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EDEN - Enhanced Dispatch for Efficient Neurointervention: mathematical model from national data

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Abstract

Background Mechanical thrombectomy (MT) has been proven to be an effective treatment for large vessel acute ischemic strokes. A debate is ongoing about whether to use the mothership or the drip-and-ship strategy for stroke patient transfers. Precious time could be lost if prehospital triage is incorrect. Combining a helicopter with an ambulance on the ground may further reduce prehospital delays.

Methods We conducted a single MT-capable center mathematical model study to assess how many individuals could reach Tampere University Hospital (Tays) within a 120-minute time limit. Population data were obtained from the Finnish Institute of Health and Welfare. Finland is divided into 1-square-kilometer grid cells in the dataset. Travel times were calculated using OpenRouteService. The primary outcome was the number of individuals reaching Tays within the time limit. We evaluated three scenarios: (1) ground transportation only, (2) the Emergency Medical Services (EMS) personnel dispatch the Helicopter Emergency Medical Services (HEMS) unit after being on scene for 10 minutes, and (3) HEMS and EMS are dispatched at the same time.

Results In the first scenario, 1,016,180 individuals could reach Tays within 120 minutes. When ground transportation is combined with a helicopter, 981,391 more individuals could reach Tays within time in scenario 2 settings, corresponding to a 97% increase. Simultaneous dispatch of EMS and HEMS further increased the population reaching Tays with 37,495 individuals. A total of 2,035,067 individuals lived within 120 minutes of the MT center we studied.

Conclusions A hybrid transportation strategy improved access to MT in a single center study. The use of a helicopter nearly doubled the population in the catchment area of Tays, while early recognition of large vessel occlusion stroke provided only a modest additional increase in the number of individuals accessing Tays within the time limit.

Keywords Air ambulances, Emergency medical services, Stroke, Thrombectomy, Transportation of patients, Health services accessibility

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Introduction

Strokes were the third leading cause of death in 2021 and the fourth leading cause of disability-adjusted life years lost worldwide [1]. Acute ischemic stroke destroys millions of neurons each minute while the cerebral artery is blocked [2]. Therefore, rapid revascularization is critical to improving neurological outcomes [3].

Non-LVO (large vessel occlusion) strokes are preferably treated with intravenous thrombolysis in the nearest certified stroke center [4, 5]. Mechanical thrombectomy (MT) has been shown to be beneficial for most people with an LVO [6]. MTs are concentrated only in comprehensive stroke units. University hospitals in Finland fulfill the criteria required to provide MT.

Two main transportation strategies are used for patients suspected of having an LVO: the "mothership" strategy, when patients are taken directly to a comprehensive stroke center (CSC), and the "drip-and-ship" strategy, when patients are first treated at a primary stroke center and then transferred if necessary to a CSC.

Precious time may be lost if prehospital triage is incorrect, which could lead to treatment delays, especially in rural areas. A debate is ongoing regarding whether patients with severe stroke symptoms should be transported directly to the MT-capable center or to the nearest primary stroke center [7–9]. Helicopters may be used under predetermined conditions to reduce prehospital delays in the rural areas [10].

The so-called hybrid strategy, when a ground ambulance transports the patients to a helicopter loading site followed by helicopter transfer to the MT center, can further reduce prehospital time [11]. Additionally, emergency call processing should distinguish small vessel occlusion and LVO stroke from one another to save time. A helicopter and a ground unit could be dispatched at the same time when the caller reports symptoms suggesting an LVO and the patient is far away from a comprehensive stroke center [12, 13].

Finland is a sparsely populated country, and providing equitable access to MT across the country requires optimized transportation strategies and minimization of prehospital time. Euclidean transport distances can be several hundred kilometers long in Finland. In comparison, Manhattan, New York, covers an area of approximately 21.6 km × 2.3 km and has three comprehensive stroke centers. Its healthcare needs differ from Finland's, even compared to Finland's most densely populated capital region, which is about four times larger in area yet has roughly one-tenth of Manhattan's population density [14].

Our aim is to determine the additional population that could be reached within a 120-minute time window from Tampere University Hospital (Tays) if a helicopter and a ground unit are dispatched simultaneously. This time limit was set to be the target for initiating intravenous thrombolysis treatment by the year 2030 [15]. We hypothesize that significantly more people could reach the CSC within the time limit with early identification of LVO patients during emergency phone calls or by ground unit at an LVO site when combined with predetermined helicopter loading sites.

Methods

Study design

This study was conducted as a mathematical model study. Our aim was to determine how many more people could reach mechanical thrombectomy (MT) within 120 minutes when comparing ground transportation alone with a hybrid transportation strategy. We evaluated three different scenarios: (1) how many people could reach mechanical thrombectomy when using ground transportation only, (2) a hybrid strategy in which Emergency Medical Services (EMS) personnel alert the Helicopter Emergency Medical Services HEMS unit when an MT candidate is suspected, and (3) HEMS and EMS units are dispatched simultaneously.

Ethical approval was not required because we did not use any real patient data.

Setting

The open study dataset containing the geographical distribution of the Finnish people was obtained from the Finnish Institute of Health and Welfare. Finland is divided into a 1-square-kilometers areas in the dataset. The dataset provided boundary coordinates, population density classification (central, suburban, rural or other area), population, number of men, women, children, working-age population and elderly for each grid cell (one square-kilometer area). We chose each grid's southwest corner as an LVO incident site. We used EMS stations from the Tampere University Hospital (Tays) administrative area and its neighboring areas.

Model description

The primary outcome of this study is the identification of the proportion of the population that can access an MT-capable center within 120 minutes. Finnish EMS and HEMS cooperation was described previously in Vuorinen et al.'s article [11]. We evaluated three different scenarios. Figure 1 illustrates the scenarios visually. Figures 2 and 3 provide more detailed illustrations of the scenarios.

We evaluate in the first scenario the number of people who could reach Tays in 120 minutes using ground transportation only. We use 90 seconds as a dispatch delay for the EMS personnel. The fastest driving route is calculated using the OpenRouteService library with the Python programming language. We used OpenRouteService with default parameters and estimated that driving with lights

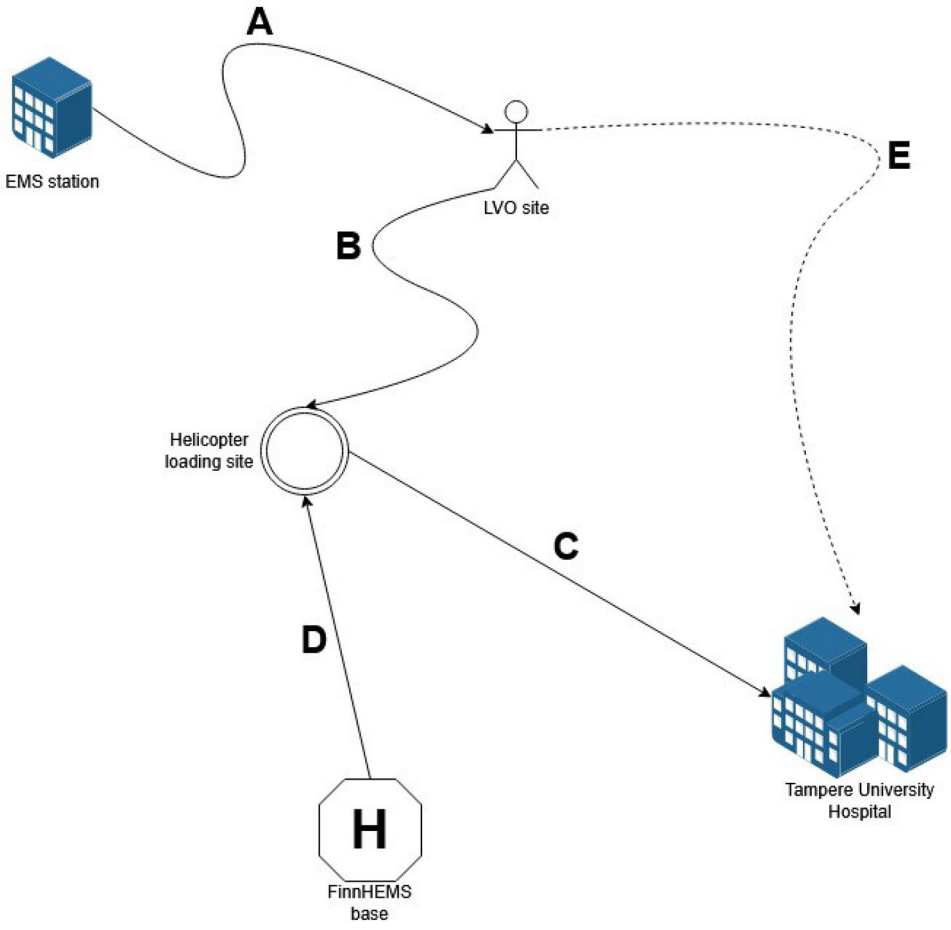
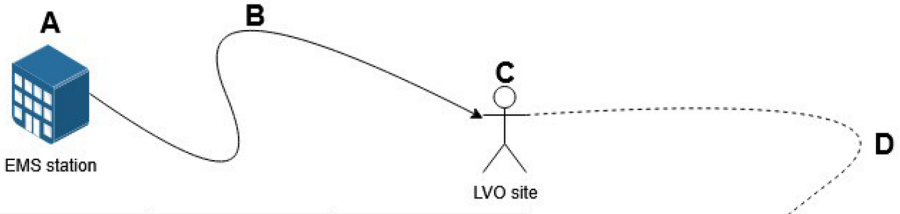
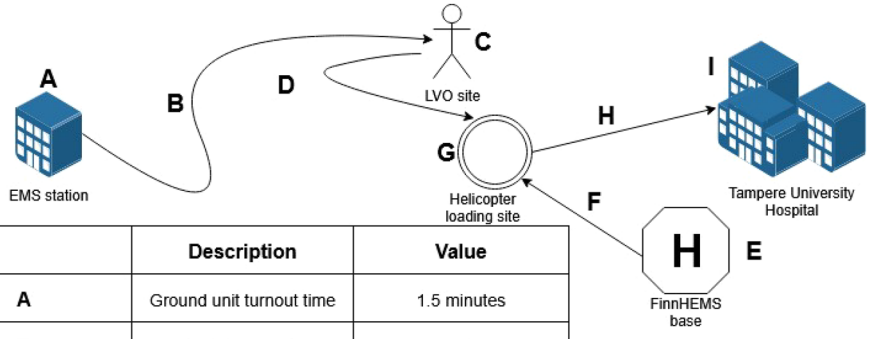


Fig. 1 Depicting scenarios. (**A**) Route from emergency medical services station to large-vessel-occlusion site. (**B**) Route from site to helicopter loading site. (**C**) Cruising route from helicopter loading site to Tampere University Hospital. (**D**) Cruising route from FinnHEMS base to helicopter loading site. (**E**) Route from large-vessel-occlusion site to Tampere University Hospital by ground unit only



	Description	Value
A	Turnout time	1.5 minutes
B	Ground route to LVO site	0.80 x driving time
C	On-scene-time	20 minutes
D	Ground route to TAYS	0.80 x driving time
E	Transferring patient to ED	5 minutes

Fig. 2 Visually illustrating scenario 1 with all the equations and constants



	Description	Value
A	Ground unit turnout time	1.5 minutes
B	Ground route to LVO site	0.80 x driving time
C	On-scene-time	20 minutes
D	Ground route to helicopter loading site	0.80 x driving time
E	Helicopter turnout time	6 minutes
F	Flying time to helicopter loading site	Euclidean distance / 200 km/h
G	Helicopter loading time	8 minutes
H	Flying time to TAYS	Euclidean distance / 200 km/h
I	Transferring patient to ED	12 minutes

Fig. 3 Visually illustrating scenarios 2 and 3 with all the equations and constants

and sirens would save up to 20% of the time, because most of the driving is on roads outside urban areas. Finally, we added a 5-minute delay to unload the patient from the ambulance to the Emergency Department (ED).

We evaluate in the second scenario how many individuals reach a CSC in time with a ground unit and a helicopter unit after the EMS personnel have been on site for 10 minutes before alerting the HEMS unit. The HEMS unit operates with an EC135 helicopter, and the take-off delay is set at 6 minutes. Driving times are now calculated from the EMS station to the incident site. The ambulance takes the patient to a meeting place with the helicopter crew after a 20-minute on-scene-time [16]. We used an aerial view from Google Maps to identify suitable meeting places for the ambulance and HEMS crews. These landing sites were also estimated to cover the night minima for an EC135 HEMS site (25 × 50 m). We decreased the helicopter cruise speed to 200 km per hour to avoid any weather effect and time spent stopping the rotor at the meeting place. An individual's loading time to the helicopter is set to 8 minutes. We set the delay from the rooftop landing site at the hospital to the ED to 12 minutes.

EMS personnel and HEMS unit dispatched at the same time in the third scenario. All other delays were identical with the second scenario.

The Python code is available via GitHub [17]. Python code was run on Spyder IDE, version 6.0.3., using Python 3.12.4 release. It took approximately 3 to 6 hours to run each script. There were total of 3 scripts used to calculate all the scenarios. ChatGPT was used during programming for debugging, and ChatGPT's suggestions were evaluated to be correct. Figures 4 and 5 explain the Python scripts in plain language.

Results

The whole dataset consists of 5,494,750 people and 393,303 1-square-kilometers grid cells. We excluded all areas with no population which left 98,001 grid cells containing at least 1 resident. We delimited the area by picking the city of Kajaani at the most northern and eastern point of the study area to lower the amount of calculation needed. The Euclidian distance from Tampere to Kajaani is 262 km, and the distance is 460 kilometers (5.5 hours) by ground route. We estimated that the study area includes all the locations from which Tampere University Hospital (Tays) can be reached within the 120-minute time limit. The population was reduced to 4,146,437 people after area limitations. In 256 1-square-kilometers grid cells (0.4% of the grid cells total), the ground route is nondefinable due to their locations in the Finnish archipelagos. A total of 8,523 people were living in these grid cells.

In the first scenario, we estimated the number of individuals who could reach Tays in 120 minutes using ground transportation only. A total of 1,016,180 individuals met this criterion (Fig. 6) from 13,281 grid cells. The

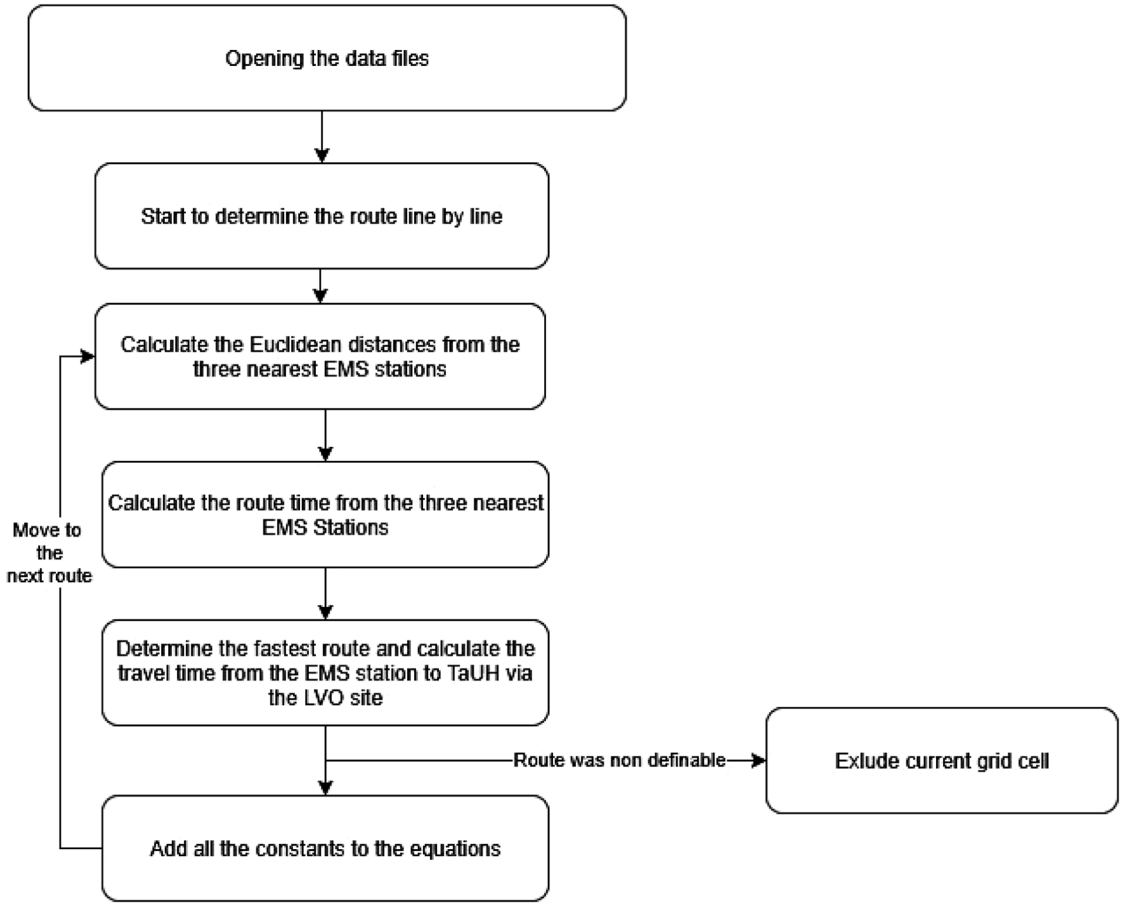


Fig. 4 Scenario 1 Python code explained in plain language

median time was 79 minutes (25th and 75th percentiles were 48 and 105 minutes, respectively).

In the second scenario, HEMS was notified after the EMS had been on site for 10 minutes. In addition to the first scenario, 981,391 more people could reach Tays in 120 minutes from 13,285 grid cells. The median time was 108 minutes (25th and 75th percentiles were 102 and 114 minutes, respectively).

In the third scenario, we assessed the additional population that could reach Tays within 120 minutes when EMS and HEMS were dispatched at the same time. Compared to ground transportation alone, this strategy enabled an additional 1,018,887 individuals from 15,521 grid cells to access Tays within the time limit. The median time was 104 minutes (25th and 75th percentiles were 99 minutes and 111 minutes, respectively). Results are displayed in Table 1.

We assessed which unit arrived later at the helicopter loading site and acted as a limiting factor. In the second scenario, the helicopter had to wait for the ground unit in 6,893 cases, and the ground unit was the limiting factor in 6,393 cases. In the third scenario, the helicopter was the limiting factor reaching the helicopter loading site in 1,506 cases, while the ambulance was the limiting agent in 14,015 cases.

If the HEMS and EMS units were dispatched at the same time, 37,496 more individuals could reach Tays within the time limit. The ground unit was the limiting factor for reaching the helicopter loading site in 3,617 more cases compared with scenarios two and three.

Figure 7 is a map illustrating where Tays can be reached within 120 minutes.

Discussion

In this study, we used grid cell-based data to create a map showing locations where HEMS dispatch enables patients to reach Tays within the 120-minutes time limit. We demonstrated in this study that a hybrid strategy combining helicopter and ground ambulance transport could enable an additional 981,391 (97% increase) individuals with a suspected LVO to reach a comprehensive stroke center (CSC) within the 120-minute target window compared to ground transportation alone. We could reach an additional 37,496 (100% total increase) people with early recognition of an LVO suspect, preferably during emergency calls. This theoretical study, which used the

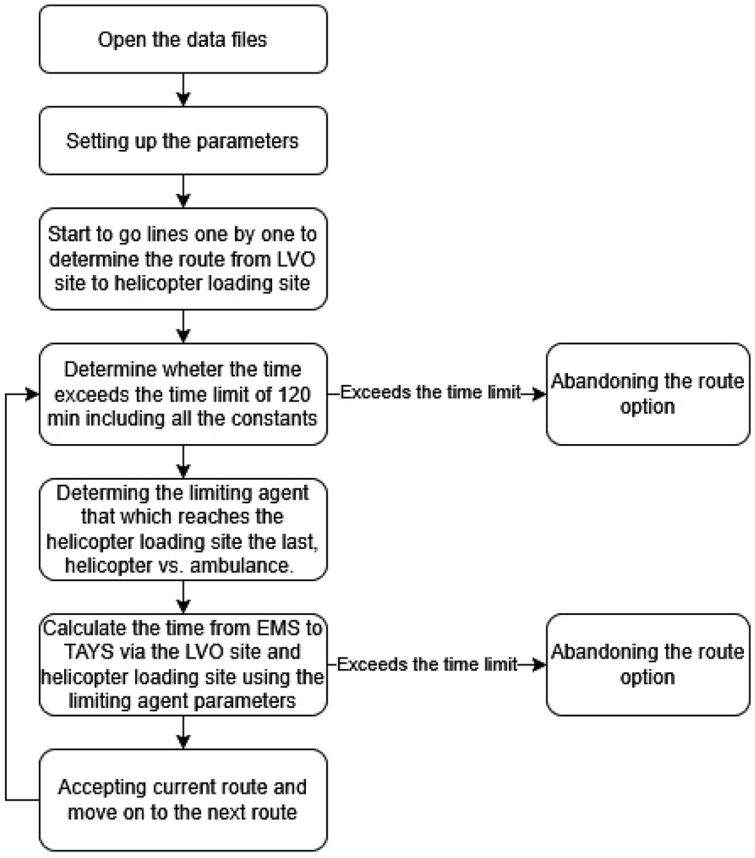


Fig. 5 Scenario 2 and 3 Python code explained in plain language

mechanical thrombectomy (MT) center as the reference point, has a catchment area in which a total of 2,035,067 Finnish individuals live within a maximum travel time of 120 minutes. The 120-minute threshold is set to be the target time for median onset-to-needle time by the year 2030 [15]. I.v., thrombolysis of a suspected LVO should be started within 140 minutes of the symptoms' onset. Previous studies show that LVO incidence rates vary from 18 to 34 per 100,000 people annually [18, 19]. Based on these figures, in scenario 2 that means 177–334 more LVO patients reach MT within the time limit annually. In scenario three, 183–346 more people in a year could reach MT within a time limit compared to scenario 1.

We used mathematical model to assess real-life scenarios in our study. Previous studies from Finland conducted by Pappinen et al. [20] estimated transportation times based on whether a helicopter could land directly at the onset site. This approach tends to overestimate the benefit of helicopter transport, because the calculated times are typically faster compared to real life. Helicopter loading sites in our model were assessed by professionals to be certain that helicopters can land on the helicopter loading points. Our models' benefit is that we can assess whether to use a helicopter depending on where the emergency call originates. Patients are actively transported towards the Emergency Department (ED) by ambulance or helicopter in the hybrid transportation strategy, which reduces the prehospital time. Transportation protocols should be assessed clearly, and EMS personnel should be able to cross the catchment and administrative areas for the EMS team to work effectively [21].

Adeoye et al. [22] assessed how many US citizens would reach, i.v. a thrombolysis center or MT- capable center within 60 minutes using either a ground unit or a helicopter alone. Adeoye et al. used the trauma patients' on-scene-time median, which may vary from stroke patients' on-scene-times. Adeoye et al.'s study evaluated that nearly 100% of US citizens live within 120 minutes of an MT-capable center. This paper's theoretical analysis, based on a single MT center, covers 34% of the Finnish population. Further studies should include all five Finnish MT centers and assess whether a hybrid strategy could enable nationwide access to MT within the time limit. Further studies should also include using a helicopter to transport patients to the nearest available MT center. It would already be possible to maintain a real-time situational overview that optimizes patient transport to the nearest MT center with available capacity.

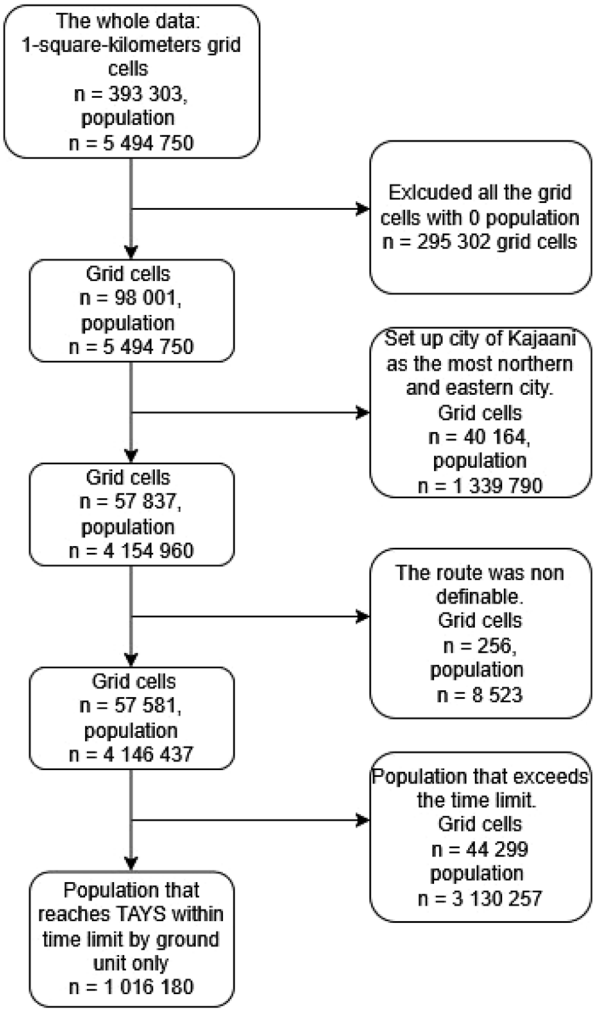


Fig. 6 Flowchart of the number of people reaching Tays by ground unit only

Previous studies have shown that the concept of using a helicopter has been beneficial for decreasing the prehospital times [23]. Jahan et al. [24] study showed that each 15-minutes increase was associated with poorer prognosis in LVO. For simplicity, we did not calculate the alternative treatment times to approximate the health benefit gained. Rather, we wanted to show that with early HEMS unit dispatch both time limits, thrombolysis under 120 minutes and endovascular thrombectomy under 200 minutes, set in the Action Plan for Stroke in Europe 2018–2030 [16], can be met in almost double the population. Herrmann et al.'s recent study [25] showed that early recognition of LVO could be done during the emergency phone or video call. Our study demonstrated that more of the population could reach an MT center with early recognition.

Ackerman et al. [26] studied the cost-effectiveness of using HEMS. In their study HEMS cost-effectiveness improved by including stroke patients into the dispatch criteria. Most of the cost came from the fixed costs, 93%, and only 7% of the costs were variable, including operational costs. Hence, increasing HEMS stroke dispatches have only a minimal effect on the costs allocated to the HEMS unit but there could be humane as well as financial benefits when time to definitive treatment is minimized.

Previous studies have shown conflicting results regarding whether to use a mothership-strategy or a drip-and-ship strategy for the patient transportation method. In the RACECAT trial [8], the mothership strategy had no statistically significant benefit for 90 days of neurological outcomes. Behrndrtz et al.'s study of the mothership strategy did not show better neurological outcomes due to the lack of strength. Onset-to-groin time was 35 minutes faster using the mothership strategy compared to the drip-and-ship strategy. The RACECAT study showed that helicopters were rarely used only in interhospital transfers, and Behrndrtz et al.'s [7] study showed that helicopters were used in transportation but did not specify how the helicopters were used. The delay of i.v. thrombolysis initiation did not result in worse neurological outcomes in both studies. Our present study encourages future randomized trials with a mothership triage strategy to consider using a hybrid transport protocol for patients distant from a CSC. Furthermore, a subanalysis of the RACECAT trial highlighted the poor prognosis of the patients triaged straight to a CSC and diagnosed with an intracranial hemorrhage [27]. These patients might benefit from a prehospital airway intervention performed by an experienced prehospital physician [28]. The presence of a prehospital physician in most HEMS systems further highlights the importance of helicopter use.

Strengths and limitations

This study has limitations. First, the driving times calculated using OpenRouteService may be slightly slower than those provided by Google Maps. Second, as a mathematical model study, its findings are not directly

Table 1 Results the total number of individuals and grid cells are presented both by subgroups and as overall totals. Overall total numbers are bolded

	Scenario 1	Scenario 2	Scenario 3
Total number of individuals reached TAYS	**1,016,180**	1,016,180 + 981,391 = **1,997,571**	1,016,180+1,018,887 = **2,035,067**
Number of grid cells	**13,281**	13,281+13,285 = **26,566**	13,281+15,521 = **28,802**
Median time	79 min	108 min	104 min
25th and 75th percentiles, respectively	48 min, 105 min	102 min, 114 min	99 min, 111 min

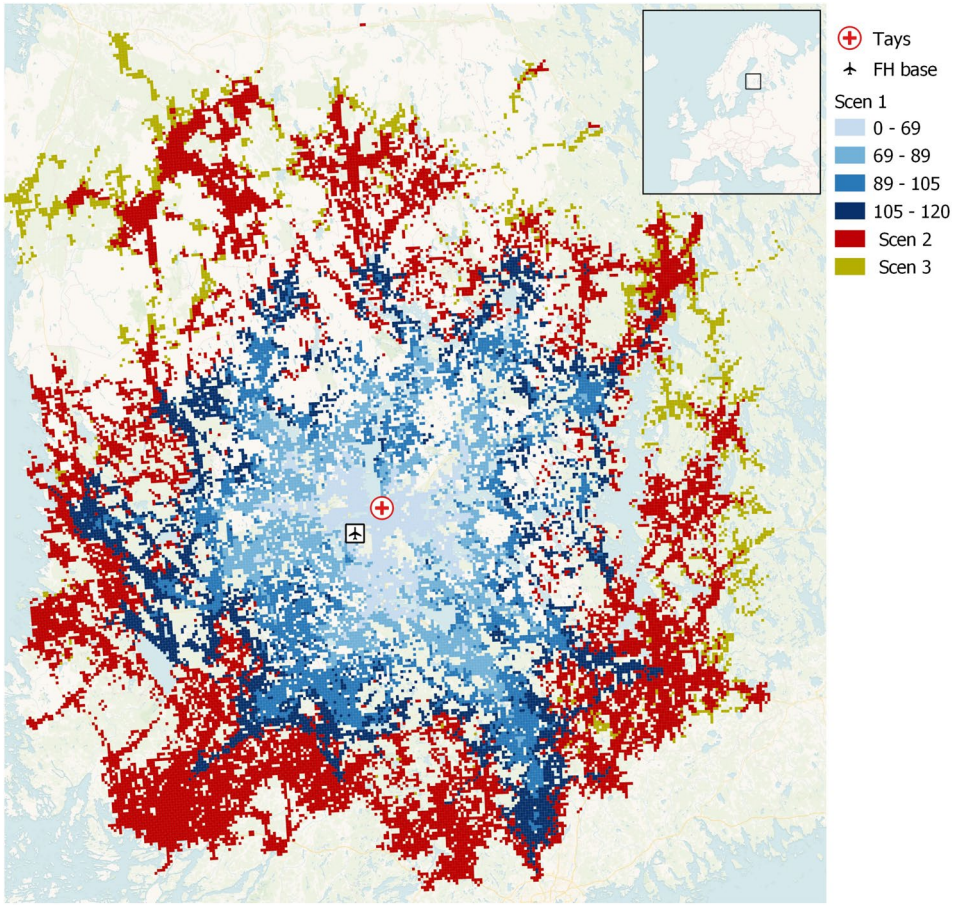


Fig. 7 Map showing areas within 120-minute access to Tays. Ground transport times appear in blue, scenario 2 in red, and scenario 3 in yellow. Ground transport travel times are divided into subcategories by travel time

transferable to real-life situations. For example, the nearest EMS crew may be unavailable when a citizen calls the emergency number for suspicion of stroke, or Tampere University Hospital (Tays) might be overburdened by 183–346 patients annually. Additionally, HEMS might be occupied in another mission or weather conditions are unsuitable for flying, when HEMS dispatch is needed. We have previously discussed HEMS unit's inevitable parallel activations [29]. These could be solved with a HEMS coordinator working in emergency call center prioritizing HEMS dispatches and possibly dispatching the second nearest HEMS unit. This mathematical model represents a best-case scenario and therefore may not fully reflect real-life factors that could reduce the catchment area and increase the transportation times. Third, we calculated times using only a single MT center in Finland, despite overlapping catchment areas. Patients should, ideally, be transported to other MT centers in the southern and southwestern parts of the study area. Additionally, we limited the analysis to three scenarios. Including more scenarios or adjusting the current ones might better support the study's hypothesis.

In this study, we aimed to describe the impact early recognition and early dispatch of helicopters have on the number of individuals reaching definite care center in Tays area. Our numbers cannot be directly generalized to other areas; however, using the code provided, one can estimate if LVO dispatch and triage could be reorganized.

A key strength of this study is the use of the free, open-source software OpenRouteService for calculating driving times. We set up the container that runs the software to run on our private personal computer (PC). We are committed to providing the source code to ensure full reproducibility of the analysis. Setting up the container to run OpenRouteService requires some technical knowledge, but with the help of an AI tool, it can be done with prior experience. Running the code used to evaluate driving times requires some programming knowledge.

Another notable strength is the assumption that the patient is immediately transported toward the helicopter and the designated MT-center once an LVO is suspected. This highlights the importance of EMS personnel being aware of specific locations where helicopter transport

should be utilized and ensuring rapid dispatch without delay in suspected LVO cases.

Conclusions

We determined in this study how many Finnish citizens live within 120 minutes from Tampere University Hospital (Tays) and in which grid cells helicopters can be used. The use of helicopters in patient transfers substantially increases accessibility, although early recognition of large vessel occlusion (LVO)-suspected patients did not substantially increase the number of people who reached Tays in 120 minutes.

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Author contributions
E.M. wrote the main manuscript text, coded the scripts for calculations and made all the figures except Fig. 7. M.M. made Fig. 7. All authors participated in study planning and finalized the manuscript.

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Data availability
The population dataset used in this study is publicly available from the Finnish Institute for Health and Welfare. The simulation code and derived data supporting the findings of this study are available from GitHub, link https://github.com/eskotmorko/EDEN---Enhanced-Dispatch-for-Efficient-Neurointervention.

Declarations

Competing interests
The authors declare no competing interests.

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