Designing Effective Ambulance Deployment Strategies – A Retrospective Study

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A. Background

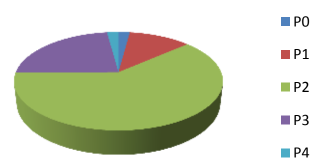
The Emergency Medical Services (EMS) of Singapore is managed by the Singapore Civil Defence Force (SCDF), which operates the national '995' emergency telephone services.

Currently there are 46 ambulances deployed in the fire stations or fire posts across Singapore. Due to an increasing and ageing population, the demand for EMS is expected to continue increasing over the next few years.

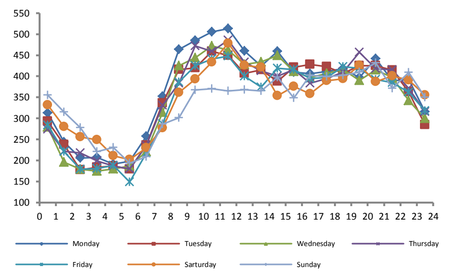
Studies have shown that EMS '995' calls are not random events, but occur in patterns and trends that can be observed from the retrospective data as shown on the left. The graphs on the right are plotted using the SCDF emergency calls data from 1 January to 30 June 2011.

The retrospective calls data shows not only the temporal patterns but also the spatial patterns across the island. The geospatial maps below shows examples of Monday's call data volume with distinct spatiotemporal patterns of the emergency calls spread across the island.

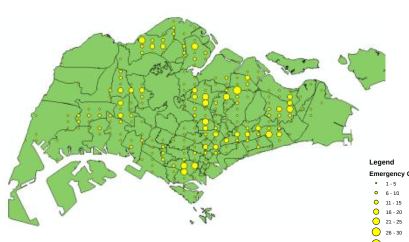
Patient Emergency Status



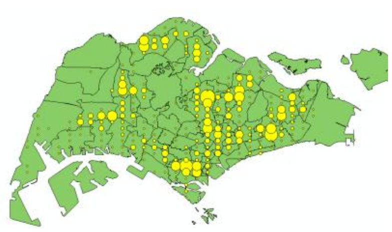
Total number of ambulance calls over 24 hours for all Mondays to all Sundays from 1 January to 30 June 2011

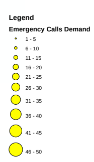


a. Monday 0000hr to 0600hr

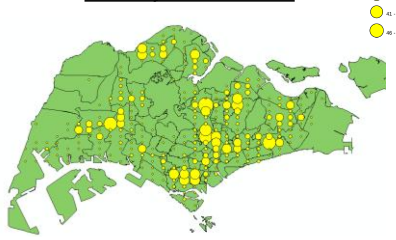


b. Monday 0600hr to 1200hr

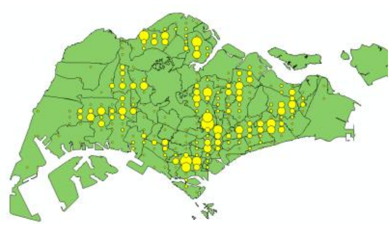




c. Monday 1200hr to 1800hr



d. Monday 1800hr to 2400hr



B. Aim

To develop improved ambulance deployment strategies for the allocation of ambulances to selected base locations so as to achieve adequate and timely coverage for emergency calls demands.

C. Methods

Dynamic ambulance deployment strategies that reallocate ambulances across different geographical regions over different time windows are developed using mathematical programming (MP) techniques.

The MP model seeks to maximize the coverage of emergency calls with primary and back-up ambulance base locations serving demands within pre-specified response time thresholds. The demands are characterized by significant temporal variations over different time of the day, day of the week and geospatial locations across Singapore.

Retrospective ambulance calls data in Singapore over a continuous period of six months from 1st Jan 2011 to 30th June 2011 was utilized for developing the model and dynamic allocation strategies. Exclusion criteria from this dataset were calls that did not result in any ambulance dispatch. Altogether 52,512 valid calls covering the entire Singapore were included in the study.

Example of MP model formulation

Maximize:

$$\sum_{i\in V, s\in S, t\in T} d_{i,s,t} x^2_{i,s,t}$$

Subject to:

$$\sum_{j\in W_i^2} y_{j,s,t} \geq 1 \quad (i\in V, s\in S, t\in T)$$

$$\sum_{i\in V} d_{i,s,t} x^1_{i,s,t} \geq \alpha \sum_{i\in V} d_{i,s,t} \quad (s\in S, t\in T)$$

$$\sum_{j\in W_i^1} y_{j,s,t} \geq x^1_{i,s,t} + x^2_{i,s,t} \quad (i\in V, s\in S, t\in T)$$

$$x^2_{i,s,t} \leq x^1_{i,s,t} \quad (i\in V, s\in S, t\in T)$$

$$\sum_{j\in W} y_{j,s,t} = p_{s,t} \quad (s\in S, t\in T)$$

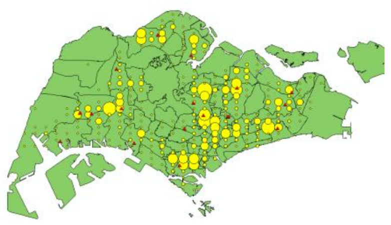
$$y_{j,s,t} \leq p_j \quad (j\in W, s\in S, t\in T)$$

$$x^1_{i,s,t}, x^2_{i,s,t} \in \{0,1\} \quad (i\in V, s\in S, t\in T)$$

$$y_{j,s,t}\ integer \quad (j\in W, s\in S, t\in T)$$

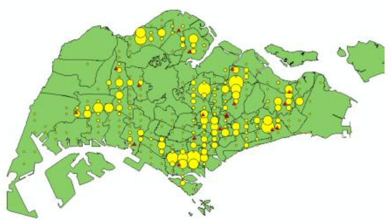
D. Results

Monday 1200hr to 1800hr

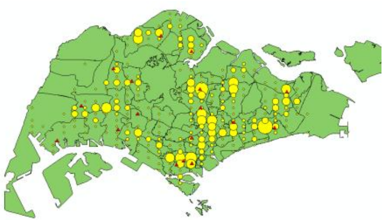


The MP modelling approach produced 28 optimal allocation plans for 4 shifts per day and 7 days per week. For each plan, a set of ideal candidate locations are chosen to cope with the geographical demands for the particular time period. As a result of the recommended plans, 52,419 out of 52,512 (99.823%) emergency incidents cases that happened during January to June 2011 are covered at least twice by ambulances placed at their nearby base locations. This is an improvement over the coverage observed from historical data.

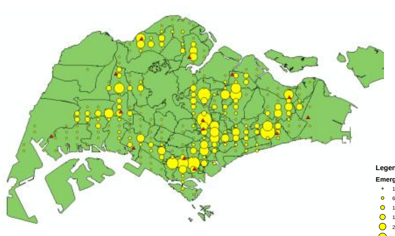
Tuesday 1200hr to 1800hr



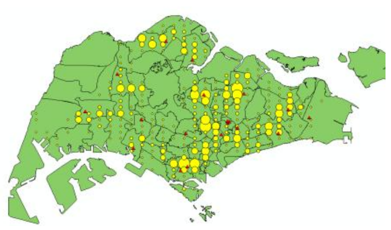
Friday 1200hr to 1800hr

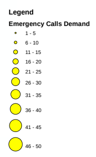


Wednesday 1200hr to 1800hr

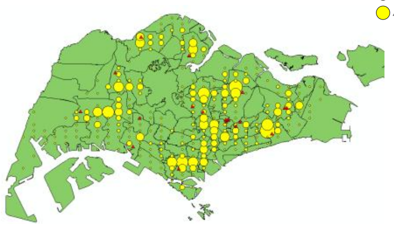


Saturday 1200hr to 1800hr

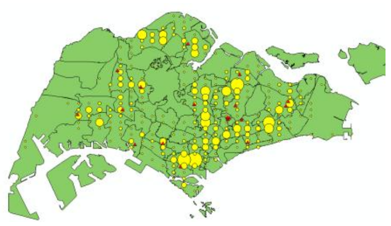




Thursday 1200hr to 1800hr

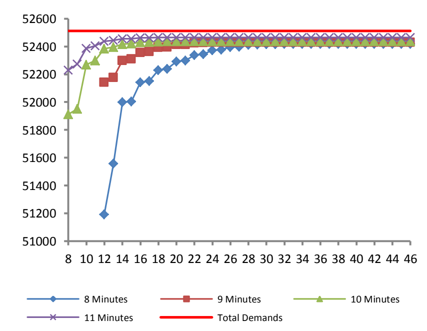


Sunday 1200hr to 1800hr



Sensitivity Analysis was carried out to find out the minimum number of ambulances required to achieve the maximum coverage of calls under each time standard. As can be seen from the table below, if the time threshold is set to be 8 minutes, then it requires a minimum number of 32 ambulances to achieve a maximum coverage of 52,419 out of 52,512 emergency incidents. As the time threshold standard is relaxed, the minimum number of ambulances required to achieve maximum coverage decreases, and the maximum coverage of incidents increases.

Demand coverage VS Number of ambulances



Minimum number of ambulances to achieve maximum coverage

Time Standard	Minimum Number of Ambulances	Maximum Coverage (Percentage)
8 min	32	52419 (99.82%)
9 min	24	52429 (99.84%)
10 min	21	52438 (99.859%)
11 min	18	52464 (99.91%)

E. Conclusion

MP is an effective tool for identifying optimal ambulance allocation plans at the strategic and tactical planning stage. The realism of the model and robustness of results can be further enhanced by considering uncertain and time-dependent travel times, the cost of relocating and maintaining ambulances, and uncertainty in incident occurrences. Given the inherent complexities of the actual system, MP can be coupled with discrete events simulation (DES) to examine the impact of policy changes and make recommendations on ambulance allocation strategies for more effective operational improvements.

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