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AMBULANCE RESPONSE OPTIMIZATION

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ABSTRACT

We live in a country where the incidents of ambulances not reaching on time are indicative enough of the dismal state of transportation for patients in need of emergency care across the country. Delhi, a city of 22 million people, has only 152 state-run ambulances. More than 20 percent of patients needing emergency treatment has died on their way to the hospital because of delays due to traffic jams. in Delhi, an ambulance takes an average of 27 minutes to reach the site. Response time can even extend into hours. Seeing the current scenario of traffic, time taken is only going to increase. And yet, no steps are being taken to improve the situation. Measures of optimizing ambulance response time prove to be widely unsuccessful due to the lack of a targeted approach. This results in sub-optimal allocation of already overstretched healthcare resources. In 2017 alone, there were more than 8,000 road accidents in Delhi. Ironically enough, about 3,000 accidents led to deaths due to ambulances not reaching on time as they were stuck in Delhi's traffic. By virtue of the factors discussed above, there arises a need for a scientific approach to optimizing the ambulance response time.

KEYWORDS: Mathematical model, response optimization, speed-density equation. algorithmic paradigms.

INTRODUCTION

The Delhi Government data shows that Delhi, a city of 22 million people, has 152 state-run ambulances. That's one for every 144,736 people. Over 20% of patients needing emergency treatment have died on their way to the hospital because of delays due to traffic congestion.

As per the World Health Organization, in any city, there must be at least 1 ambulance for every 80,000 people. However, when we speak of the national capital Delhi, the ratio is appalling. Here, each ambulance has to cater to nearly 150,000 people. The situation for other cities is worse.

Out of the available ambulances, some are booked for non-emergency cases, such as transferring a patient from one healthcare center to another or simply taking back a discharged patient home. Ambulances can also be pre-booked for pregnant women or patients with disabilities, to help them reach the medical establishments in a convenient manner. Needless to say, this further puts a dent in the ambulance - people ratio.

WHO recommends a standard response time of 8-10 minutes for an ambulance. However, given the overall lag in Delhi's emergency services, the response time is far from ideal.

As per the data published by the All India Institute of Medical Sciences (AIIMS), as many as 28% of the patients lose out on efficient and reliable emergency medical services due to non-availability of ambulances.

Furthermore, the road conditions, the infrastructure facilities and other aspects such as high traffic situations, and the absence of distinct pathways for emergency assistance vehicles result in extreme delays.

Taking into consideration all the above-mentioned factors, we aim to construct a mathematical model equipped with the fundamental parameters for optimizing the ambulance response time to reach a crash or a road accident victim. This has been done to increase the feasibility of the suggested model and obtain more accurate results.

We believe that the model would be an incredible aid in optimizing the response time as well as proving extremely useful to hospitals and prioritizing emergencies according to risk zones.

LITERATURE REVIEW

A. Greedy algorithm

A greedy algorithm is an algorithm which makes the choice that seems to be the best at a particular moment in a stage. It helps to allocate resources in the best possible way to minimize average response time.

B. Regression Lines

A regression line is simply a single line that best fits the data. By using the equation obtained from the regression line we will be able to forecast future behaviors of the dependent variable, in our case, time.

C. Genetic Algorithm

The Genetic Algorithm tests various scenarios and strategies, and on the basis of these, selects the best strategy for a particular situation.

D. Speed-density equation

The Castillo-Benitez speed-density equation estimates route not on the basis of time but on the basis of velocity and jam density, to find the least congested path.

Basic Assumptions

1. We assume that all ambulances will drive with the intent of reaching the location of the accident in the shortest time.
2. We will assume there are enough ambulances for all crash sites in a day. In Delhi, the number of ambulances (152) far exceeds the number of accidents in a day (around 20), so it would be plausible to assume that we have enough ambulances for any emergency.
3. We assume that all ambulances are the same in terms of travelling capacity. In actuality, most ambulances in Delhi are the same model, so not much accuracy is lost through this assumption.

METHODOLOGY

- Allocating ambulances through a greedy allocation algorithm
- Finding the optimal dispatch strategy in case of multiple accidents through genetic algorithm
- Optimizing the route through the Castillo-Benitez speed-density equation

Greedy Allocation algorithm will be used for allocating the available ambulances among various allocations in the best possible way. We will be taking wards as a basis for our project, allocating ambulances according to the number of crash sites in an area to make ambulance dispatch an efficient process. What the Greedy Allocation Algorithm does is maximize this marginal benefit in this case, benefit will be in terms of time.

Definition of key terms and variables

- **A**, a certain allocation of ambulances.
- **a**, no. of new ambulances being added (in our case 1)
- **T**, defined as the average response time of a certain allocation of ambulances A. We define response time as the time taken for an ambulance from any hospital to reach a crash accident location.
- **U**, a function that is defined as the total benefit received from using a certain allocation A.
- Δ**u**, a function defined as the marginal benefit received from adding an ambulance "a" to ascertain allocation A.
- **k**, the total number of ambulances in New Delhi.

In order to allocate the ambulances efficiently, we need to now specify which ambulance is needed in which hospital. Since there are 148 hospitals, we can allocate a1 to any of the 148 hospitals.

We then assume that an allocation *A* has no ambulances.

We must now consider placing an ambulance in Hospital 1 and note the average response time *T* of this allocation.

Similarly, the second ambulances can also be allocated to any of the 148 hospitals.

With this we concluded that one ambulance can be iterated 148^k times.

Total iterations are 148^{152}

After the 148th iteration, we would have allocated all the ambulances accurately with the average response time T minimized. This means we will have reached our goal of finding an allocation of ambulances that minimizes the average response time to accidents in Delhi.

Utility in Greedy algorithm

The average response time will either go down or stay the same once we add an ambulance to the allocation. The response time cannot increase if we add an additional ambulance.

Therefore, our marginal benefit in terms of time would be **Δ*u*.** Now, we will calculate this by simply multiplying the average time T of an allocation to A and subtracting this from time taken by allocation AUa.

The formula cannot be non-submodular since time can never be negative: the smaller the value of T(AUa), the more the efficiency of the allocation in terms of time.

We now move on to substituting actual experimental values based on NCR data. We take our first allocation to be A1 which currently has 8 ambulances. T(A) is 32 mins. Now we add *an ambulance* to this allocation. Since a is 1, the total no of ambulances in A1 becomes 9. $T(A_1 \cup a)$ comes out to be 28 mins. By substituting these values in our equation, we get a marginal benefit of 4 mins.

We now test this in allocation A2 which currently has 11 ambulances. T(A) for this allocation is 24 mins. We add *a* to A2 thus, increasing the no. of ambulances to 12. $T(A_2 \cup a)$ becomes 19 mins and our efficacy increases by 5 mins.

To further supplement the algorithmic paradigm, the final equation comes out to be $\mathbf{A_n + ka = t - 4.5}$

Where n is the allocation number.

- OUR **1**$^{\mathbf{ST}}$ ALLOCATION = $A1$
- CURRENTLY HAS = 8 AMBULANCES
- T($A1$) = 32 MINUTES
- TIME TAKEN IN THIS ALLOCATION = 32 MINUTES
- NOW WE ADD 1 AMBULANCE TO $A1$
- ($A1$ +a)
- SO $A1$ NOW HAS 9 AMBULANCES
- TIME TAKEN NOW IS 28 MINUTES

$=|T(A1 \cup a) - T(A1)|$

$=|(-32 + 28)|$

$=|-4|$

=4 MINUTES

- OUR **2**$^{\mathbf{ND}}$ ALLOCATION = $A2$
- CURRENTLY HAS = 11 AMBULANCES
- T($A2$) = 24 MINUTES
- TIME TAKEN IN THIS ALLOCATION = 24 MINUTES
- NOW WE ADD 1 AMBULANCE TO $A2$

- $(A2 + a)$
- SO $A2$ NOW HAS 12 AMBULANCES
- TIME TAKEN NOW IS 19 MINUTES

$=|T(A2 \cup a) - T(A2)|$

$=|(19 - 24)|$

=5 MINUTES

Final equation

$\boldsymbol{An + (s)a = T - \square.\square}$

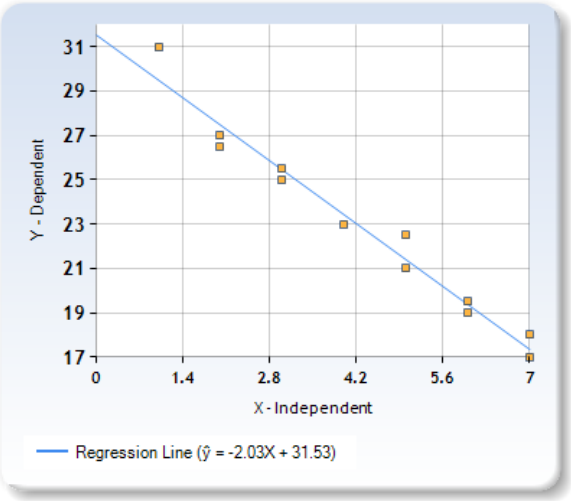
To reaffirm the fact that the algorithm provides us with absolutely correct data we have used the y-on-x regression lines for 12 randomly generated points or allocations. Here, y is the time and x is the no. of ambulances. Since time is dependent on the number of ambulances we chose to regress y on x.

Mean of X is 4.25 and the mean of Y is 22.9167. Hence, we conclude that our allocation is the most efficient.

S. No.	X - M_x	Y - M_y	$(X - M_x)^2$	$(X - M_x)(Y - M_y)$
1.	-1.25	2.0833	1.5625	-2.6042
2.	-2.25	4.0833	5.0625	-9.1875
3.	0.75	-0.4167	0.5625	-0.3125
4.	-3.25	8.0833	10.5625	-26.2708
5.	1.75	-3.9167	3.0625	-6.8542
6.	1.75	-3.4167	3.0625	-5.9792
7.	2.75	-4.9167	7.5625	-13.5208
8.	0.75	-4.9167	0.5625	-1.4375
9.	-0.25	0.0833	0.0625	-0.0208
10.	-1.25	2.5833	1.5625	-3.2292
11.	-2.25	3.5833	5.0625	-8.0625
12.	2.75	-5.9167	7.5625	-16.2708

- Sum of X = 51
- Sum of Y = 275
- Mean X = 4.25
- Mean Y = 22.9167
- Sum of squares (SS_X) = 46.25
- Sum of products (SP) = -93.75
- Regression Equation = $Y = bX + a$
- $b = SP/SS_X$ = -93.75/46.25 = -2.02703

- $a = M_Y - bM_X = 22.92 - (-2.03*4.25) = 31.53153$
- $\boldsymbol{Y = -2.02703X + 31.53153}$



Now that we have calculated the optimal allocation strategy of ambulances, we need to consider how to dispatch the ambulances in the event of multiple car accidents. We know that at no point in time will there be a single accident because if it were so the optimal response strategy would be to send the ambulance nearest to it. However, there might be a huge no. of accidents and that too concentrated in a particular region or ward. For this, we will be using a genetic algorithm.

The Genetic Algorithm tests various scenarios and strategies, and on the basis of these, selects the best strategy for a particular situation.

We will now proceed by generating 10 random strategies and choose the best one out of these 10.

On the basis of data collected by us the first setup comes out to be {3,7,10,14,2,5….}

The response time for this setup is {24,18,14,17,25,28….} and the average response time comes out to be 21 minutes.

As per the genetic algorithm, we now start the crossover of values to match the perfect allocation which we generated using greedy allocation.

The second setup now would be {5,1,4,3,25,8….} and the response time for this allocation is {19,23,20,21.5,7,14….}. The new average response time thus reduces from 21 minutes to

17.41 minutes. This optimizes the ambulance response time by approximately 4 minutes. This ladies and gentlemen, is just for one allocation.

Also, since the model is an experimental one, we have only generated 2 strategies. The algorithm, however, is programmed in a way so as to further reduce the time until it can no longer reduce. This would give us the best dispatch strategy.

Routing

With the optimal dispatch strategy for ambulances in all allocations, we come to one of the most important steps in our model: finding the best route for an ambulance on the basis of the average speed, congestion rate and jam density. Now, we could have used the A* Algorithm in our model provided that Delhi had a perfect grid system. We will now be using an equation that is our major addition to the model.

The equation has been used to devise a partial speed-density model and calculates the velocity of the flow of traffic for every possible route. The route with maximum velocity would obviously be the best suited.

The first step is to find out the velocity of free-flowing traffic when congestion is minimal. We take this to be V_{free}. We carried out alpha testing of our model for Aurobindo Marg which is near the AIIMS campus and the Safdarjung Hospital. V_{free} came out to be 70 kmph. We then take the traffic flow rate in terms of vehicles per hour(1200 vph) represented by ρ. The congestion rate for this particular route comes out to be 412 c_m where c_m is used to denote kinematic wave speed. Variable V is the average velocity of all vehicles in our case ambulances. The jam density is the density of traffic of a particular route when it is heavily congested. We use ρ_{jam} to denote this. The experimental value of ρ_{jam} is 42.24. We then substitute the values in the given equation where.

$$\mathbf{V = V_{free}[1 - \exp.\{\frac{Cm}{Vfree}(1 - \frac{\rho jam}{\rho})\}]}$$

The final average velocity came out to be 47.6910 kmph. We also calculated the average velocities for other routes leading to the same location and the experimental values came out to be 35.45 kmph and 41.267 kmph, making this the most optimal route.

$$V = V_{free}\{1 - \beta\left[\frac{\alpha}{Vfree}\right](1 - \frac{\rho jam}{\rho})\}$$

- V_{free} = free flow speed of traffic = 70km/hr
- ρ=traffic per km^2 = 1200 vehicles per hour

- Congestion rate = α = 412
- V_{avg} speed vehicles (here ambulance)
- ρ_{jam} = jam density = 42.24
- β = experimental value

$$V = 70\left|\{1 - \left[\frac{412}{70}\right](1 - \frac{42.24}{1200})\}\right|$$

$$= 70\left|\{1 - \left[\frac{412}{70}\right](\frac{1200-42.24}{1200})\}\right|$$

$$= 70\left|\{1 - \left[\frac{412}{70}\right](1157.76)\}\right|$$

$$= 70|\{1 - 6814\}|$$

$$= 70|-6813|$$

$$= 70 \ X \ 6813$$

= 476910 vph

To convert vph-kmph

$$= \frac{476910}{10000}$$

=47.6910 km/hr.

So, the average speed of an ambulance in normal traffic will be 47.6910 km/hr.

CONCLUSION

Through this process, we are able to successfully optimize time through three aspects: allocation, dispatch and routing.

We are planning to implement the system in collaboration with AIIMS Delhi with the help of an app which has been calibrated with the required equations, which will perform the required calculations using real-time values.

FUTURE PROSPECTS

1. In the near future, we can engage both private and public ambulances and hospitals, allocating ambulances according to population size, taking crash sites as a secondary factor.
2. We can also establish ambulance centers to get a lower response time. These will be located in various parts of the city, catering to different areas instead of being restricted to hospitals.
3. Systems for prioritizing emergencies according to risk zones can also be implemented where: -

- Level 1 - two-wheelers on main roads

- Level 2 - four-wheelers on main roads
- Level 3 - two-wheelers on lanes
- Level 4 four-wheelers on lanes

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