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Combining traffic efficiency and traffic safety in countermeasure selection to improve pedestrian safety at two-way stop controlled intersections

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A B S T R A C T

Decision makers are encouraged to consider multiple objectives (such as traffic efficiency, safety, and environment) together to make decisions. Although there are methods to evaluate each objective respectively, there are few reports or research papers showing how to incorporate these objectives and put it in practice. Thus, this study aims to develop a procedure to incorporate traffic efficiency into the traffic safety countermeasure (CM) selection process. To illustrate the procedure, the economic benefits of four pedestrian safety improvements at crosswalks of major-streets at two-way stop controlled intersections (TWSC) were calculated, considering not only the safety benefits but also the efficiency impacts. First, for each countermeasure the efficiency impacts were calculated as the average delay reduction for both pedestrians and motorists. Sensitivity analysis was conducted to examine how the crucial parameters, including vehicular volume, pedestrian volume, and motorist yield rate, offset the average vehicle and pedestrian delay. Next, the safety impacts were calculated as the crash reduction benefits for different CMs using safety performance functions (SPFs) and crash modification factors (CMFs). Finally, the equivalent uniform annual return (EUAR) method was used to combine the countervailing effects of efficiency and safety by evaluating the economic effectiveness of different CMs. The Monte Carlo (MC) simulation method was used to conduct uncertainty analysis by using random sampling from probability descriptions of uncertain input variables to generate a probabilistic description of results. The findings showed that, first, CMs can have tradeoff impacts for pedestrians and motorists. Second, the efficiency impacts accounted for a large proportion of the total impacts, which can significantly affect the selection of CMs. Third, the rankings of the CMs differ depending on whether the safety impacts alone are considered, or whether both safety and efficiency impacts are integrated. The study illustrates the detailed process of evaluating projects considering multiple objectives for multiple road users. This process offers policy and decision makers a solid and practical reference using existing guidebooks. The findings also explain how safety and efficiency objectives can countervail with each other in improving pedestrian safety at TWSC.

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Nomenclature

List of symbols and abbreviations

CM	countermeasure
TWSC	two-way stop controlled intersection
SPF	safety performance function
CMF	crash modification factor
EUAR	equivalent uniform annual return
MC	Monte Carlo
LCC	life-cycle cost analysis
NPV	net present value
B/C	benefit/cost
VOT	value of time
AADT	average daily traffic
μ	the vehicle arrival rate for all through lanes
λ	the pedestrian arrival rate
D_{ped}	average pedestrian delay (s)
i	crossing event ($i = 1–n$)
h	average headway for each through lane
$P(Y_i)$	probability that motorists yield to pedestrians in crossing event i for a two-lane pedestrian crossing at a TWSC intersection
P_d	probability of a delayed crossing
D_{gd}	average gap delay for pedestrians who incur nonzero delay
n	$\text{Int}(D_{gd}/h)$, average number of crossing events before an adequate gap is available
D_{veh}	the expected average vehicle delay (s)
D_{veh1}	the expected vehicle delay with vehicular headway larger than pedestrian critical headway
D_{veh2}	the expected vehicle delay in cases in which vehicular headway is smaller than pedestrian critical headway, with pedestrians who must wait to cross because previous vehicular gaps are smaller than critical headways and leading vehicles fail to yield
D_{veh3}	expected vehicle delay in the case of headway being smaller than critical headway when there are no pedestrians waiting to cross
L	the probability that there are pedestrians waiting to cross the street when a vehicle starts to make a yielding decision on the condition that vehicle headway is smaller than critical headway
ρ	lost time
δ	pedestrian critical headway
L_{cr}	crosswalk length
s_p	average pedestrian walking speed
t_s	pedestrian start-up time and end clearance time (s)
$\Delta B_{TT,m,h}$	travel time saving benefits during hour h for CM m compared with CM 1
VOT_{veh}	the value of time for motorists
$D_{veh,m,h}$	total vehicle delay during hour h for CM m
$D_{veh,1,h}$	total vehicle delay during hour h for CM 1
VOT_{ped}	the value of time for pedestrians
$D_{ped,m,h}$	total pedestrian delay during hour h for CM m
$D_{ped,1,h}$	total pedestrian delay during hour h for CM 1
$\Delta B_{TT,m,yearly}$	the yearly travel time savings benefits for CM m compared with that of CM 1
N_{bi}	predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions)
N_{spf}	predicted total average crash frequency for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions)
N_{bimv}	predicted average number of multiple-vehicle collisions for base conditions
N_{bisv}	predicted average number of single-vehicle collisions for base conditions
$AADT_{maj}$	average daily traffic volume (vehicles/day) for major road (both directions of travel combined)
$AADT_{min}$	average daily traffic volume (vehicles/day) for minor road (both directions of travel combined)
a, b, c	regression coefficients, which can be obtained from HSM
N_{pedi}	predicted average crash frequency of vehicle-pedestrian collisions
CMF_i	crash modification factors for intersections
f_{pedi}	pedestrian crash adjustment factor, which is 0.022 for 4-leg stop controlled intersection (AASHTO, 2010a)
$AADT_{yj}$	the AADT for year j
r	the annual traffic volume growth rate
i	discount rate