1 Introduction

2 Model Formulation

Table 1: Notations

Sets and indices	
I	set of evacuation sources, $i \in I$
J	set of potential shelters, $j \in J$
K	set of potential relief distribution centres, $k \in K$
A_1	set of arcs between evacuation sources and potential shelter nodes, $\{(i,j)\|i \in I, j \in J\}$
A_2	set of arcs between potential relief distribution centres and potential shelter nodes, $\{(k,j)\|k \in K, j \in J\}$
L	set of levels of road capacity increase, $l \in L$
Parameters	
p_i	population at landfall node $i \in H$
q_j	capacity of potential shelter $j \in J$
Q_k	capacity of potential relief distribution centre $k \in K$
ϕ	quantity of relief material consumed per person
μ	transportation cost per unit transportation time
α	coefficient in the BPR function
β	coefficient in the BPR function
T	planning horizon for emergency supply transportation
Π	penalty for failing to evacuate a person
U_{ij}, U_{kj}	practical flow rate capacity of arcs $(i,j) \in A_1$ and $(k,j) \in A_2$, respectively
B_{ij}, B_{kj}	background traffic flow rate of arcs $(i,j) \in A_1$ and $(k,j) \in A_2$, respectively
t_{ij}, t_{kj}	free-flow transportation time through arcs $(i,j) \in A_1$ and $(k,j) \in A_2$, respectively
Δu_{ijl}	increase in capacity of arc $(i,j) \in A_1 \cup A_2$ by choosing capacity level $l \in L$
f_j	fixed cost of opening a shelter at location $j \in J$
F_k	fixed cost of opening a relief distribution centre at location $k \in K$
g_{ijl}	fixed cost of expanding capacity of arc $(i,j) \in A_1 \cup A_2$ to level $l \in L$
Decision Variables	
x_{ij}	evacuee flow from source $i \in I$ to shelter $j \in J$
s_i	unmet evacuee demand at $i \in I$
$\widehat{x}_{kj}$	relief material flow from relief distribution centre $k \in K$ to shelter $j \in J$
y_j	$= 1$ if shelter is opened at node $j \in J$; otherwise 0
z_k	$= 1$ if warehouse is opened at node $k \in K$; otherwise 0
w_{ijl}	$= 1$ if capacity level $l \in L$ is chosen for arc $(i,j) \in A_1 \cup A_2$; otherwise 0

2.1 Objective

$$\text{Min} \sum_{j\in J} f_j y_j + \sum_{k\in K} F_k z_k + \sum_{l\in L} \sum_{(i,j)\in A_1} g_{ijl} w_{ijl} + \mu \sum_{(i,j)\in A_1} t_{ij} \left(1 + \alpha \left(\frac{x_{ij} + B_{ij}}{U_{ij} + \sum_{l\in L} \Delta u_{ijl} w_{ijl}}\right)^{\beta}\right) x_{ij} T$$
$$+ \mu \sum_{(k,j)\in A_2} t_{kj} \left(1 + \alpha \left(\frac{\widehat{x}_{kj} + B_{ij}}{U_{kj}}\right)^{\beta}\right) \widehat{x}_{kj} T + \Pi \sum_{i\in I} s_i \tag{1}$$

2.2 Transfer of evacuees to shelter

$$\sum_{j\in J} x_{ij} + s_i = p_i \qquad \forall i \in I \tag{2}$$

2.3 Shelter capacity constraints

$$\sum_{i\in I} x_{ij} \leq q_j y_j \qquad \forall j \in J \tag{3}$$

2.4 DC capacity constraints

$$\sum_{j\in J} \widehat{x}_{kj} \leq Q_k z_k \qquad \forall k \in K \tag{4}$$

2.5 Transfer of relief material to shelter

$$\sum_{k\in K} \widehat{x}_{kj} \geq \phi \sum_{i\in I} x_{ij} \qquad \forall j \in J \tag{5}$$

2.6 Evacuation source to shelter link capacity constraints

$$x_{ij} \leq U_{ij} + \sum_{l\in L} \Delta u_{ijl} w_{ijl} \qquad \forall (i,j) \in A_1 \tag{6}$$
$$w_{ijl} \leq y_j \qquad \forall (i,j) \in A_1, j \in J, l \in L \tag{7}$$
$$\sum_{l\in L} w_{ijl} \leq 1 \qquad \forall (i,j) \in A_1 \tag{8}$$