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COVERAGE BASED EMPIRICAL MODELLING FOR EMS RESCUE SYSTEM OF KARACHI (PAKISTAN)

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Original scientific paper

Emergency Medical Services (EMS) is a major source of handling emergencies. Most of the emergencies have one patient. The routine systems are not able to respond to emergencies in which there are many casualties. The mass-casualty disaster response and EMS services plans have become more popular in case of ordinary disasters and terrorist attacks over the past decades. But it might not be possible to construct such plans due to limited resources and budget. There may be such more factors including the number of ambulances deployed, their position/location, and dispatching strategies that affect the EMS system. One more factor is the variation in number of vacant ambulances at different time of the day. In order to sustain coverage, it is necessary to locate ambulances at the station in functional states. In this paper we proposed an optimization model dealing with EMS to assist the medical treatment in the region of Karachi, Pakistan (by using two years data from the year 2010 to 2011). We also conducted and estimated an empirical analysis of ambulance response times, travel times to a hospital and the time spent at the hospital. Google maps are used to facilitate EMS's provider to view and analyse the entire scene of the accident with the help of GPS or other sources of information. Physical simulation and results are used as part of the planning process, which shows the integrity and efficiency of the time threshold based on the acuity of the patient at the time when the 15 call is made (Rescue 15).

Keywords: *covering model, EMS (Emergency Medical Services), MERGe, Google Mapping, Universal Transverse Mercator (UMT)*

Empirijsko modeliranje sustava službe prve pomoći (EMS) u Karačiju (Pakistan) temeljeno na pokrivenosti

Izvorni znanstveni članak

Hitne slučajeve uglavnom rješava služba hitne pomoći (EMS). U većini se slučajeva radi o jednom pacijentu. Osnovni sustavi nisu u stanju reagirati kod hitnih slučajeva s više unesrećenih. EMS je u zadnje dvije godine morao prilagoditi svoje planove takvim slučajevima zbog sve većeg broja nesreća i terorističkih napada. Ali takvi bi se planovi mogli osujetiti smanjenim proračunom i izvorima financiranja, a i brojem ambulantnih kola i njihovim položajem/lokacijom, te strategijom njihova slanja, što sve utječe na EMS. Dodatni faktor je promjenljivost u broju slobodnih ambulantnih kola u različito vrijeme tijekom dana. U svrhu održavanja pokrivenosti potrebno je pripaziti i da su ambulantna kola uvijek u stanju pripravnosti. U radu predlažemo model optimalizacije u EMS-u koji će pomoći kod medicinskih postupaka u regiji Karachi, Pakistan (uporabom podataka iz dvije godine, 2010. i 2011.). Također smo proveli i empirijsku analizu vremena reagiranja ambulantnih kola, njihovo vrijeme dolaska u bolnicu i vrijeme provedeno u bolnici. Korištene su Google mape kako bi se olakšalo praćenje i analiziranje mjesta nesreće uz pomoć GPSa ili nekog drugog izvora informacija. Fizikalna simulacija i rezultati su korišteni kao dio procesa planiranja što pokazuje integritet i učinkovitost vremenske granice temeljene na hitnosti pacijenta u vrijeme poziva (Spasilačka ekipa 15).

Ključne riječi: *Google kartiranje (Google Mapping), model pokrivenosti, EMS (služba hitne pomoći), opći sustav kartografije područja (UMT), središnja služba raspodjele hitne pomoći (MERGe)*

1 Introduction

EMS is a form of disaster service devoted to providing acute medical care, (Out-of hospital) service to people and patients in case of accidents and illness. These services play a leading role in saving road accident victims life through providing emergency treatment on the spot by trauma health care centres and in reducing threats in traffic safety systems. Threats can generally be reduced with the help of quick response of the strategic action plans. EMS is based on different components in the strategic action plans, e.g. prepared planning, response, recovery and mitigation. EMS providers use a tool called "Compliance Table" for day to day operation [1]. This table contains the pre-computed set of ultimate locations to place available ambulances. If the number of accessible ambulances changes, the ideal set of location may change. This change occurs due to several events, such as new call, a vehicle returning to service, etc. According to the survey of the emergency medical service in 2001, the regional Rescue 15 EMS received a large number of calls, because it is responsible for regional rescue. The Rescue 15 EMS received 48 165 calls in the month of July, 2012. In anticipation of this growth of calls, EMS demanded more facilities of the Rescue 15 to make it more efficient. The main purpose of this paper is to provide uniform operation background that makes an efficient EMS for Karachi, in Pakistan, so that trauma care centre can make the best strategic action plans for approaching to zero death levels. With the rapid growth in transportation engineering system, EMS has become the most important research field over the last few decades especially in [2, 3].

- Fire station and ambulance locations.
- The delivery of the ambulance/vehicle to the spot.
- Techniques, staff, the number and the type of vehicles
- System Status Management (for a dispatching vehicle).

The rest of this paper is organized as follows. In Section 2 we discuss the existing model of EMS system; Section 3 describes the features of our chosen EMS group known as Rescue 15. In Section 4 we present a new modelling technique of locating ambulances at work and in rest position. Section 5 concludes the paper.

2 Countermeasures of surveyed on modelling of EMS system

There are several existing methods for EMS systems. Most of the models follow the standard rules. At first, cities are separated out into small areas called "zones" instead of locating the call location. A call raised from any zone is considered as a zone centre and coverage and voyage or operational times are estimated simultaneously. The efficient accuracy is expected to become higher and higher in case of supplementary no of zones, Hillsman [4] and Rhoda in 1978 defined three basic errors that result from the creation zones.

A) Measurement of distance error for the call; it may happen if the original call location is not the incident place or fake call.
B) Measurement of distance error in case true location is unknown.
C) Vehicle dispatching error in case of not knowing the correct distance from EMS to aggregated zone.

2.1 Covering models (Probabilistic Location Models)

These types of problems are solved by different models. Church and ReVelle (1974) developed a probabilistic model that explains the process of locating a fixed number of models. According to the covering model "a zone is treated as covered if it is within the travel time of an ambulance" [16]. Also it is necessary that a vehicle should be available with a huge demand and dispatch calls. Daskin and Stern (1981) improved this idea by maximizing the number of zones covered by more than one ambulance. Covering methods are not appropriate and reliable enough for urban EMS needed [17]. The constant area over a period of time and ambulance availability on a base station is a requirement of these models. As in urban area the population is dependent upon whether people are in industrial, commercial or residential area, the demand of a particular service varies from time to time. A decision support system model is developed to overcome this problem of ambulance location with Lousiville K. Y. and John F. Repede develops a model known as TIMEXCLP [5, 6] focusing on time variation in maximal predictable reporting site dilemma (1994). Set covering is also used to eliminate ambulance problems. Toregas, et al. (1971) designed a set model; it reduces the cost by investigating minimum number of ambulances/ vehicle faces of all the zones. There is no regard to the demands of each zone or whether an ambulance is busy or available for use in a covering model. Deterministic approaches determine the demand, travel time and service time for these models. The same technological equipment is used to respond to the call, so there is no difference among the calls needing life support of any extra services. Busy vehicles did not get and regard [7]. That results in magnified probable values of system coverage. ReVelle improved this model (see, e.g., ReVelle, Cohen, and Elzinga (1980); ReVelle, Schweitzer, and Snyder (1996); ReVelle and Hogan, (1999)).

2.2 Queuing approaches

A queuing system normally consists of three components; Arrival Process, Service mechanism and Queue discipline. The arrival process is how a customer/caller goes through the system. If T_i is inter-arrival time, if $(i-1)$ and i the customer, the mean time (inter arrival time) can be denoted by $E(T)$ and call as $\mu = \frac{1}{E(T)}$. But due to some short outcomes these models are not suitable enough. The best approach in queuing strategy is hypercube model by Larson (1974, 1975) [8]. The model contains a set of vehicles working in a zone. Then the shortest path theory will be implemented to locate the ambulances' shortest distance. It is noted that either one vehicle is providing a service to the entire caller request, or that the vehicle is in busy state over a period of time. For accomplishing this system keep track of information and standards to respond a call. It will depend upon the circumstances the system is currently in. NP-complete model is achieved by 2_N states.

3 Overview of our purposed service (Rescue 15 Services)

Rescue 15 is an EMS service currently working in the area of Pakistan. It provides different services that mainly include:

- Crisis helpline (24-hours)
- Electronic Verification of vehicles
- Elite Crisis team
- Child Lost/Found Centre
- Antiriot Reserve
- Crime unit for Mobile
- Bomb Disposal Squad
- Reserved Police Armed force
- Fire Brigade
- IMEI System (for Mobile theft and snatches)
- CNIC card identification for Investigation
- Criminal Sketch for Investigation.

The calls of 15 are automatically received, responded, lodged and digitally recorded by three assistants through their computers. The caller data is recorded, such as caller name, time and date, address, concerned position, nature of crime, dispatched police mobile, etc. Team Leader (TL) is authenticated to listen between caller and assistant 15 (A15). Also TL has access to A15. In case of some wrong decisions TL provides instructions to A15 that are not hearable to caller. Then the TL forwards information to wireless and GPS in command that send police mobile to the incident.

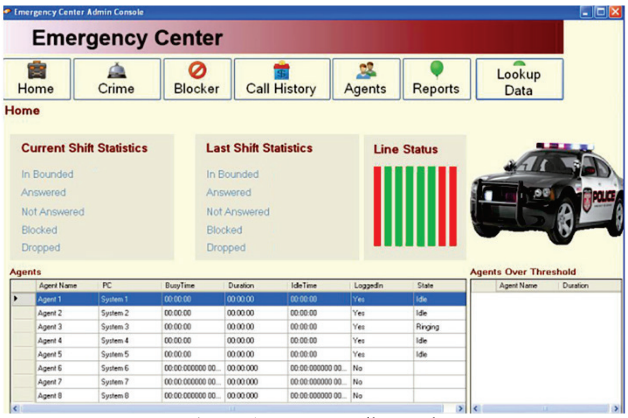

Figure 1 Frequent call records

GPS helps out to inform wireless centre about the position of the nearest patrolling vehicle. The response time for urban area is from 3 to 5 minutes and 7 to 10 minutes for rural areas. After arrival of patrolling vehicle to incident TL receives information ACK from wireless control office. After receiving an ACK, SMS is being sent to caller mobile on behalf of the SSP Karachi, Pakistan (as our concerned area is Karachi). Manual information about first information report (FIR) No, recovery of stolen, accident detail etc. are also recorded. In case of fight, if both parties are agreed to compromise then "offence has been compounded" and written on prescribed Performa as shown in Figs. 1 and 2.

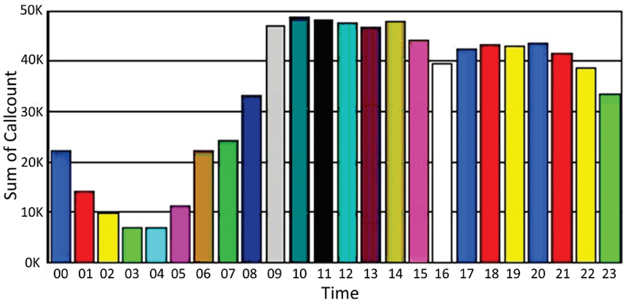

Figure 2 Hourly call graph at Rescue Karachi, Pakistan

The Rescue 15 is also responsible for stolen cars/ vehicle. Detailed data is recorded in 15 centres i.e. registration number, engine number and chassis number, etc. The information is available online for the customer satisfaction. The service is also accessible through sending an SMS to 8521. In Pakistan, National Database and Registration Authority (NADRA) and cell phone companies have a contract for verification of Computerized National Identity Cards (CNICs) through SMS to 7000. As well a person if send his/ her ID card number to 8300 to check vote status (Including electoral area name, block code and serial number, etc.). PTA formulates a system of tracking the location by IMEI number in case of mobile phone theft/ snatches. All mobile phone companies install EIR (electronic identification register) in their switches to block the phone over the country. Criminal Identification and sketching system (CISS) is a latest innovation of Rescue 15 service. The latest kit enables 15 to identify a wanted person. This will help to control the terrorism and crime throughout the country. For this reason CPLC software is used with the approval of FBI. Normally two types of systems are used for this identification. First is Imagine – criminal identification and sketching system as shown in Fig. 3 is a comprehensive tool that rapidly produces pictorial line-ups, news/ bulletins, such as missing and wanted persons. It reduces the time and efforts of performer design, as shown in Fig. 3.

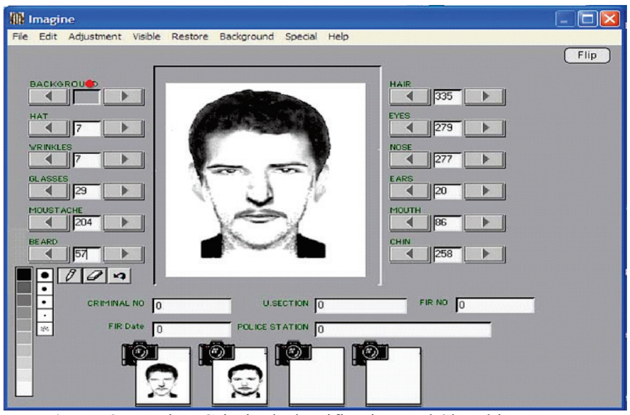

Figure 3 Imagine-Criminal Identification and Sketching system

Scenes of Crime Officer (SOCO) is responsible for gathering evidence against crimes for the Karachi police. It is referred by Forensic Scene Investigators (FSIs), Crime Scene Investigators (CSIs) or Crime Scene Examiners (CSEs). Evidence is then later passed to the detectives of the Criminal Investigation Department and to the forensic laboratories. Rescue 15 introduce investigation help centre in district Karachi are facilitating to use relevant data and scientific technology to investigate an incident and also involve adopting modern technology for crime prevention and detections.

4 Our proposed work (EMS modelling)

Before developing our own EMS system we thoroughly assessed the existing EMS system, also interviewed key managers and stakeholders. The entire analysis was based on two years particular data obtained from Rescue 15. The new provincial response time standards (t^{SLC}) have different response level categories (SLCs) depending on patient's symptoms [10]. Some calls require quick response action i.e. either an ambulance or fire vehicle in case of fire to respond within six minutes. To calculate all this we need to know about ambulance/ fire trucks/service vehicle location and number of SLCs in model construction. EMS data is recorded in term of Google maps strategy for our proposed system that uses Universal Transverse Mercator (UTM) mapping system [7]. The UTM system divides a geographic area into one square kilometre pockets. Each UTM is further represented by vertex (nodes).

Generally, let us assume D_p is the set of demanded location. We have an emerging vehicle/ambulance and S is the vertex set of Rescue station. F is the location set of fire vehicle/ ambulance and R is the set of area defined as $\left(D_\mathrm{p} \cup S \cup F\right)^2$. Our model defined as $G = \left(D_\mathrm{p} \cup S \cup F, A\right)$ i.e. $(i, j) \in R$, that is ambulance response time between i & j, call arrival rate by queuing theory is $\lambda_i, i \in D_\mathrm{p}$. The response time threat hold t^{SLC} is being calculated we use probabilistic coverage modelling to find the probability of ambulance location at vertex $j \in S$ dependent on $i \in D_\mathrm{p}$ in time is less than threshold time. The final expression to find the probability is $C_{ij}(t^{SLC})$. In the same fashion we can find the probability for fire truck, i.e. $F_{ij}(t^{SLC})$[12].

4.1 Modelling using covering approach

Let us assume utilization rate of each vehicle is ρ, our approach is based on Gendreau et al. [19]. 2006 but we changed some of the coverage constraints. Let $C_{ij}(t^{SLC})$ be a provision at station j to location vertex i given a threshold. We have several outcomes (Tab. 1) that include busy service, availability of vehicle with no service or availability of vehicle with limited threshold.

According to Tab. 1 only last outcome serves the incident successfully so that probability of S vertex is calculated by $S_{ij}^{SLC} = C_{ij}(t^{SLC})(1-\rho)$, where S_{ij}^{SLC}, a service ambulance at location j (probability) can reply to location i within specific time threshold [12]. If a service has more than one ambulance/vehicle for serving in case of incident let us assume x_j the probability is $S_{ij}^{SLC} = C_{ij}(t^{SLC})(1-\rho x_j))$ by increasing the No. of stations, the chance that one vehicle covered is (Eqs. (1) & (2)) and the sudden calls require a quick action tends to six minutes.

Table 1 Threshold outcomes

Out comes	Probability
Busy state (on service)	ρ
Available vehicle with no service within time	$(1-\rho)(1-C_{ij}(t^{SLC}))$
Busy vehicle (no call passable)	$\rho(1-C_{ij}(t^{SLC}))$
Available vehicle with on service within time	$C_{ij}(t^{SLC})(1-\rho)$

$$\sum_{j=1}^{m}(1-C_{ij})(t^{SLC})(1-\rho x^j)), \quad (1)$$

$$S_i^{SLC} = 1-\sum_{j=1}^{m}(1-C_{ij})(t^{SLC})(1-\rho x^j)). \quad (2)$$

4.2 Empirical analysis

For our optimization model we need to calculate various parameters. We consider a full year data from rescue 15 data base. The database has more than 30 000 calls per month without time span, time to hospital or time at hospital. To calculate the ambulance schedule for rescue 15 consider that ambulance is busy from the time crew member notified the incident suppose T1 until he is busy with patient on the way to discharge to hospital T2. The busy ambulance hours are calculated by summing T1 & T2. [13] For all calls during that time the utilization rate of ambulance is calculated by eq.3.

$$\rho = \frac{Total\ busy\ time}{Total\ available\ time}. \quad (3)$$

4.3 Binomial distribution test

The probability distribution of available ambulances and corresponding utilization rate is tested by binomial distribution test. For this we need to know the exact No. of busy ambulances, from Rescue database.

Suppose m No. of ambulance is $(A-m)$. The total available time is calculated as Eq. (4)

$$q_m = 1-\frac{Time(K-m)}{Total\ time}. \quad (4)$$

Gendreanin 2006, gives an idea that no ambulances in an EMS system should be based on binomial distribution, so that the probability of success p=1–ρ is the utilization rate of ambulance. The state of busy ambulances on July 09, 2010 is shown in Fig. 4. On demand, ambulance will be dispatched and the state of graph will change [9]. When ambulance finishes the call, the graph drops one unit. Five months data is being considered [14] for ambulance utilization. The empirical probability distribution for busy state ambulances is shown in Tab. 2.

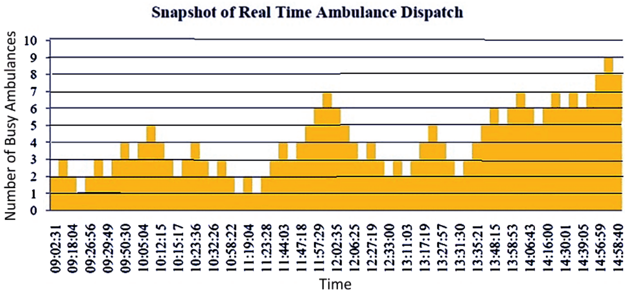

Figure 4 Busy Ambulances states on July 9, 2012

Table 2 Probability distribution for busy state ambulances

Busy Units	Quiet	Moderate Busy	Busy
0	5,67 %	0,50 %	0,07 %
1	9,76 %	1,07 %	0,04 %
2	23,35 %	8,49 %	0,80 %
3	19,44 %	15,24 %	2,56 %
4	12,80 %	18,66 %	7,86 %
5	9,36 %	15,99 %	10,87 %
....	....	....	....
....	....	....	....
19	N/A	N/A	N/A
Expected numbers	2,86	4,50	7,12

In a round robin fashion we can check the probability of ambulances available at all times. For example number of ambulances are 10, 12, 17 in time period (Quiet, Moderate busy, Busy), respectively. Then the ρ by empirical study is obtained as 28,9 %, 37,5 %, and 37,45 % respectively. The probability of success $1-p$ is calculated and obtained as 71,1 %, 62,5 % and 62,55 %. Then the value of q_m is obtained by the Eq. (5).

$$q_m = \binom{A}{m}p^m(1-p)^{A-m}. \quad (5)$$

4.4 Response time calculation

RTC is calculated by T1-T3, where T1 is busy time when an A15 responds to call and T3 is the time when the vehicle arrives on scene. Fig. 5 shows the average response time at several time spans. Ambulance location affects the response time.

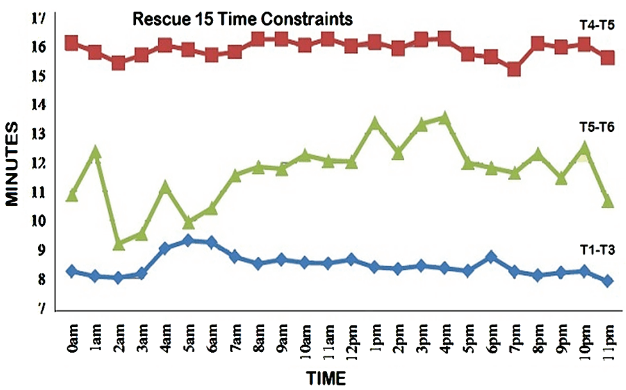

Figure 5 Service time correspondent calculation

4.5 Time on scene (T_4–T_5 and T_5=T_6)

T_4 − arrival on scene
T_5 − departure time
T_6 − arrival in hospital.

In a quiet period the average time on scene is 15,75 minutes, and there is only a minor change during busy time.

Table 3 Time variable calculation

Time matrix							
	Orangi	Landhi	Clifton	Others	Medical unit via orangi	Aga khan unit	CMH
Orangi	2	9	7	10	118	31	53
Landhi	9	1	21	21	110	23	65
Clifton	9	21	1	20	131	42	42
Others	8	19	18	23	128	44	62

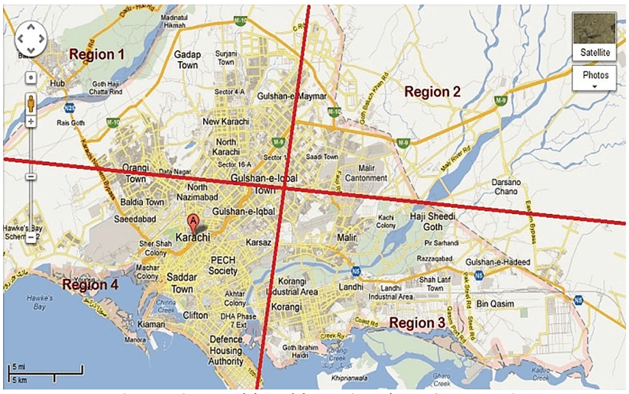

Figure 6 Karachi, Pakistan (Regions & Rescue)

EMS system paramedics stay with their patients while they wait to the admitted for care. The overload gives red alert and increased costs of EMS are 0 ÷ 20 minutes. The area of Karachi is divided into 4 regions for Rescue 15 system (as shown in Fig. 6) Time variable (in Tab. 3) was calculated from two factors. One is the use of Google map and the other is driving directions obtained from the Rescue centre [15].

4.6 Normal Call Calculation

Time between normal call is 192 minutes. This shows 6 normal calls during a day. As the previous data of Karachi is available so it is convenient to detect the normal or fake calls. According to the CMH and Aga khan medical unit survey the No. of emergencies completed by an ambulance is approximately 3,5 % of population per year. EMS system here is efficient enough to control the rate of causalities over a year.

4.7 Rescue Locations

Karachi is a part of Sindh, Pakistan. Disaster preparedness is something that this region has taken seriously. The system is known as MERGe [2, 7] Major Emergency Response Group. The communication between ambulance district, response plans and combine training is provided by the MERGe group. If in a region some type of disaster occurs within the coverage area, the MERGe ambulances provide the service at a glance.
Fig. 7 gives a pictorial view of ambulances participating in Rescue process MERGe group.

The time consumption is calculated through the graph theory using the vertex as a valued route. Tab. 4 is a clear image of each level of service and coverage of the model during n No. of calls. The planning shows the overall call coverage up to (86,30 %, etc.) in quiet period 84,20 %, in busy time 89 %. The average coverage time is 84,56 %, as shown in Fig. 7 and Tab. 4.

Table 4 Average time calculation of MERGe

Time period	$t(L)$	Initial %	Proposed %	Overall coverage / %
Quiet	10:30	28,93	22,30	94
Moderate	12	37,50	31,90	93
Busy	14	37,45	36,90	91

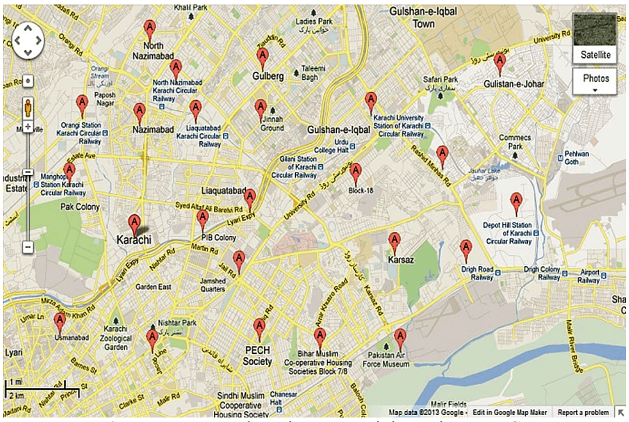

Figure 7 Rescue location to participant in MERGe

Fig. 8 shows the coverage area of an ambulance in a white marsh manner. The simulation result shows that the proposed modelling has a better converge time especially in busy time period.

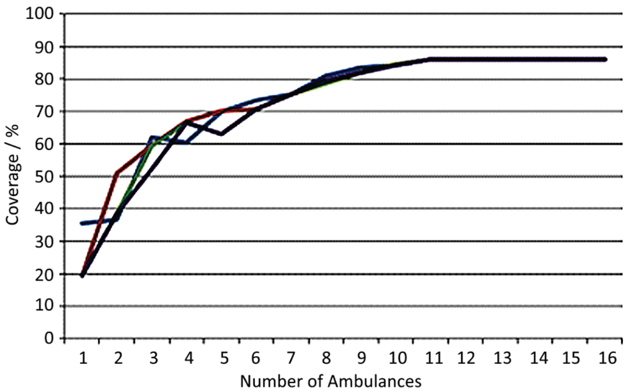

Figure 8 Rescue convergence time

5 Conclusion

In this empirical study we introduced a covering based probabilistic model for solving the problem of ambulance locations. The results show that the convergence time for high priority call is reduced by assigning a low priority tag to the normal and fake calls. The model shows that the No. of ambulances varies from time to time over the course of the day. The model has association with the fire department so that our model is suitable when analysing multi-region systems managed by a central planner, such as Region of Rescue 15 EMS system.

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