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Research

Medical first response models in rural villages and towns: A simulation study of response times

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Abstract

Introduction
Medical first responders (MFR) shorten the response times and improve outcomes in, for example, out-of-hospital cardiac arrests. This study demonstrates the usability of open geographic data for analysing MFR service performance by comparing simulated response times of different MFR models in rural town and village settings in Finland.

Methods
Community first response (CFR) models with one to three responders obeying the speed limit were compared to a volunteer/retained fire department (FD) model where three responders first gather at a fire station and then drive to the scene with lights and siren. Five villages/towns, each with a volunteer/retained FD but no ambulance base within a 10 km radius, were selected to test the models. A total of 50,000 MFR responses with randomly selected buildings as potential responder and patient locations were simulated.

Results
In central areas, the simulated median response time for the one-responder model was 1.6 minutes, outperforming the FD model's simulated response time median by 4.5 minutes. In surrounding rural areas, the median response times of one- and two-responder CFR models were still shorter (15.0 and 15.9 minutes, respectively) than in the FD model (16.4 minutes), but the FD model outperformed the three-responder CFR model (16.8 minutes).

Conclusion
Open geographic datasets were useful in performing logistic simulations of MFR. Based on the simulations, CFR without emergency vehicles may reach patients faster than FD-based MFR in central areas, whereas in surrounding rural areas the difference is less pronounced.

Keywords:
emergency medical services; rural health services; spatial analysis; computer simulation

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Introduction

Medical first responders (MFR) are common in emergency medical services (EMS) to shorten response times. They improve survival in out-of-hospital cardiac arrests (OHCA) (1,2), although some studies have indicated that they have a negligible effect (3,4). Studies of trauma patients in low-income countries have shown improved survival rates with MFR systems in rural areas (5,6). Yet, in medical emergencies other than OHCA, the effect of MFR is mostly unknown. As most potential benefits of MFR seem to be associated with shorter delays in cardiopulmonary resuscitation (CPR) and defibrillation, decreasing response time appears to be a reasonable target in any EMS.

In Finland (excluding the autonomous province of Åland), EMS is organised into 20 hospital districts that are joint municipal authorities responsible for organising secondary care. By legislation, a hospital district may supply the service itself in co-operation with a regional fire department (FD), buy the service from a private company by public tender or organise the service with a mixture of these. MFR service is mostly provided by FDs, although a few other MFR service providers also exist (eg. volunteer lifeboat associations and Finnish Red Cross teams in mass gatherings). In small towns and villages, a local volunteer or retained FD usually provides the MFR services. They are dispatched by emergency response centres via the same dispatch system used in fire and rescue missions, using a TETRA-based radio network and/or mobile phone SMS messages (7). Dispatched volunteers first gather at a fire station, and an MFR team then drives to the scene using a rescue vehicle. Fire stations are generally located near village or town centres, leaving the smallest hamlets in dispersed rural areas without MFR services.

In this current Finnish practice (the FD model), the response team usually consists of at least three people, a practice justified by safety issues. Using fire vehicles is rationalised by faster response times with lights-and-siren (LS) driving. The fact that the existing fire and rescue service dispatch system can be used for this purpose has also been used as an argument for the current system.

However, MFR services can be organised in several ways. For example, the community first responder (CFR) system is common in the United Kingdom (8), Australia and New Zealand (9), and a layman response system utilising modern smartphone applications for locating and dispatching exists in various countries (10-12). In these settings, responders go directly to the scene with the necessary equipment.

The aim of this study is to demonstrate the usability of open geographic data for analysing and developing EMS systems and to compare the simulated response times of different MFR models in selected rural towns and villages and their surrounding areas.

Methods

Study design
A logistics simulation study based on real-world building locations and route networks.

Procedure
A virtual simulation approach was used instead of real mission data or real-time responder locations. Three different CFR models were compared to the reference FD model currently used in Finland (Table 1). To test the models, five rural villages or towns were selected around Finland with volunteer or retained FD but no ambulance base within a 10 km radius based on the corresponding author's expertise as a paramedic in Finland. Each FD's location was geocoded using a local address map. An open building address database published by the Population Register Centre was used for potential locations of FD/CFR responders and patients (13).

Table 1. Compared models

Model	Description
CFR 1	One CFR drives directly to the scene
CFR 2	Two CFRs drive directly to the scene, and the longest travel time is recorded
CFR 3	Three CFRs drive directly to the scene, and the longest travel time is recorded
FD (reference model)	Three responders drive to the fire station, and one minute after the last one arrives, they drive to the scene 20% faster than the speed limit

Most MFR missions are assumed to take place within a maximum 15 km distance from the fire station. This area within a 15 km drive was split between the town and village centres and the surrounding rural areas according to the densely populated area classification of the Finnish Environmental Institute, which is constructed on a 250 x 250 metre statistical grid based on building stock and population (14).

A Monte Carlo-style simulation has been used for analysing emergency logistics (15), and this study used a similar method to produce an adequate number of response times for comparing the outcome distributions of various MFR models. First, a random building within a 15 km drive from the fire station was chosen as the mission scene. Then, three random buildings within the designated town or village centre surrounding the fire station were chosen as the responders' origins. Drive times and distances from each origin directly to the scene and via the fire station were calculated and saved to a file. A purpose-made Python program utilising OpenStreetMap (14) data and the GraphHopper (15) routing engine were used to calculate drive time and distances between points. Default speed limit-based routing speeds were used for legs from the start point to the scene (CFR models) and to the fire station (FD model). Based on a review article on LS driving's effect on patient outcomes and safety (18), driving speed was increased by 20% to simulate LS driving from the fire station to the scene.

The procedure was repeated 10,000 times for all five areas, resulting in 50,000 simulations. Due to a positively skewed distribution of response times, medians and time ranges of 95% of missions (2.5% trimmed at each end) were reported. Statistical testing was not performed since the p-value depended on the number of simulations performed, thus making comparison between models unnecessary.

Ethics

The study is based on public data sources and does not contain patient or mission data, so no research ethics committee permission was acquired.

Results

Of the 50,000 missions simulated, 6310 missions took place in town and village central areas and 43,699 in surrounding rural areas. Within town and village centres, the median response time of all three CFR models were shorter than the median response time of the FD model. The shortest response time was in the one-responder model (CFR 1), with a 1.6-minute median response time (95% between 0.1 and 4.6 minutes).

Within the total area of the 15 km radius, the median response time for the three-responder CFR model (CFR 3, 15.7 minutes) and the FD model (15.5 minutes) were virtually the same (Table 2), while the median response times of the one- and two-responder CFR models were slightly shorter than in the FD model.

The cumulative percentages of response times in town and village centres (Figure 1) and surrounding rural areas (Figure 2) indicated that all CFR models outperformed the FD model. The FD model was faster than the CFR 3 model (a median difference 0.3 minutes) in surrounding rural areas.

Discussion

The results suggest that in small towns and villages and surrounding rural areas patients would be reached faster with CFR models than with the FD model currently used in Finland, especially in town and village centres. Based on the simulation, response times could be shortened by several minutes with the CFR models.

When responding to rural areas, the faster LS driving compensates for the time lost by gathering at the fire station in the FD model. The response time difference between the FD and CFR models decreases as the distance increases, but within a 15 km range the potential benefit of LS driving appears to be negligible compared to driving at the speed limit.

A simulation study setting allows the testing of complex service system changes that would be expensive and difficult to test in the real world. This study shows that relevant results can be achieved with a relatively simple, inexpensive method using open-access data and common software tools. We have also demonstrated how open datasets can be used to produce pragmatic research results in healthcare study settings.

In OHCA, the rule of thumb is that a patient's chance of survival decreases by 10% each minute until resuscitation efforts begin (19), and the time from collapse to the beginning of CPR and defibrillation are the most important predictors of survival (20-22). Hence, any method to shorten CPR and defibrillation delays will improve patients' prognoses and outcome, and even relatively small improvements in MFR response times improve their chances of survival.

The results are in line with previous studies (18-23). The benefit of LS driving in MFR operations is less significant than often thought. Most likely, these results are generalisable to any country or area with similar spatial features, and they encourage the real-world testing of various models to gather more evidence for improving MFR response times.

Limitations of the study

Simulation is always based on assumptions. For example, the LS driving speed may be higher or lower depending on vehicle type, weather and road conditions. Responders may drive faster than the speed limit to reach the fire station, or they may use other forms of transportation (eg. bicycle, moped) that may

Table 2. Simulated response time median and range with 95% of values in town/village centres and rural areas

		Town/village centre (n=6301)		Surrounding rural area* (n=43,699)		Total area* (n=50,000)	
		Median (minutes)	95% within	Median (minutes)	95% within	Median (minutes)	95% within
Model	CFR 1	1.6	0.1-4.6	15.0	2.7-30.3	14.0	0.7-29.9
	CFR 2	2.8	0.6-5.7	15.9	3.7-31.2	14.8	1.5-30.6
	CFR 3	3.9	1.0-7.1	16.8	4.5-31.9	15.7	2.4-31.4
	FD	6.1	2.6-10.0	16.4	6.0-29.3	15.5	4.0-28.8

*up to 15 km travel distance

allow shortcuts. Also, each building most likely has a different probability to act as a mission or responder location; the data contained no information about the number of residents or the exact use of the buildings. Obviously, non-residential buildings (warehouses, barns, etc.) have a much lower mission probability than a block of flats. Collecting real-world data on driving speeds and population are necessary to improve simulation accuracy.

However, volunteer FDs often have important, respected roles in their communities, and tampering with the existing system may face strong resistance. In consequence a study on real data may be challenging to perform, and its results may be biased. The purpose of this study was not to point out specific towns or villages but to evaluate the concepts. Due to the sensitive nature of the issue, we decided not to publish the names or locations of the study areas.

Financial issues were not within the scope of this study, as the cost structure of MFR in the different models is unknown. However, in CFR models more investment is needed in equipment, but there may be some savings in fire vehicle driving costs. In services where responders are paid for the time spent on missions or costs are otherwise compensated, decreasing the number of responders lowers costs. The cost effects of different MFR models on the whole EMS system should also be examined in future research.

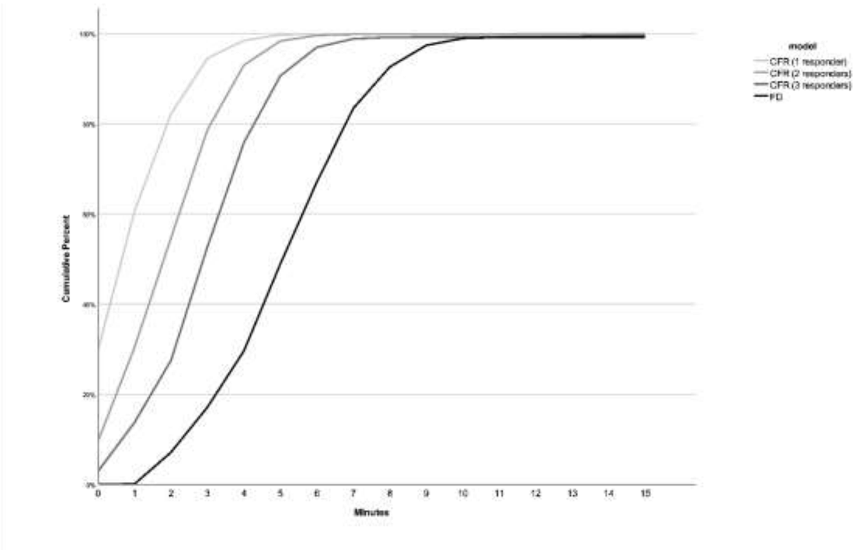

Figure 1. Cumulative simulated response times in town and village centres

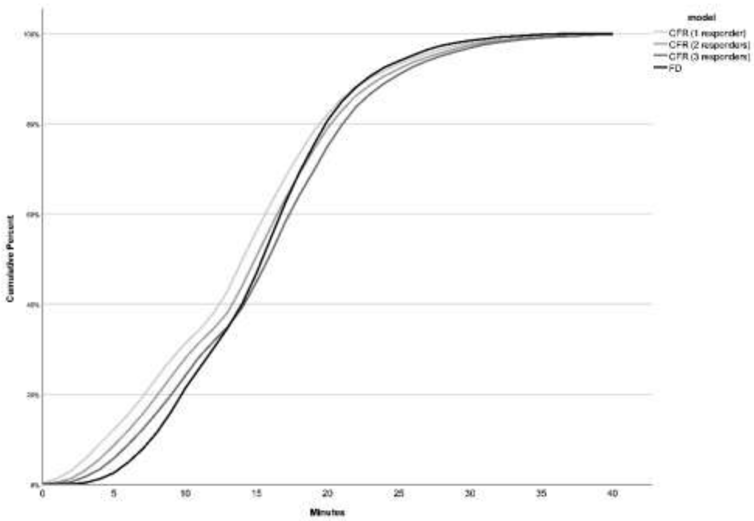

Figure 2. Cumulative simulated response times in surrounding rural areas (up to 15 km)

Conclusion

The utilisation of open geographic datasets was found useful in performing spatial analysis of EMS. Based on the simulations, in villages or towns without an ambulance base, CFR without emergency vehicle may reach patients faster than an FD-based MFR, whereas in rural areas the difference is less pronounced.

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Map data is copyrighted by OpenStreetMap contributors and is available from https://www.openstreetmap.org.

Competing interests

The authors declare no competing interests. Each author of this paper has completed the ICMJE conflict of interest statement.

Author contributions

JP was a major contributor to the conception and writing of the manuscript and contributed to the data interpretation. AO contributed to the analysis, interpretation of the results and writing of the manuscript. PL-N made substantial contributions to the conception, design, analysis and interpretation of the data and writing the manuscript. All authors have read and approved the final manuscript.

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