DESIGN OF AN EFFICIENT EMERGENCY RESPONSE SYSTEM TO MINIMIZE THE INCIDENT IMPACTS ON HIGHWAY NETWORKS: A CASE STUDY FOR MARYLAND DISTRICT 7 NETWORK

by Hyeonmi Kim, Woon Kim, Gang-Len Chang and Steve M. Rochon

University of Maryland at College Park & Maryland State Highway Administration

Abstract

- This study presents a model for optimizing the deployment locations of emergency response units.
- Unlike most existing studies, the proposed model is designed to assign the available units to minimize the total delay caused by incidents, rather than just to minimize their average response times.
- The proposed model with the Maryland incident data outperforms both the popular *p*-median model and the current practice.
- Extensive sensitivity analyses with respect to various traffic volumes and incident frequencies have also confirmed the superior performance of the proposed model with respect to minimizing the total delay caused by incidents.

Research Background

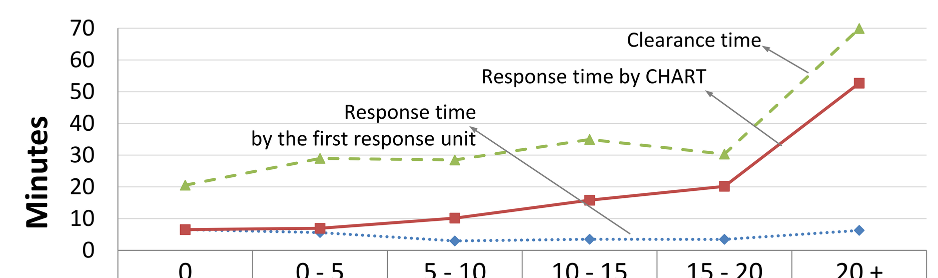
EFFECTS OF AN INCIDENT MANAGEMENT PROGRAM ON INCIDENT DURATION

- MDSHA has operated an incident traffic management program, named Coordinated Highway Action Response Team (CHART), to minimize the impacts of incidents on highway networks by prompt response, efficient clearance, and effective traffic management.
- The efficient response of an incident management team can indeed contribute to the reduction in not only the response time but also the clearance time.
- The clearance time can be reduced significantly if the incident management team arrives at the scene faster than other agencies.

<Average Clearance Time (minutes)>

		TOC-3	TOC-4	TOC-7	AOC	SOC
CHART not involved		24.40	29.06	39.92	26.42	60.04
CHART involved		22.47	22.53	26.12	17.55	44.23
First Responder	CHART	20.04	19.80	21.06	12.89	35.99
	Others	29.18	32.09	41.43	22.47	54.95

- Data of incidents occurring during a.m. peak hours (7 a.m. – 9:30 a.m. on weekdays) in Maryland in 2012 and having clearance times between 1 minute and 4 hours.



	0	0 - 5	5 - 10	10 - 15	15 - 20	20 +
Response time by the first response unit	6.53	5.62	2.96	3.50	3.47	6.29
Response time by CHART	6.53	6.95	10.16	15.80	20.19	52.69
Clearance time	20.54	28.99	28.48	34.96	30.34	69.92

- Horizontal axis: differences in arrived times between CHART and the first arriving agency
- Data: incidents occurring during a.m. peak hours (7 a.m. – 9:30 a.m. on weekdays) in Maryland in 2012 and having clearance times between 1 minute and 4 hours.

<Clearance Times regarding Delayed Response of CHART >

Methodology

- ***Objective Function***

$$\min_{x,y} \sum_i \sum_j x_{ij} \cdot f_j \cdot d_j(t_{ij})$$

- ***Subject to***

① $d_j(t_{ij}) = \frac{1}{2} {T_{ij}}^2 (q_j - rc_j) \left(\frac{c_j - rc_j}{c_j - q_j} \right) \qquad \forall (i,j) \in N$

② ${T_{ij}}^2 = \begin{cases} Type\ 1: \ (RT_1 + \overline{CT}_1)^2 + Var(CT_1), & 1-\alpha \\ Type\ 2-1: \ (t_{ij} + \overline{CT}_{2-1})^2 + Var(CT_{2-1}), & \alpha, \beta \\ Type\ 2-2: \ (RT_2 + \overline{CT}_{2-2})^2 + Var(CT_{2-2}), & \alpha, 1-\beta \end{cases} \qquad \forall (i,j) \in N$

③ $\sum_i x_{ij} = 1 \qquad \forall\ i \in N$

④ $\sum_i y_i \le R \qquad \forall\ i \in N$

⑤ $x_{ij} \le y_i \qquad \forall\ j \in N$

⑥ $x_{ij} = [0,1] \qquad \forall (i,j) \in N$

⑦ $y_i = [0,1] \qquad \forall\ i \in N$

$G(N, A)$: Network of freeways, where N and A are the sets of nodes and links
i and j: Index for nodes. $i, j \in N$
x_{ij}: Binary decision variable, indicating if a node *j* is covered by a unit at a node *i*
y_i: Binary decision variable, indicating if a unit stays at a node *i*
f_j: Incident frequency at a node *j*
t_{ij}: Travel time from *i* to *j*
d_j: Predicted delay from incidents occurring at a node *j*
T_{ij}: Incident duration equal to the sum of response time and clearance time
α: Proportion of incidents served by freeway incident management teams at a given time
β: Proportion of incidents responded by freeway incident management teams first at a given time
RT_1: average minimum response time by other agencies in *Type 1*
RT_2: average minimum response time by other agencies in *Type 2-2*
CT_1: Clearance times of incidents that freeway incident management teams are not involved in response and clearance
CT_{2-1}: Clearance times of incidents that freeway incident management teams respond faster than any other agencies
CT_{2-2}: Clearance times of incidents that freeway incident management teams respond later than other agencies
$\overline{CT}_1$: Average clearance time of incidents that freeway incident management teams are not involved in their response and clearance
$\overline{CT}_{2-1}$: Average clearance time of incidents that freeway incident management teams respond faster than any other agencies
$\overline{CT}_{2-2}$: Average clearance time of incidents that freeway incident management teams respond later than other agencies
q_j: Traffic volume at a node j
c_j: Capacity at a node j
rc_j: Reduced capacity at a node j
R: Available resources

Experimental Design

- The study site: I-270, I-70, and US-15,
  - 63-mile long with 30 exits
  - Operated by 3 units from TOC-7
  - During AM peak hours (7:00 – 9:30) on weekdays
- Input data and data source
  - CHART II Database (data from Year 2010 to Year 2012)
    - Incident frequency on freeway segment i (f_i)
    - Average response times for each type (RT_1 and RT_3)
    - Average and variance of clearance times for each type ($\overline{CT}_k$ and Var(CT_k))
    - α = 0.87 and β = 0.75
    - Average number of lane closures to determine the reduced capacity (rc_j)
  - RITIS (Regional Integrated Transportation Information System)
    - Traffic volume (q_j)
- Reference models for the comparative study
  (1) the dispatch strategy to minimize the average response times
  (2) the experience-based patrolling strategy operated by CHART

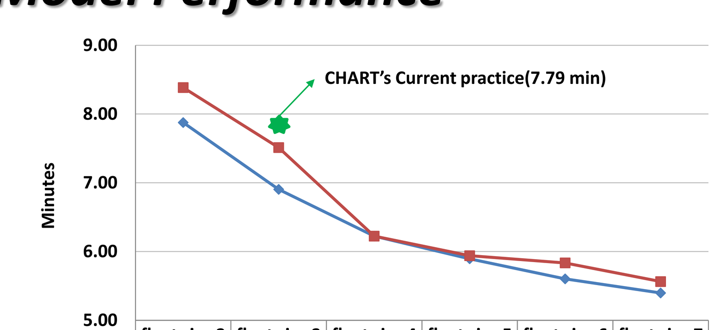
Result analysis

- ***Model Result***

No. of Units Available	Assigned Stations (Exits) by: Dispatch minimizing total delay	Dispatch minimizing avg. response time	CHART practice
2	I-70: 42 and 53	I-70: 52 and 68	N/A
3	I-70: 42, 53 / I-270: 26	I-70: 52, 68 / I-270: 22	Patrolling all segments
4	I-70: 42, 52, 68 / I-270: 26	I-70: 42, 52, 68 / I-270: 26	N/A
5	I-70: 42, 53, 68 / I-270: 26 / US-15: 16	I-70: 42, 52, 62, 80 / I-270: 26	
6	I-70: 42, 48, 53, 68 / I-270: 26/ US-15: 16	I-70: 42, 52, 62, 80 / I-270: 26 / US-15: 17	
7	I-70: 42, 48, 53, 62, 82 / I-270: 26 / US-15: 16	I-70: 42, 52, 62, 68, 80 / I-270: 26 / US-15: 17	

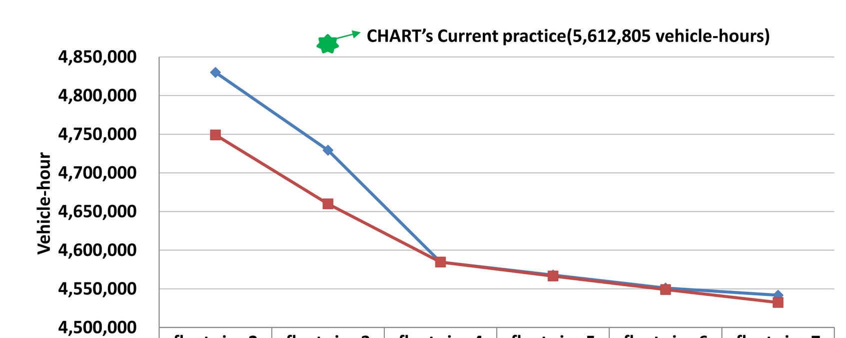
No. of Units Available	Assigned Coverage by: Dispatch minimizing total delay	Dispatch minimizing avg. response time	CHART practice
2	(35 - 42 on I-70), (others)	(others), (62 - 87 on I-70)	N/A
3	(35 - 42 on I-70), (others), (22 - 26 on I-270)	(others), (62 - 87 on I-70), (22 - 26 on I-270)	Patrolling all segments
4	(35 - 42 on I-70), (others), (62 - 87 on I-70), (22 - 26 on I-270)	(35 - 42 on I-70), (others), (62 - 87 on I-70), (22 - 26 on I-270)	N/A
5	(35 - 42 on I-70), (others), (62 - 87 on I-70), (22 - 26 on I-270), (13-17 on US-15)	(35 - 42 on I-70), (others), (59 - 68 on I-70), (73 - 87 on I-70), (22 - 26 on I-270)	
6	(35 - 42 on I-70), (48 - 59 on I-70), (others), (62 - 87 on I-70), (22 - 26 on I-270), (13-17 on US-15)	(35 - 42 on I-70), (others), (59 - 68 on I-70), (73 - 87 on I-70), (22 - 26 on I-270), (14 - 17 on US-15)	
7	(35 - 42 on I-70), (48 - 59 on I-70), (others), (62 - 73 on I-70), (76 - 87 on I-70), (22 - 26 on I-270), (13-17 on US-15)	(35 - 42 on I-70), (others), (59 - 62 on I-70), (68 - 73 on I-70), (76 - 87 on I-70), (22 - 26 on I-270), (14 - 17 on US-15)	

- ***Model Performance***



	fleet size 2	fleet size 3	fleet size 4	fleet size 5	fleet size 6	fleet size 7
Dispatch minimizing avg. response time	7.88	6.90	6.22	5.89	5.60	5.40
Dispatch minimizing total delay	8.38	7.51	6.22	5.94	5.83	5.56

<Average Travel Times (in minutes)>



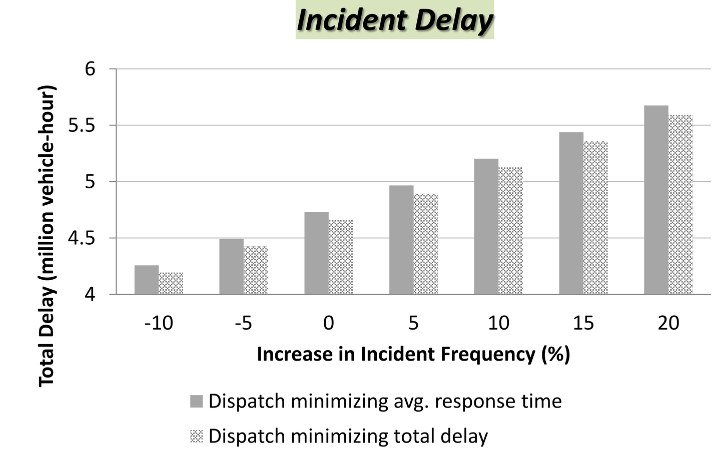
	fleet size 2	fleet size 3	fleet size 4	fleet size 5	fleet size 6	fleet size 7
Dispatch minimizing avg. response time	4,829,998	4,729,356	4,584,707	4,567,920	4,551,095	4,541,785
Dispatch minimizing total delay	4,749,141	4,659,967	4,584,707	4,566,630	4,549,114	4,532,457

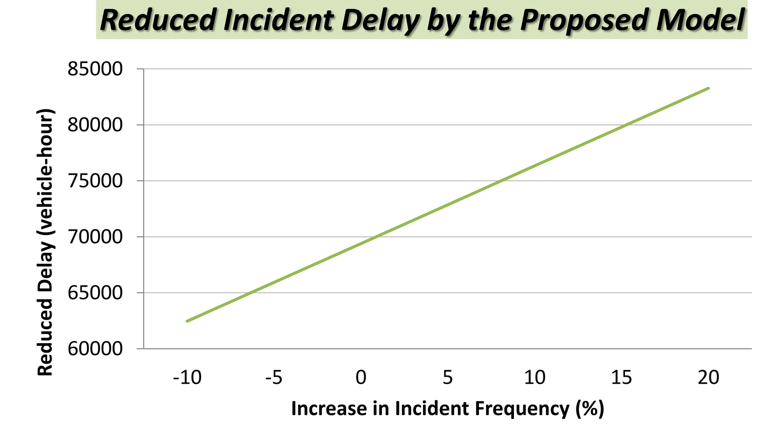
<Total Delays (in vehicle-hour)>

- ***Sensitivity Analysis on Incident Frequency and Traffic volume***

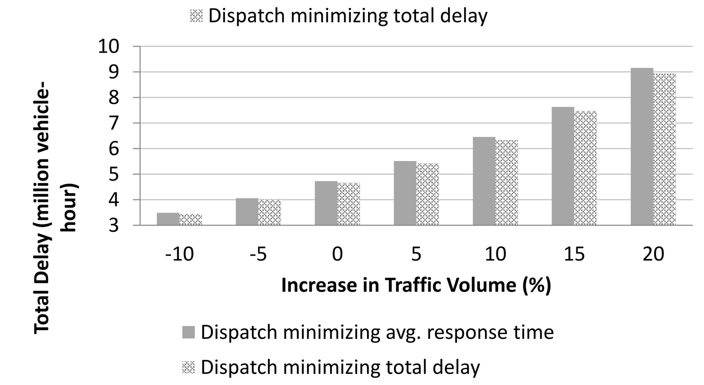
Incident Delay | ***Reduced Incident Delay by the Proposed Model***

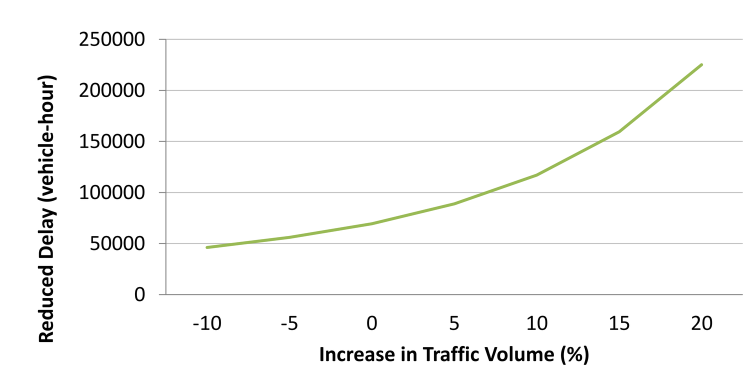
Incident Frequency





Traffic Volume





Conclusions

- This study proposes an integer programming model to deploy incident response units at optimal locations, while minimizing the total delay as the objective function.
- Successful freeway incident management programs noticeably contribute to alleviating the non-recurrent congestions not only by prompt response, but also by efficient incident clearance and traffic management.
  - The Maryland incident data clearly show that the average clearance time of incidents operated by Maryland incident management program (CHART) is shorter than the one without CHART.
  - The incidents first responded by CHART present a shorter average clearance time than those responded by CHART but arriving at the scene later than other agencies.
  - This findings confirm that the freeway incident management program plays an important role in expediting the incident clearance and consequently reducing the incident delay.
- The empirical study for various fleet sizes from 2 to 7 and sensitivity study on traffic volume and incident frequency using CHART II Database show that the total incident delays with the proposed model are smaller than those with the traditional deployment model and the current practice by CHART.
- The reduced delays along with the byproducts of reduced fuel consumptions and emissions due an efficient incident management program could produce significant socioeconomic and environmental benefits.