	1.227	1.17	1.16
Lost time (sec)			$x^{-3.424}$	$x^{-0.209}$	$x^{-1.739}$		
Split-phasing	0.69		5.256	1.57	0.95	2.47	1.21
Full left-turn protection		0.71					
Coordinated	1.31						0.71
Advanced detector	2.06						0.44
Mast arm signal display	0.74						
Median island	0.67	1.22					
Merge on intersection exit						1.47	0.65
Cycle facilities		1.35	0.706	0.753	1.257		
Approach bus bay			1.309	0.908		1.6	1.27
Upstream parking						0.58	0.7
CBD area				0.9	0.819		1.83
Residential area						0.75	

EMISSIONS MODEL

Hadi et al. (2017)

$$CO(g) = 10.875 \times VMT + 3078.297 \times \frac{1}{avgspeed} + 1.470 \times \frac{NumStops}{avgspeed} \quad (1)$$

$$NO_x(g) = 1.241 \times VMT + 185.490 \times \frac{1}{avgspeed} + 0.206 \times \frac{NumStops}{avgspeed} \quad (2)$$

$$EC(joule) = 7.223 \times 10^6 \times VMT + 1.084 \times 10^9 \times \frac{1}{avgspeed} + 2.388 \times 10^6 \times \frac{NumStops}{avgspeed} \quad (3)$$

$$CO_2Equi(g) = 519.1 \times VMT + 77950.6 \times \frac{1}{avgspeed} + 171.6 \times \frac{NumStops}{avgspeed} \quad (4)$$

Implementation In HCS V 7.4 – Streets Module

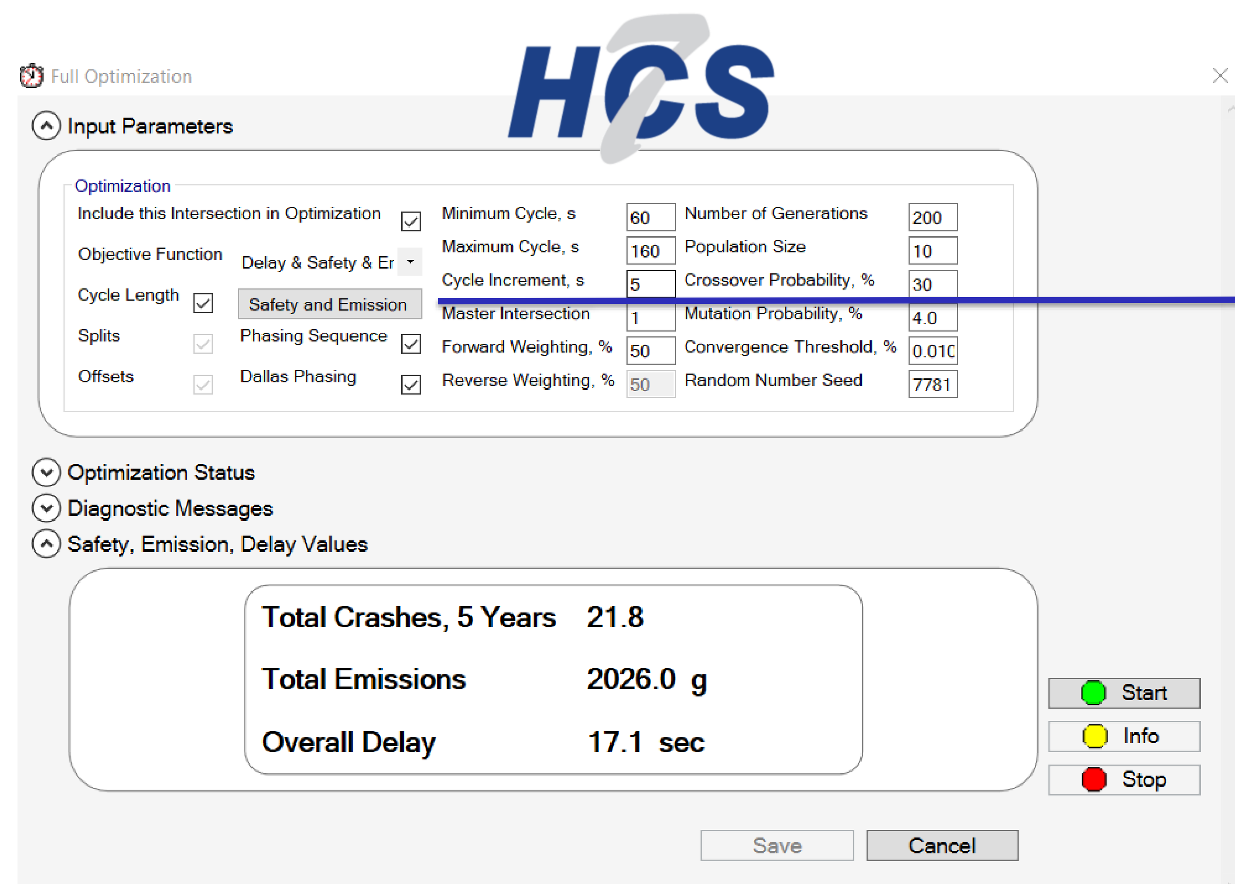

Figure 1. Highway Capacity Software Optimization Screen

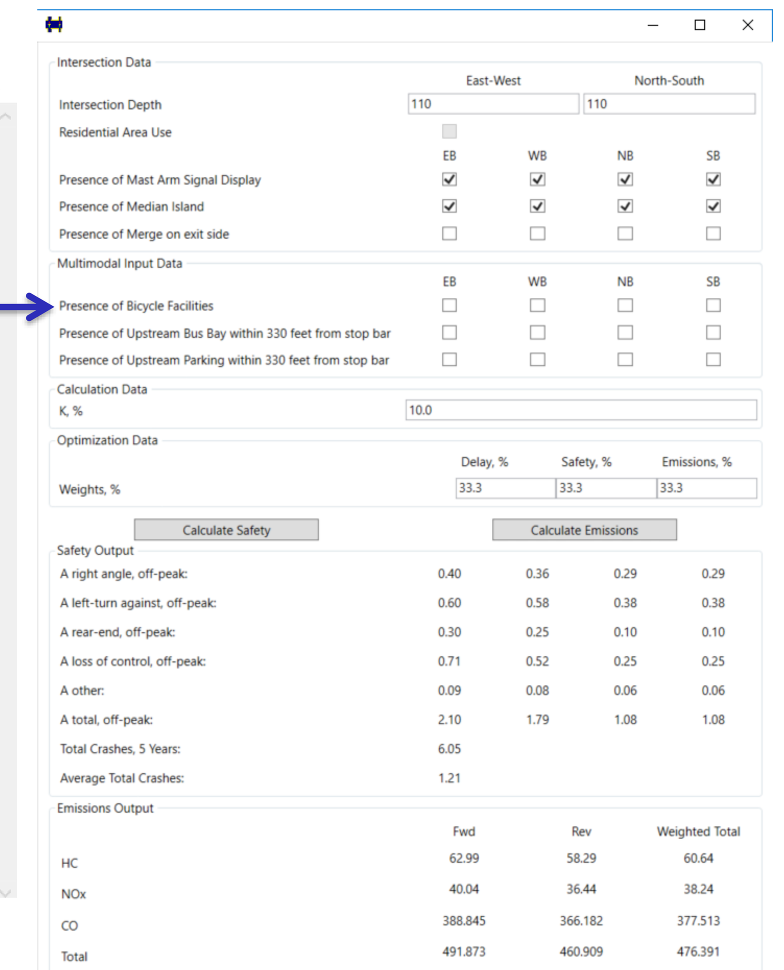

Figure 2. Safety and Emissions Details

OBJECTIVE FUNCTION

$$\text{Min}\left(w_{delay}\frac{f_{delay}-\varepsilon_{delay,good}}{\varepsilon_{delay,bad}-\varepsilon_{delay,good}}+w_{safety}\frac{f_{safety}-\varepsilon_{safety,good}}{\varepsilon_{safety,bad}-\varepsilon_{safety,good}}+w_{emission}\frac{f_{emission}-\varepsilon_{emission,good}}{\varepsilon_{emission,bad}-\varepsilon_{emission,good}}\right) \quad (5)$$

- *w are user-defined weights*
- *"good" and "bad" are upper and lower boundaries*

Sensitivity Analysis

For the sensitivity analysis, a 3-intersection arterial was used. 22 variables were tested, using the Factorial Effect Method proposed by Morris (1991), Campolongo et al. (2007) and Nunes (2012).

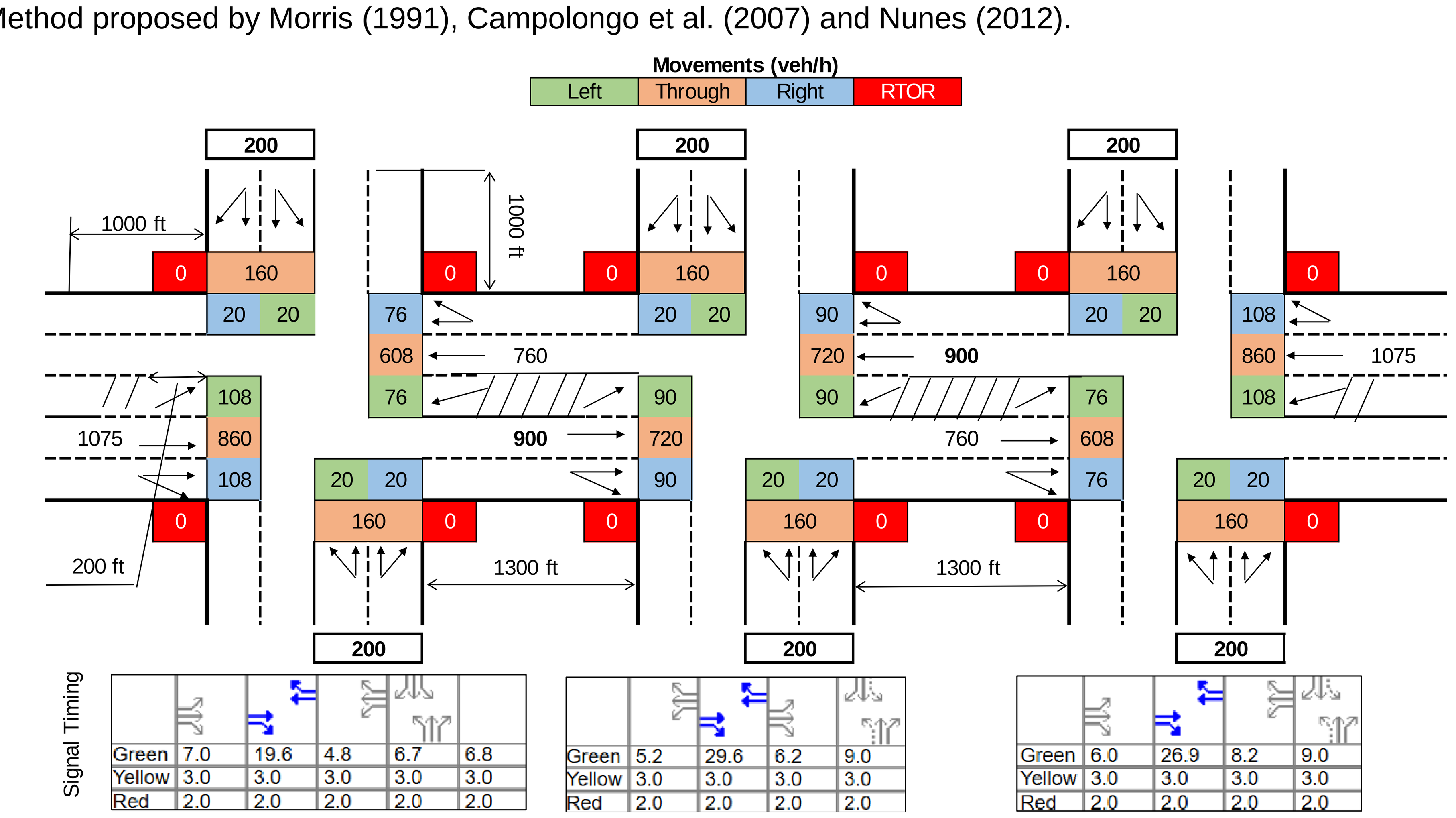

Figure 3. Configuration, Demand and Initial Signal Timing on Testing Arterial

SCENARIO GENERATION

Scenarios are generated by successively varying each factor, keep all other constant (6). A total of **550 scenarios** were performed.

$$z = \begin{vmatrix} x_1 & x_2 & x_3 \\ x_1 & x_2+\Delta_2 & x_3 \\ x_1+\Delta_1 & x_2+\Delta_2 & x_3 \\ x_1+\Delta_1 & x_2+\Delta_2 & x_3+\Delta_3 \end{vmatrix} \quad (6)$$

MEASURES

The Factorial Effect Method stablish the importance of each variable using a measure analogous to price-elasticities (d_i). The average μ and standard deviation σ of d_i are calculated for all scenarios and each variable.

$$\mu_i = \sum_{j=1}^{r}\frac{d_{i,j}}{r} \quad (7) \qquad \sigma_i = \sqrt{\sum_{j=1}^{r}\frac{(d_{i,j}-\mu_i)^2}{r}} \quad (8) \qquad \mu_i^* = \sum_{j=1}^{r}\frac{|d_{i,j}|}{r} \quad (9)$$

Variable Effects Compared (μ)

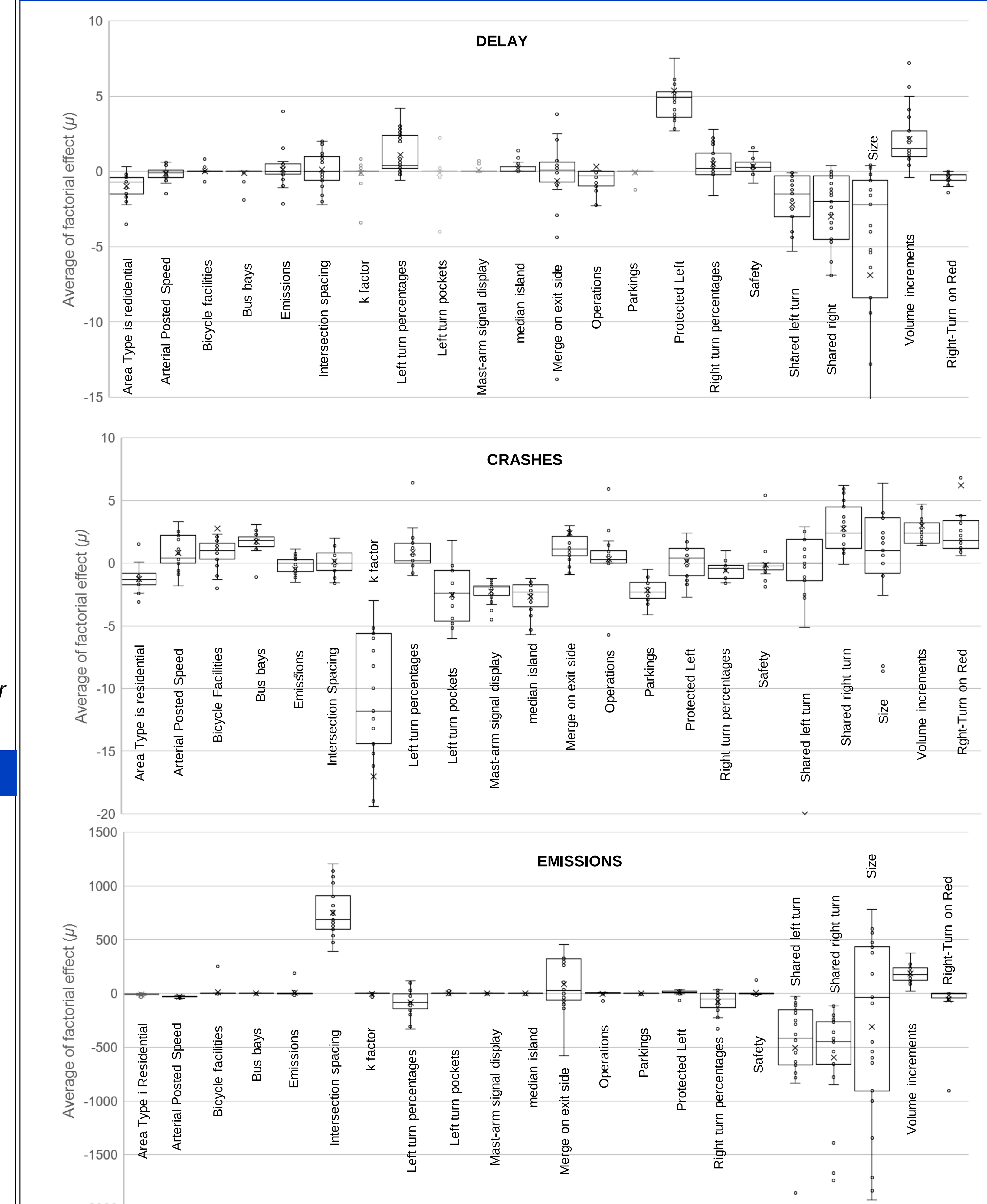

Figure 4. Variability of the Factorial Impact of Each Variable

Remarks and Recommendations

- The HCS engine is now capable of optimizing signal timing on arterials based on mobility, safety and emissions. The resulting methodology is available for users on HCS 7.4 – Streets module.
- The effect of each variable highly depends on other inputs. Overall, permitted left improved operations without compromising safety. Large intersections with no pockets were associated with a much higher number of crashes. Demand level variables are directly related to delay and emissions. The K factor affects the AADT, used by the safety model, largely impacting its outcome. Weight schemes did not impact the outcome significantly.
- For future studies, the effect on pedestrian and bicycle mobility and safety should be investigated.

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