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A double standard model for allocating limited emergency medical service vehicle resources ensuring service reliability

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ABSTRACT

This paper introduces a new double standard model (DSM), along with a genetic algorithm (GA), for solving the emergency medical service (EMS) vehicle allocation problem that ensures acceptable service reliability with limited vehicle resources. Without loss of generality, the model is formulated to address emergency services to human injuries caused by vehicle crashes at intersections within an urban street network. The EMS fleet consists of basic life support (BLS) and advanced life support (ALS) vehicles suited for treating crashes with different severity levels within primary and secondary service coverage standards corresponding to extended response times. The model ensures that all demand sites are covered by at least one EMS vehicle within the secondary standard and a portion of which also meets the service reliability requirement. In addition, a portion of demand sites can be covered by at least one of each type of EMS vehicles within the primary standard. Meanwhile, it aims to achieve maximized coverage of demand sites within the primary standard that complies with the required service reliability. A computational experiment is conducted using 2004–2010 data on top two hundred high crash intersections in the city of Chicago as demand sites for model application. With an EMS fleet size of 15 BLS and 60 ALS ambulances maintained by the Chicago Fire Department, at best 92.4–95.5% of demand could be covered within the secondary standard at 90% of service reliability; and 65.5–68.4% of high severity demand and 50.2–54.5 low severity demand could be covered within the primary standard at 90% of service reliability. The model can help optimize EMS vehicle allocation in urban areas.

1. Introduction

In an environment of ever-increasing urban travel demand, traffic safety becomes a major concern in urban areas around the globe. An incident caused by vehicle crashes imposes adverse impacts on both traffic safety and mobility at and around the incident site. It may lead to severe vehicle damages, property losses, and personal injuries and fatalities. In order to mitigate losses of a traffic incident particularly related to the loss of human lives, maintaining effective responses is critical and immediately providing emergency medical services (EMS) is an essential part of such actions (Dobson, 2003; Wells, 2007). The average response time, which is greatly affected by the distribution of EMS vehicle depots and allocation of available EMS vehicles to incident sites, becomes a key measure to assess the effectiveness of emergency responses. However,

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Nomenclature

Symbols

q_i^k	local busy fraction of one type k vehicle deployed at any $j \in S_{i,r'}$
r, r'	service coverage standards
r_1	primary service coverage standard
r_2	secondary service coverage standard
$\bar{t}^k$	average service time of type k vehicle, hours per service
t_{ij}	vehicle travel time on the shortest path from vehicle location j to demand site i
f_l	frequency of requests for emergency service by competing demands around demand site i, demand calls per day
$S_{i,r'}$	$\{\forall j \mid t_{ij} \leqslant r'\}$, the set of depot locations within r' of demand site i
$C_{i,r}$	$\{\forall m \mid t_{mj} \leqslant r,\ j \in S_{i,r'}\}$, the set of m competing demand sites around demand site i, which are located within r of any depot location $j \in S_{i,r'}$
y_j^k	number of type k vehicles deployed at vehicle location j
ρ_i^k	utilization ratio
$e_{i,r'}^k$	smallest number of type k vehicles assigned around demand site i at depot location $j \in S_{i,r1}$, that satisfies $1 - \left(\frac{\rho_i^k}{e_{i,r'}^k}\right)^{e_{i,r'}^k} \geqslant \gamma$
e_{i,r_1}	smallest number of vehicles assigned around demand site i at depot location $j \in S_{i,r1}$, that can satisfy $1 - \left(\frac{\rho_i}{e_{i,r1}}\right)^{e_{i,r1}} \geqslant \gamma$
e_{i,r_2}	smallest number of vehicles assigned around demand site i at depot location $j \in S_{i,r2}$, that can satisfy $1 - \left(\frac{\rho_i}{e_{i,r2}}\right)^{e_{i,r2}} \geqslant \gamma$
D	set of demand sites
D_1	set of high crash severity demand sites
D_2	set of low crash severity demand sites
N_d	total number of demand sites
d_i	demands at demand site $i \in D$
p_j	maximum number of vehicles that can be deployed to vehicle location j
p^k	fleet size of type k vehicles
S	vehicle depot locations
$S_{i,r1}$	set of depot locations that can reach demand site i within primary standard r_1
$S_{i,r2}$	set of depot locations that can reach demand site i within secondary standard r_2
z_{i,r_1}^k	1, if demand site i is reachable by at least one type k vehicle within primary standard r_1; 0, otherwise
γ	service reliability level
x_{i,r_2}^k	1, if demand site i is covered by type k vehicle within secondary standard r_2 at service reliability level γ; 0, otherwise
x_i	1, if demand site i is covered within primary standard r_1 at reliability level γ; 0, otherwise
α	the portion of demand sites covered within the primary standard r_1
β	the portion of demand sites covered within the secondary standard r_2
m_i	indicator of covered demand calls at demand site i
M	fitness measure
i	demand site i
j	vehicle depot location j
k	vehicle type k, 1 for ALS, 2 for BLS

Abbreviations

DSM	double standard model
GA	genetic algorithm
EMS	emergency medical service
BLS	basic life support
ALS	advanced life support
SCLP	set covering location problem
MCLP	maximal coverage location problem
MEXCLP	maximum expected covering location problem
NP	nondeterministically polynomial
PDO	property damage only
FB	frequency-based scenario
SB	severity-based scenario
CFD	Chicago Fire Department