

Umsögn um tillögu til þingsályktunar um fasta starfsstöð þyrlu Landhelgisgæslunnar á Akureyri (þingskjal 334)

Þyrlur mannaðar læknum eru sífellt meira notaðar til sjúkraflutninga í þróuðum löndum, enda telja margir að gagnsemi þeirra við sjúkraflutninga sé oft mikil og felist hún í betra aðgengi að svæðum sem erfitt er að komast að með öðrum hætti, skjótum flutningi á starfsmönnum með mikla færni til flókinna ákvarðanatöku og læknisfræðilegra inngripa, og ekki síst skjótum flutningi á veikum eða slösuðum sjúklingum til viðeigandi sjúkrahúss.¹ Í nágrennlöndum okkar eru notaðar bæði sjúkraþyrlur (e. helicopter emergency medical service, HEMS) og björgunarþyrlur (e. search and rescue helicopters, SARH) sem eru búnaðar til sjúkraflutninga.^{2,3} Björgunarþyrlur eru oftast stærri og aflmeiri en sjúkraþyrlur, með fleiri áhafnarmeðlimi og meiri búnað, svo sem afísingarbúnað og öflugari ratsjár. Þær henta því oft betur þegar fljúga þarf í myrkri eða slæmu veðri og þegar hætta er á ísingu. Aftur á móti eru sjúkraþyrlur sneggri í snúningum og ódýrari í rekstri.

Ísland er um 103,000 km² að flatarmáli og teygir sig um 350 km frá norðri til suðurs og 500 km frá austri til vesturs. Sjúkraflug með flugvélum hefur lengi verið mikilvægur þáttur í bráðabjónustu í dreifbýli á Íslandi, en í nýlegri rannsókn kom berlega í ljós að viðbragðstími í sjúkraflugi með sjúkraflugvélum er oft mjög langur og mun lengri en í löndum sem við miðum okkur gjarnan við.³⁻⁶ Sjúkraflugvellir eru líka mun færri en áður var og slys og veikindi eiga sér oft stað fjarri flugvelli.⁷ Því er eðlilegt að velja fyrir sér hvort nota megja þyrlur í meira mæli til sjúkraflutninga hér á landi.⁸ Allar þrjár björgunarþyrlur Landhelgisgæslu Íslands hafa bækið á Reykjavíkflugvelli. Þær eru í vaxandi mæli notaðar til sjúkraflutninga, en þó sjaldan á Norður- og Austurlandi þar sem langur viðbragðstími dregur verulega úr notagildi þeirra í bráðatilvikum. Sjúkraþyrla hefur ekki verið starfrækt á Íslandi, en lagt hefur verið til að gera það á suðvesturhorni landsins.⁹ Breytingar á skipulagi sjúkraflugs á Íslandi eru því vonandi á næsta leyti og ráðamenn hafa tækifæri til að byggja þær á vísindalegum rökum.

Víða gilda ákveðin þjónustuviðmið um opinbera heilbrigðisþjónustu, oft tímalengd. Í Noregi var árið 2000 sett þjónustuviðmið fyrir bráðabjónustu utan spítala sem segir að sjúkraflutningstæki með lækni skuli ná til 90% íbúa innan 45 mínútna frá því að beiðni berst¹⁰ og lang oftast tekst það með þyrlu eða sérútbúnum bíl (e. rapid response car).¹¹ Hér á landi hafa slík þjónustuviðmið ekki verið sett, en sjúkraflugvél á að vera tilbúin til brottfarar innan tiltekinna tímamarka. Ísland er mjög strjálbýlt land með aðeins eitt háskólasjúkrahús og eitt kennslusjúkrahús þar sem hægt er að veita þróaða bráðabjónustu (e. advanced emergency care). Því gefur auga leið að aðgengi að slíkri þjónustu er mjög háð búsetu, en flestir óska sér þess að fá skjóta og sem fullkomnasta heilbrigðisþjónustu í bráðatilvikum, hvar svo sem þeir eru staddir. Sjúkraflug er mikilvæg leið til að auka jöfnuð í aðgengi að slíkri þjónustu og auka þar með sanngirni.

Vísindarannsókn til að velja réttar staðsetningar fyrir starfsstöðvar

Nýlega lauk teymi sem ég stjórnaði vísindarannsókn þar sem við reiknuðum út hvar best og sanngjarnast væri að staðsetja þyrlur til sjúkraflutninga á Íslandi. Niðurstöður rannsóknarinnar birtust í ritryndu tímariti, Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine (sjá fylgiskjal).¹² Við notuðum tvö flókin stærðfræðilíkön við þessa útreikninga. Fyrst notuðum við Maximal Covering Location Problem (MCLP) sem telst traust líkan og hefur oft verið notað til að finna bestu staðsetningar fyrir starfsstöðvar sjúkraflutningstækja.¹³⁻¹⁷ Líkanið hefur það markmið að þekja (e. cover) sem mest af eftirspurn, en tekur ekkert tillit til eftirspurnar sem liggur utan þjónustuviðmiðs. Til eru afbrigði af MCLP sem gera hvort tveggja og henta því vel til að finna sanngjarnar staðsetningar,

en hafa þó tiltölulega sjaldan verið notuð.^{16, 18-22} Við notuðum eitt slíkt afbrigði, svokallað Fringe Sensitive MCLP, hér eftir kallað FS-MCLP, sem miðar að því að hámarka eftirspurn sem er þakin, en lágmarkar líka (e. bicriterion) heildar fjarlægð og þar með tíma sem það tæki að ná til allra sem ekki næst að þekja innan tiltekins viðbragðstíma.¹⁸ Góð leið til að ná síðara markmiðinu er að uppfylla hið fyrra.²³ Forrita þarf sérstaklega hvernig líkanið vegur þessi markmið og var valið að leggja eins mikla áherslu og hægt var á það síðara til að leitast við að ná jöfnuði og meiri sanngirni í framboði á þjónustu.

Við útreikninga þarf að gefa ákveðnar forsendur. Til að áætla mögulega eftirspurn eftir þjónustu fyrir þyrlur til sjúkraflutninga á Íslandi notuðum við gögn frá Hagstofu Íslands um búsetu allra landsmanna og einnig gögn frá Neyðarlínu um staðsetningar útkalla í fyrsta forgangi (e. demand locations) á sjö ára tímabili. Það er ekki hægt að ganga að því sem vísu að búseta endurspegli eftirspurn eftir sjúkraflutningum þar sem veikindi og slys eiga sér gjarnan stað fjarri heimilum.¹⁵ Þetta á ekki síst við á svæðum eða tímabilum þar sem mikið er um ferðamenn. Auk þess getur eftirspurn verið breytileg milli svæða, t.d. vegna mismunar í aldursdreifingu sem hefur áhrif á líkur á bráðum heilsuvanda.²⁴ Það er heldur ekki víst að útköll í hæsta forgangi sem fara í gegnum Neyðarlínu endurspegli eftirspurn, meðal annars vegna þess að einhver hluti útkalla á björgunarþyrlum Landhelgisgæslunnar fer einungis í gegnum stjórnstöð hennar. Við framkvæmdum því alla útreikninga fyrir bæði búsetu og útkallsstaði.

Nákvæmar upplýsingar um útkallstíma (tímalengd frá boðun að flugtaki) í bráðaútköllum á þyrlum Landhelgisgæslunnar lágu ekki fyrir, en þar sem áhafnir þeirra eru ekki á staðarvakt á Reykjavíkflugvelli má áætla að hann sé að jafnaði ekki skemmri en 30 mínútur. Við fundum ekki dæmi um svo langan útkallstíma á sjúkra- eða björgunarþyrlum í nágrenni okkar. Í Noregi er miðað við að útkallstími sé ekki lengri en 15 mínútur og útkallstími á sjúkraþyrlum er í reynd aðeins 5.5 mínútur að meðaltali.^{5, 25} Við teljum líklegt að áhafnir á þyrlum Landhelgisgæslunnar muni áður en langt um líður fara að ganga staðarvaktir og völdum því að miða við 15 mínútna útkallstíma í útreikningum okkar. Flughraði (e. ground speed) á þyrlum er háður vindstefnu, vindstyrk og fleiri þáttum. Uppgefinn flughraði á þyrlum af þeirri gerð sem Landhelgisgæslan hefur til umráða er um 260 km/klst, en gera má ráð fyrir lægri meðalhraða í útköllum vegna landfræðilegra og veðurfræðilegra aðstæðna á Íslandi. Í nýlegri rannsókn á Nýja Sjálandi var miðað við 182 km/klst flughraða á sjúkraþyrlum,¹³ en við kusum að miða við 220 km/klst í okkar útreikningum, eins og gert var í norskum rannsóknum.^{14, 15} Við 60 mínútna viðbragðstíma er því gert ráð fyrir 15 mínútna útkallstíma og 45 mínútna flugtíma sem nægir til að þekja svæði með 165 km radíus.

Við forritun líkana var þeim gert að velja bestu staðsetningu og var gefinn möguleiki á að velja alla flugvelli sem eru notaðir reglulega fyrir sjúkraflug og nokkra landingastaði til viðbótar, alls 21 punkt vítt og breitt um landið, en þó ekki óraunhæfa valkosti á miðju hálendi eða fjarri mannabyggð. Líkönin hámarka þekjun á eftirspurn með þyrlu frá að minnsta kosti einni bækistöð, miðað við tiltekið þjónustuviðmið (e. service time or distance) og gefinn fjölda bækistöðva. Gert er ráð fyrir að þyrla sé alltaf til taks í bækistöð og að slæmt veður eða aðrar hindranir komi ekki í veg fyrir flug. Líkanið var forritað til að finna lausnir fyrir mismunandi þjónustuviðmið (viðbragðstími 45, 60 eða 75 mínútur) og eina til þrjár bækistöðvar. Tvær mismunandi sviðsmyndir voru settar upp; „Brownfield scenario“ þar sem líkanið staðsetur ávallt eina bækistöð á Reykjavíkflugvelli og „Greenfield scenario“ þar sem ekki er tekið tillits til fyrirleggjandi bækistöðvar á Reykjavíkflugvelli.

Niðurstöður

Mikilvægasta niðurstaða rannsóknarinnar var að mögulega mætti ná rúmlega 97% þekjun á eftirspurn eftir bráðaþjónustu utan spítala með þyrlum frá tveimur bækistöðvum. Þetta miðast við 60 mínútna viðbragðstíma og þar af færu 15 mínútur í að kalla út áhöfn og komast af stað. Fjölgun í þrjár

bækistöðvar myndi bæta litlu við þekjun, en myndi að sjálfsögðu draga úr líkum á að ekki væri hægt að sinna útköllum fljótt, til dæmis þegar þylur frá öðrum bækistöðvum væru uppteknar eða ekki flughæfar af einhverjum orsökum. Samkvæmt bæði MCLP og FS-MCLP líkönum væru ákjósanlegar staðsetningar fyrir tvær bækistöðvar á Húsafelli í Borgarfirði og Grímsstöðum á Fjöllum. Við val á staðsetningum þarf að taka tillit til margra þátta. Það yrði til dæmis mjög kostnaðarsamt að færa bækistöð frá einum stað til annars og rekstrarkostnaður yrði mun meiri þegar áhafnir þurfa að ferðast um langan veg til vinnustaðar og dvelja langdvölum að heiman. Einnig þarf að vera mögulegt að fá ýmiskonar þjónustu, t.d. sérhæfða viðgerðarþjónustu. Þegar þetta er tekið með í reikninginn er ljóst að skynsamlegt er að hafa bækistöðina áfram á Reykjavíkflugvelli. Grímsstaðir liggja miðja vegu milli Akureyrar og Egilsstaða, en staðsetning á bækistöð þar væri að mörgu leyti óheppileg, til dæmis vegna mikillar fjarlægðar frá nauðsynlegri þjónustu, mikils rekstrarkostnaðar og óhagstæðs veðurfars. Akureyri og Egilsstaðir koma hins vegar til greina. Á báðum stöðum eru alþjóðaflugvöllur með góðum aðflugsbúnaði, sem skiptir mjög miklu máli. Akureyri hefur ákveðna kosti umfram Egilsstaði; bærinn er margfalt stærri og þar er kennslusjúkrahús og löng reynsla af sjúkraflugi og því líklega auðveldara að tryggja mönnun og þjónustu. Mögulegt væri að ná um 94% þekjun frá starfsstöðvum í Reykjavík og á Akureyri, en 89% með starfsstöðvum í Reykjavík og á Egilsstöðum.

Umræður

Það er utan okkar sérsviðs að fjalla í smáatriðum um mun á tæknilegum atriðum og möguleikum sjúkra- og björgunarþyrla til að athafna sig við erfiðar aðstæður, en ljóst er að munur á þeim er mikill. Það nægir í þessu sambandi að benda á að Ísland hefur víðtækar skyldur varðandi leit og björgun á gríðarlega stóru hafsvæði umhverfis landið og veðurskilyrði til þyrluflugs á Norður- og Austurlandi eru vart betri en í vesturhluta Noregs þar sem mjög oft reynist ómögulegt að sinna útköllum með sjúkraþyrlum vegna veðurs.¹¹ Auk þess er árlegur fjöldi bráðaútkalla sem krefjast sjúkraflugs á Norður- og Austurlandi tiltölulega lítill og því skilvirkara að nota þylur sem geta nýst við margskonar verkefni, jafnvel þó svo að björgunarþyrlur séu yfirleitt mun dýrari í rekstri en sjúkraþyrlur. Samgirnir í aðgengi landsmanna að þróaðri bráðaþjónustu óháð búsetu (n. geografísk rettfærdighet) myndi batna verulega við það að staðsetja eina af þyrlum Landhelgisgæslunnar á Akureyri og það sama gildir um möguleika til leitar og björgunar með þyrlum. Við teljum að góð og sanngjörn lausn felist í að staðsetja eina af þyrlum Landhelgisgæslunnar á Akureyri og styðjum þessa þingsályktunartillögu heilshugar.

Fyrir hönd rannsóknarteymisins,

Dr. Björn Gunnarsson, svæfinga- og gjörgæslulæknir

Yfirlæknir sjúkraflugs, Sjúkrahúsinu á Akureyri

Dósent við Heilbrigðisvísindastofnun Háskólans á Akureyri

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ORIGINAL RESEARCH

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Locating helicopter ambulance bases in Iceland: efficient and fair solutions

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Abstract

Background Fixed-wing air ambulances play an important role in healthcare in rural Iceland. More frequent use of helicopter ambulances has been suggested to shorten response times and increase equity in access to advanced emergency care. In finding optimal base locations, the objective is often efficiency—maximizing the number of individuals who can be reached within a given time. This approach benefits people in densely populated areas more than people living in remote areas and the solution is not necessarily fair. This study aimed to find efficient and fair helicopter ambulance base locations in Iceland.

Methods We used high-resolution population and incident location data to estimate the service demand for helicopter ambulances, with possible base locations limited to twenty-one airports and landing strips around the country. Base locations were estimated using both the maximal covering location problem (MCLP) optimization model, which aimed for maximal coverage of demand, and the fringe sensitive location problem (FSLP) model, which also considered uncovered demand (i.e., beyond the response time threshold). We explored the percentage of the population and incidents covered by one to three helicopter bases within 45-, 60-, and 75-min response time thresholds, conditioned or not, on the single existing base located at Reykjavík Airport. This resulted in a total of eighteen combinations of conditions for each model. The models were implemented in R and solved using Gurobi.

Results Model solutions for base locations differed between the demand datasets for two out of eighteen combinations, both with the lowest service standard. Base locations differed between the MCLP and FSLP models for one combination involving a single base, and for two combinations involving two bases. Three bases covered all or almost all demand with longer response time thresholds, and the models differed in four of six combinations. The two helicopter ambulance bases can possibly obtain 97% coverage within 60 min, with bases in Húsafell and Grímsstaðir. Bases at Reykjavík Airport and Akureyri would cover 94.2%, whereas bases at Reykjavík Airport and Egilsstaðir would cover 88.5% of demand.

Conclusion An efficient and fair solution would be to locate bases at Reykjavík Airport and in Akureyri or Egilsstaðir.

Keywords Air ambulance, Facility location problem, Fairness

Background

Iceland is an island located in the North Atlantic Ocean, in the middle of a storm track that causes strong winds and frequent precipitation [1]. The landmass covers an area of 103,000 km², extending 350 km from north to south and 500 km from east to west. Iceland is the most sparsely populated country in Europe, with only 387,750 inhabitants as of January 1, 2023, and an average population density of 3.76 people/km². The population is

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unevenly distributed, with most people residing in the southwest part of the country where the capital Reykjavik is located. No one lives in the interior, which is characterized by glaciers, mountains, sand, and lava fields.

Hospital services are also unevenly distributed. A 700-bed national university hospital is located in Reykjavik. There is a 110-bed hospital with some medical and surgical subspecialties in Akureyri and three small hospitals, in Akranes, Ísafjörður, and Neskaupsstaður, that are capable of providing some emergency surgeries under anesthesia (e.g., appendectomy and cesarean section). Given this, providing quality emergency medical services to those in need is challenging. There is a single national emergency dispatch call center for the whole country. Incoming calls are classified by the emergency dispatcher, with the help of a computer program, into one of four priority groups. The highest priority is used for all life-threatening conditions, at the discretion of the dispatcher.

The country has recently become a major tourist attraction, with an estimated 2,400,000 tourists visiting the country in 2023. Many tourists travel by car and are more likely to be involved in traffic accidents than locals [2] who are more experienced in operating vehicles on gravel roads, passing single-lane bridges, and driving over mountain passes that can have ice and snow in any month of the year. Data collected by the Transportation Authority shows that 20.1 tourists per million died or sustained severe injuries in traffic-related accidents during the period of 2013–2022, and more than one-fourth of drivers injured in accidents during the peak years of tourism, 2017–2019, were either tourists or immigrants [3].

Survival probability for out-of-hospital emergencies is an indicator of the quality of care. Research has shown that factors determining survival include the response time of emergency medical services [4] and transport time to a hospital capable of managing emergencies appropriately [5, 6]. In many areas of Iceland, air ambulance services are the only means for rapid retrieval and transport of seriously ill and injured patients to advanced emergency care centers. Most people are flown to the national university hospital by fixed-wing air ambulances based in Akureyri, which transport approximately 200 patients with life-threatening illnesses or injuries per year [7]. Our recent study showed that the median response time for such transports is 84 min [7], during which local healthcare providers are compelled to manage ill and injured patients using limited means. The physician-manned Icelandic Coast Guard Search and Rescue helicopters based at Reykjavik Airport are used for some scene responses as well as secondary transfers—approximately 100–150

patient transports per year. However, the Coast Guard rarely responds to emergencies in the north and east parts of the country that are far away from the base in Reykjavik [8]. There are no other air ambulance bases in the country.

In Norway, one of Iceland's closest neighbors, the importance of timely response to emergencies is stressed by the government's official service standards (distance or time from facility); a physician-manned ambulance should be able to reach 90% of the population within 45 min [9]. The ability of helicopter ambulances to respond to scenes and access areas that are difficult to reach by other means helps the country to reach such goals [10]. Seriously ill and injured patients may benefit from timely decision making and procedures performed by highly trained physicians on board [11], as well as rapid transport to an appropriate hospital. The Icelandic authorities have realized this and intend to locate the country's first helicopter emergency medical service base somewhere in the southwest, but details have not been provided publicly [12]. An official service standard for air ambulance service in Iceland has yet to be set. The Icelandic standard may need to be less stringent than the Norwegian one because of Iceland's lower population density. The location of helicopter ambulance bases will determine who in the population can or cannot be reached within the set service standard.

A frequently used model for siting ambulance bases is the robust maximal covering location problem (MCLP) [13–17]. The MCLP model aims to maximize coverage of demand within the set service standard (distance or time from base), and the optimal model solution inevitably favors those living in densely populated areas. The model ignores the distance/time for demand beyond the service standard, which can disadvantage people living in the most rural and remote places. Recent research has questioned whether the most efficient use of ambulance resources is fair [18]. The concept of fairness can be included in location problems, and the outcome of such models will likely site bases slightly further away from densely populated areas, which may well introduce additional logistical challenges [16]. The fringe sensitive location problem (FSLP) [19, 20] model provides a relatively simple means to incorporate fairness by optimizing a weighted sum of coverage and distance for those who are not covered within a set service standard [16]. Another means to incorporate fairness is to exclude demand that might be covered using physician-staffed rapid response car, which is faster than helicopter ambulance within variable distance or time [21]. The aim of this study was to use the MCLP and FSLP models to find optimal and fair locations for helicopter ambulance bases in Iceland.

Methods

Data material

We used aggregated population and incident data as a proxy for possible demand for helicopter ambulances. Statistics Iceland produced data on a fine grid with 1 km² cells to provide detailed information about the population density of Iceland on January 1, 2022. The National Emergency Number Service provided and gave permission to use incident data for the period from December 2015 to August 2022 (93 months). Ambulances responded to a total of 45,394 highest-priority incidents during this period. Of this total, road ambulances responded to 43,983 incidents, fixed-wing air ambulances to 1216 incidents, and Coast Guard helicopters to 195 incidents. The data included exact locations (latitude and longitude) of each incident, which were aggregated to the same fine grid cells as population data for de-identification. Relative population and incident density in each 1 km² cell were compared using Pearson's correlation coefficient to measure the linear correlation between the two measures of demand.

We applied to the National Bioethics Committee for study permission (referral no. 22–125), which determined that ethics approval was not required.

Service standard—response time

The service standard is the desired maximal travel distance or time from the facility to the demand location. In the context of this study, it is the time from an emergency call until the moment of helicopter arrival, referred to as the response time. It consists of a reaction time, which includes the essential preparations for a flight, followed by the flight time. There is no literature on helicopter ambulance reaction times in Iceland. In our models, we used a 15-min reaction time, which is the maximum allowed time for helicopter ambulances in Norway [22], followed by the desired maximal flight time of 30-, 45-, and 60-min. In the mathematical models, we used an average helicopter speed of 220 km/h, a number used in similar studies [14, 15].

Models

As a proxy for demand for ambulance helicopters, we used, in turn, all populated cells and all cells containing incidents. It was not realistic to use all the demand locations as potential base locations. Instead, we used all 15 airports in Iceland that are used by the fixed-wing ambulance service and six additional airstrips, for a total of 21 potential bases that span all inhabited parts of the country, but exclude the interior.

The optimal base location was determined by applying the MCLP model that maximizes demand and is covered by at least one helicopter ambulance base within the

desired response time. The model does this by weighing demand (i.e., cells with more numbers are more likely to be covered than cells with fewer numbers). The model implicitly assumes that each base has an available helicopter at all times. We explored this for 45-, 60-, and 75-min response times and one, two, or three potential helicopter bases.

We addressed fairness in ambulance helicopter base locations using the FSLP. This model has two objectives: to maximize coverage of demand (efficiency) and minimize the weighted response time for those not covered within the service standard (fairness). It does not require a solution that maximizes coverage, but one of the best ways to fulfill the second objective is to cover as much demand as possible within the service standard [20]. The weights for the two objectives were set to 1 and 1000, respectively, to emphasize the fairness objective. The basic idea is to provide some degree of equity by locating facilities closer to demand that is not currently covered. In Additional file 2, we provide details about the FSLP model.

Using both population and incident data, we first modeled base locations conditioned on the existing base at Reykjavík Airport, which is referred to as brownfield analysis. We also computed the optimal and fair base locations assuming no bases existed, which is referred to as greenfield analysis. This resulted in a total of eighteen combinations of conditions for each model. It may be irrational to use helicopters when a physician-staffed rapid response car can respond faster. We therefore repeated the analysis with 18,722 (41.24%) incidents that were greater than 10 km straight-line distance and 15,816 (34.84%) incidents that were greater than 30 km straight-line distance from Landspítali—the national university hospital of Iceland. Finally, we repeated the brownfield analysis with 26,258 (58.5%) incidents that occurred prior to the onset of the COVID-19 pandemic in March 2020, as the pandemic likely affected the distribution of calls for assistance. The models were implemented in R and solved using Gurobi [23].

Results

Figure 1 shows the population density of Iceland in 1 km² cells. On January 1, 2022, the population was 376,230, and only 3710 of the cells were inhabited. The number of people in the inhabited cells was heavily skewed, with a median (5–95 percentile) of 4 (1–392). Figure 2 shows the incident density (heat map) in the 1 km² cells. Only 2145 cells had one or more of the highest priority incidents. This was also heavily skewed, with a median (5–95 percentile) of 2 (1–112). Figure 3 shows the correlation between the two sets of data. The Pearson's correlation coefficient was 0.89. Figure 4 shows a map of Iceland with

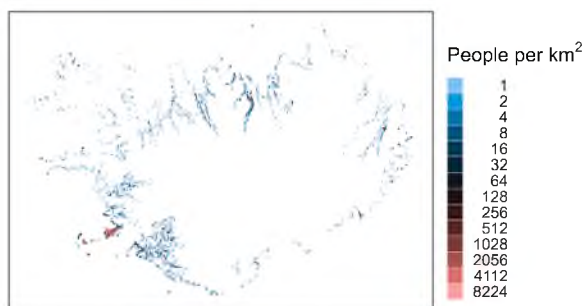


Fig. 1 Population density of Iceland as of 2022 in 1 km² cells

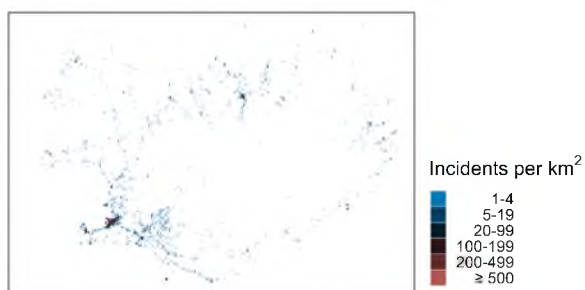


Fig. 2 Highest priority incident density in Iceland for December 2015–August 2022 in 1 km² cells

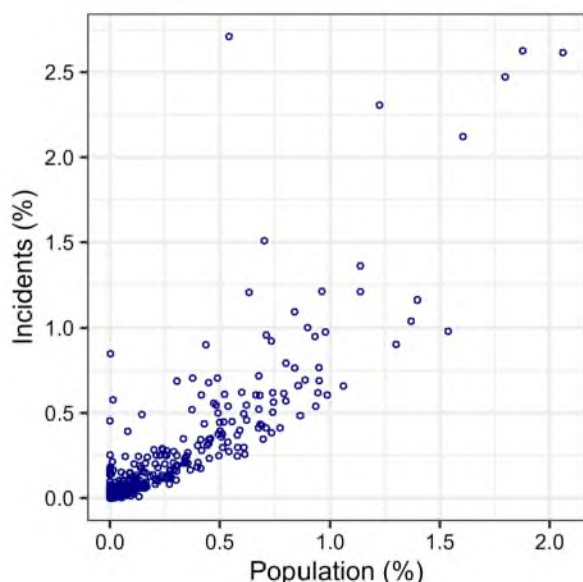


Fig. 3 Correlation between the two sets of demand data

possible base locations randomly numbered. These base numbers are used in Tables 1 and 2.

Optimal solutions for incident data are shown in Table 1, displaying coverage percentage for each combination: one, two, or three helicopter bases; 45-, 60-, or

75-min response time; and greenfield or brownfield scenario. The solutions for population coverage percentage were identical to those shown in Table 1, with two exceptions shown in the footnotes. Six of 21 potential bases were never used. Base locations differed between brownfield and greenfield scenarios in thirteen of the eighteen combinations.

Base locations differed for one combination between the MCLP and FSLP models when siting one base with 45-min response time in a greenfield scenario; the MCLP model located the base at Reykjavík Airport, but the FSLP model sited the base further east, in Flúðir. Base locations differed for one combination in each scenario between the models when two bases were sited at 45-min response time; the MCLP model located the second base in Sauðárkrúkur, but the FSLP model located it further east, in Grímsstaðir. Three bases covered all or almost all demand with longer response times, and base locations differed for four of six combinations.

With only one helicopter ambulance base, it would not be possible to obtain 90% coverage within a 75-min response time (lowest service standard) unless the base was moved from Reykjavík Airport to Húsafell. Adding a base at Egilsstaðir would increase coverage to 100% within 75 min. For a 60-min service standard, 97% coverage is possible with two bases located in Húsafell and Grímsstaðir. This same response time in a brownfield scenario with the second base located at Egilsstaðir would suffice to cover 88.48% of incidents, and if a second base were located in Akureyri, the coverage would be 94.16%. Figure 5 shows the effect of moving or adding bases on incident coverage for different response times.

Solutions for incident data that are greater than a 10 km straight-line distance from the University Hospital of Iceland are shown in Table 2. Base locations differed from those in Table 1 for five of 12 combinations when three bases were sited, and the coverage percentage was lower—particularly when only one base was sited. Base solutions for incident data that are greater than a 30 km straight-line distance from the hospital were identical for all but one combination (see Table 2 footnote). Solutions for incident data prior to the onset of the COVID-19 pandemic are shown in Additional file 2. Base solutions differed from those in Table 1 for half of the combinations when three bases were sited, but coverage percentage was almost identical.

Discussion

The most important finding of this study is that 97% coverage of estimated demand for out-of-hospital emergencies in Iceland is possible with the addition of one helicopter ambulance base. This is true for a 60-min



Fig. 4 Possible sites for base selection by the location models. The large circles show the area that can be covered within 60 min from bases at Reykjavík Airport, Akureyri and Egilsstaðir. The background image was reprinted from <https://geo.vedur.is> with permission from Veðurstofa Íslands

Table 1 Location of bases for combinations of one, two, and three bases and 45-, 60- and 75-min response times in brownfield (brown cells) and greenfield (green cells) scenarios for the MCLP and FSLP models. Coverage of population and incidents is shown in percentages

	Response time (minutes)	One base			Two bases			Three bases		
		Location	Coverage (%)		Locations	Coverage (%)		Locations	Coverage (%)	
			Population	Incidents		Population	Incidents		Population	Incidents
MCLP	45	6	81.80	81.80	6, 17	91.75	91.75	6, 17, 21	94.93	94.66
	60	6	84.35	84.35	6, 10	97.27	97.27	5, 6, 8	99.64	99.44
	75	6	86.81	86.81	1, 6	98.82	98.82	6, 12, 15	100.00	100.00
	45	6	81.80	81.80	6, 17	91.75	91.75	6, 17, 21	94.93	94.66
	60	16	86.33	86.33	10, 16	97.92	97.92	10, 18, 19	100.00	100.00
	75	16	95.47	95.47	5, 16	100.00	100.00	5, 14, 20	100.00	100.00
FSLP	45	6	81.80	81.43	6, 10	90.51	90.89	6, 10, 12	94.62	94.22
	60	6	84.35	84.42	6, 10	97.27	97.34	5, 6, 8	99.64	99.44
	75	6	86.81	86.73	1, 6	98.82	99.15	6, 10, 19 ^a	100.00	100.00
	45	7	80.45	80.82	6, 10	90.51	90.89	6, 10, 12	94.62	94.22
	60	16	86.33	86.22	10, 16	97.92	98.14	10, 18, 19	100.00	99.44
	75	16	95.47	95.45	5, 16	100.00	100.00	3, 6, 10 ^b	100.00	100.00

The table shows base locations for the incident data. Using population data resulted in different base locations for two combinations: ^a6, 11, 17 and ^b4, 5, 6

response time in which the first 15 min are used for crew scrambling and flight preparation. Adding a third base would add little to the coverage.

It is very expensive to open and run helicopter bases and therefore unlikely that more than two helicopter ambulance bases will be operated in Iceland in the foreseeable future. According to both models used, the optimal location of the two bases would be Húsafell in the southwest and Grímsstaðir in the northeast. However, many factors must be considered in the selection of bases for helicopter ambulances. It is expensive to relocate an

established base and more expensive to run a base when the staff has to travel long distances from home to work and remain there for days. It is also important to have sufficient access to different services, for example specialized maintenance. It is therefore almost certain that the base at Reykjavík Airport will not be moved.

Grímsstaðir is a farm settlement beside the main road between Akureyri and Egilsstaðir. Locating a second base in Grímsstaðir is infeasible for many reasons (e.g., lack of necessary infrastructure, lack of nearby services, and a very harsh climate). Akureyri and Egilsstaðir both

Table 2 Location of bases for combinations of one, two, and three bases and 45-, 60-, and 75-min response times in brownfield (brown cells) and greenfield (green cells) scenarios, showing coverage for incidents that are greater than a 10 km straight-line distance from the University Hospital of Iceland

	Response time (minutes)	One base		Two bases		Three bases	
		Location	Coverage (%)	Locations	Coverage (%)	Locations	Coverage (%)
			Incidents >10 km		Incidents >10 km		Incidents >10 km
MCLP	45	6	54.98	6, 17	78.50	6, 17, 21	87.06
	60	6	62.24	6, 10	93.56	6, 10, 12	98.61
	75	6	67.83	1, 6	97.94	6, 12, 15	100.00
	45	6	54.98	6, 17	78.50	6, 17, 21	87.06
	60	16	66.60	10, 16	95.50	10, 18, 19	99.98
	75	16	88.97	10, 16	97.94	6, 12, 15 ^a	100.00
FSLP	45	6	54.97	6, 10	77.91	6, 10, 12	85.98
	60	6	62.23	6, 10	93.55	6, 8, 10	98.61
	75	6	67.82	1, 6	97.94	6, 8, 15	100.00
	45	7	53.49	6, 10	77.91	6, 10, 12	85.98
	60	16	66.58	10, 16	95.50	10, 18, 19	99.98
	75	16	88.96	10, 16	100.00	5, 15, 16	100.00

Using data for incidents that are greater than a 30 km straight-line distance from the hospital resulted in different base locations for one combination: ^a5, 14, 20

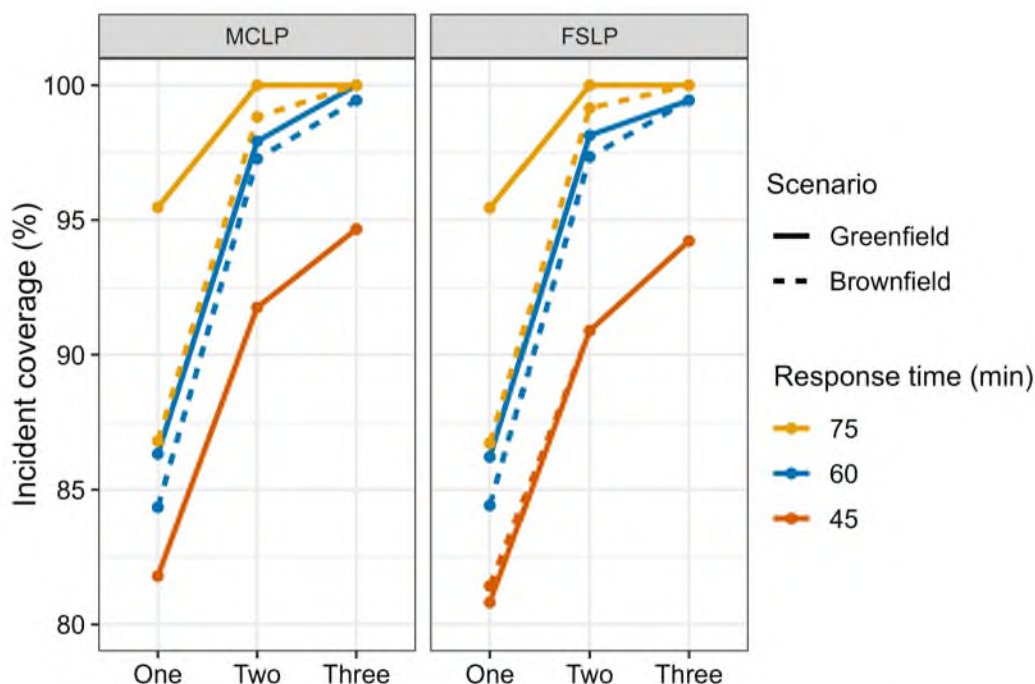


Fig. 5 Coverage of incidents for combinations of one, two, and three bases and 45-, 60-, and 75-min response times in brownfield and greenfield scenarios for the MCLP and FSLP models

have international airports with the possibility for instrument approaches, which is important considering the climate in Iceland. Akureyri is a town of 20,000 residents with a hospital and necessary infrastructure and services. Locating a new base there would increase coverage for large areas that are underserved today. However, locating a base in Egilsstaðir would likely be favorable to people in

the eastern part of the country, where the availability of advanced emergency care is limited.

One strength of this study is the quality of data regarding population and incident locations. Few, if any, studies have used data at this level of granularity for an entire country for the purpose of locating ambulance helicopter bases. It cannot be taken for granted that population

density mirrors demand for ambulances, as injuries and illnesses often take place far from home [15] and many incidents involve tourists who do not reside in Iceland. Furthermore, demand can vary between regions (e.g., due to differences in age distribution that have an impact on the likelihood of an emergency) [24]. A study from Norway concluded that it is better to use incident data than population data [15], but our study showed only minor differences, which were limited to the lowest service standard. It is possible, however, that our results could have been impacted by the low frequency of tourist-related emergencies during the COVID-19 pandemic, which overlapped, in part, with the historic incident data. We accounted for this by modeling incident data that was dated prior to the onset of COVID-19 in a brownfield scenario and found that solutions were the same as those based on data for all incidents, except when three bases were sited and coverage was complete or almost complete—as several base solutions are almost equivalent given such conditions. Another potential limitation is the fact that requests for helicopter assistance frequently go directly to the Coast Guard Operations Centre and are not recorded by the national emergency number. Such requests may involve patient transport with the highest priority, but we were unable to obtain accurate data about such missions and acknowledge that this may have influenced our findings.

Most of the literature on ambulance locations has examined how to efficiently allocate resources, and the most widely used measure for efficiency is expected coverage [25]. However, an overarching goal of Icelandic air ambulance services must be to increase equity or fairness in access to advanced healthcare for all. Equity has been evaluated in models for ambulance coverage [18, 26, 27], but there is no consensus on the best way to do this [27]. To our knowledge, the FSLP model has not been used to locate helicopter ambulance bases. The solutions from this model differed from the MCLP model for seven of the eighteen combinations, in some instances with significant consequences for those living in remote and rural places. This was perhaps most obvious when the second of two bases was located in Sauðárkrókur by the MCLP model—leaving the whole eastern part of the country largely uncovered. We find it a major advantage that the model objectives are easily explained and do not require interpretation or special knowledge to understand [18]. Maximum efficiency is not fair to people in remote and rural parts of Iceland. We found the FSLP model to be superior to the MCLP model for locating facilities in our sparsely populated country, even though the models concurred in the likely scenario of two bases and 60-min response time.

Modeling efficient and fair locations for ambulance helicopter bases is by no means a simple task, and methods that are appropriate for locating other services, such as road ambulances or automatic external defibrillators, might not be ideal for this purpose. The coverage construct is based on the notion that the benefit of service is of some positive value [16]. In contrast, the benefit of helicopter ambulance response, as opposed to ground ambulance response, starts some time or distance away from major hospitals, depending on weather, traffic, and other factors [21]. Some helicopter ambulance services even use rapid response cars when cars are deemed to be superior to helicopters or when weather conditions prohibit flying [28–30]. The relative benefit of helicopters over ground ambulances beyond this distance must be some function of distance or time, and the transport time to a hospital clearly impacts patient outcomes. This is, for example, true for patients with time-critical conditions, such as ischemic stroke, for which the benefit of thrombolysis given at a hospital rapidly declines with time [31]. We consider it a potential weakness of both models used in our study that demand close to hospitals has equal weight as demand further away from hospitals. We addressed this by re-running the models after the exclusion of all incidents within a 10 km and a 30 km straight-line distance from the national university hospital in Reykjavík and found that neither changed the outcome when one or two bases were sited. However, this clearly showed that coverage from the existing base is poor.

Conclusion

An efficient and fair solution is to locate helicopter ambulance bases at Reykjavík Airport and in Akureyri or Egilsstaðir.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13049-023-01114-9>.

Additional file 1: Formulation for the FSLP.

Additional file 2: Table 3. Location of bases for combinations of one, two, and three bases and 45-, 60-, and 75-minute response times in the brownfield scenario showing coverage of incidents prior to the COVID-19 pandemic.

Acknowledgements

We thank the Icelandic Centre for Research and the Akureyri Hospital Research Fund for their financial support.

Received: 4 June 2023 Accepted: 4 September 2023
Published online: 01 November 2023

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