# Mapping Opportunities for Enhancing Effectiveness of Health Care System by GIS Based Accessibility Analyses: Locating Core and Support Services within Long Distances in Northern Finland

Ossi Kotavaara[1], Tommi Hakkarainen[1], Tiina Huotari[1], Timo Keistinen[2], Jarmo Rusanen[1]

[1] Department of Geography, University of Oulu, Finland
[2] Department for Social and Health Services, Ministry of Social Affairs and Health, Finland

**Abstract.** Finnish healthcare services have pressure for reorganisation. Particularly peripheral areas having decreasing and aging populations are challenging for health care, which is indeed evident in Northern Finland. Transport of goods and travels of people form an essential factor in designing effective and reachable health care network. In addition to accessibility of population to core health care services, such as health centres and hospitals, accessibility of support services, extending from pharmaceuticals and medical equipment to laundry, need to be managed effectively. In this paper, geographic information systems (GIS), accessibility analyses and spatial data covering population, road network and potential locations of service and storing facilities are applied to analyse spatial context of core and support health care services with aim to indicate potentials to increase cost-effectiveness of service network within long distances. In analysing accessibility, location-allocation (p-median) and vehicle routing analyses are applied with aim explore accessibility issues in service network coverage and in locating warehousing functions by potential delivery routes. By location allocation, efficiency of service network may be enhanced with minimum harm to equality and centralised logistics may improve cost-effectiveness of support services. By these analyses, the study has also a practical aim to establish future scenarios for health care design in Northern Finland.

**Keywords.** Accessibility; Transport; Health care; Geographic information systems (GIS); Long distances; Sparse population

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## 1. Introduction

A number of accessibility analytical approaches are developed to measure and optimize accessibility in spatial and geographic context. Geographic information systems (GIS) is applicable framework in analysing accessibility by using spatial data of transport networks, supply and demand (Páez et al. 2012). Furthermore, accessibility in the context of health care has been analysed by as a spatial problem in many studies. To mention some examples, location of health care services in relation to location of potential patients been considered by location-allocation approach in planning purposes in analysis covering Southern England (Harper et al. 2005). Accessibility to health care is measure by floating catchment area and traditional gravity-based methods in Chicago (Luo & Wang 2003) and by the gravity integrated two-step floating catchment area in Springfield, Missouri (Luo 2014). Mestre et al. (2015) propose two location–allocation models for the strategic planning of hospital networks by the case of in Portugal, with aim to inform how the hospital system may be reorganised geographical access is wanted to be improved while minimizing costs. In health care service network, also accessibility of supporting services, transport of goods and warehousing may affect to the cost-efficiency by decreasing costs related to stock, shelving and deliveries. Thus, optimizing accessibility of warehousing facilities and spatial components in supply chains are also essential to be considered, and various techniques are available for this purpose (see Melo et al. 2009).

Health care accessibility analysis carried out within long distances and covering deeply rural or peripheral areas are rare and matter spatial accessibility in health care logistics is rather unstudied field. In Finland, location-allocation analysis has been applied in planning of special health care in sight of birth hospital network (Huotari et al. 2012) and in optimizing coverage of emergency departments of the basic health care (Huotari et al. 2013). Accessibility issues in health care in Northern Finland give and interesting and also challenging field for optimisation as deep and regressive periphery characterises much of the northernmost areas, rural zones in southern areas are mainly vital and population is increasing in a few growth centres and their fringes (Fig. 1). There are no signs that migration to cities and ageing of the population, except in a few local occurrences, would slow down in the future. Thus, peripheries of Northern Finland have a clear demand for health care services, but supply will get more complicated all the time due to diminishing volumes of demand.

Present economic conditions set a high pressure to rationalize the use of public funds in social and health care sectors. The basic health care system and partly also the health centre network originates to 1970s and Finnish hospital network originates to 1950s-1970s (Vuorenkoski et al. 2008).

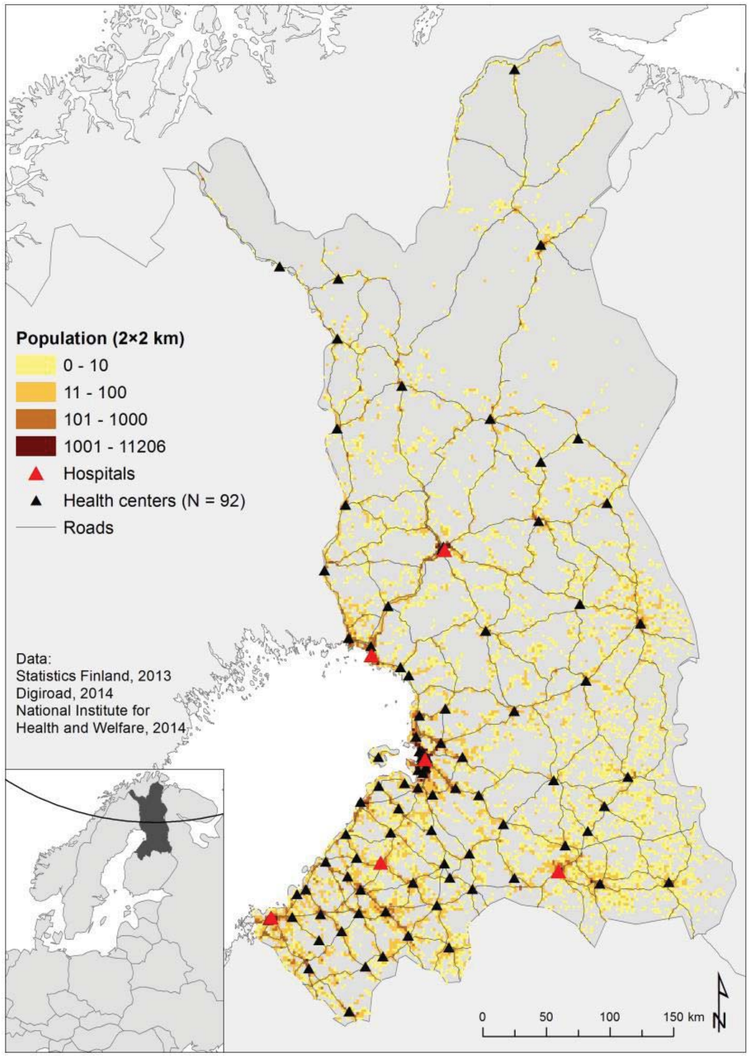


**Figure 1.** Key health care services and population structure in Northern Finland.

However, the legal outline for geographically extensive health care in Finland is still clear. Public authorities have to organize adequate social and health care services, and promote the health of the population (Constitution 731/1999, 19§ 1999) and local and regional authorities are responsible to provide health care services to the residents locally unless regional centralization of services is justified in order to ensure the quality (Health Care Act 1326/2010, 10§ 2010). Thus, basic health care services are organised mainly in publicly health centres, special medical care is given in 20 central hospitals (five in Northern Finland), while highly specialised medical care is concentrated in five university hospitals (one in Northern Finland). Even though, services are given by the authorities, citizens are free to choose the desired health centre or hospital, and accessibility is clearly an essential factor in this.

In this paper, the aim is to introduce and pilot accessibility analytical perspectives in optimizing effectiveness health care services within the context of reducing resources, long distances and sparse population structure, which are evidently present in Northern Finland. First it is analysed, how service network and accessibility of basic health care changes in the case of potentially reducing number of service units, if the spatial structure of services are optimised. Second, the scenario of centralised warehouses supporting material deliveries of health centres is scrutinised by simulating potential delivery routes in relation to potential warehouse locations. We seek to answer to the following research questions:

1) How health centres should be located to reach the population of the most effectively, if number of service units has to be reduced?

2) How decreasing amount of health centres would affect to the accessibility of services?

3) What would be the most optimal location(s) of centralised warehouses serving health centres, and how effectively centralised warehouses would be linked to health centres by optimised delivery routes?

4) How decreasing amount of health centres would affect to the optimal locations of warehouses?

## 2. GIS based accessibility analyses and their implementation to the study

This study relies on GIS based accessibility analyses and spatial data. Key methods applied to accessibility analyses are p-median location-allocation analysis and vehicle routing functions connected to cumulated opportunities index. The data of the study consists of route-able road network data with metric accuracy, health care facility locations and population grid cell data at 2×2 km resolution. All data management, analyses and maps are produced by ESRI ArcGIS and Python scripts.

### 2.1. Location-allocation

GIS based location-allocation methods are applicable in optimizing basic health care service network in relation to residential locations in the extent of the Northern Finland, as citizens have been free to choice of hospital or health centre, when using public services since 2014 and distance is clearly an essential factor in selecting services. Location-allocation refers to spatial optimization of facility locations by transport costs in relation to distribution of service demand and study settings may include e.g. median problems, covering problems and central problems (Miller & Shaw 2001). In this study, p-median i.e. minimize impedance approach is used as aim is to increase effectiveness of non-urgent basic health care. As the travel time sum of population to health centres is minimised, the analysis maximises the average accessibility of population, but does not take the spatial coverage into account. In this study, location-allocation analysis was applied to four scenarios of diminishing service network. Present network of 92 health centres were reduced in 10 facility intervals until to 52 and optimal accessibility of population the network was computed for each scenario.

### 2.2. Vehicle routing and hub location-allocation

There is pressure to rationalize also warehousing functions of basic health care, and centralizing warehousing activities to one or a few warehouses is relevant opportunity for this. By centralizing warehousing functions, cost-effectiveness may be increased remarkably by the scale economies as wastage may be reduced, inventory turnover may be higher, reserve stock may be decrease and quality and quantity of stock item may be rationalised. Thus, scenarios for locating centralised warehouses serving health centres are considered in this study. Accessibility of warehouse locations, or their combination, is considered by applying 'vehicle routing problem' (VRP) method in establishing optimised routes for deliveries to health centres. By the definition, the solution for VRP calls for the determination of a set of routes, each performed by a single vehicle which starts and ends at its own depot, fulfilling all the requirements of the customers and minimizing transport costs (Baldacci et al. 2010). Computationally VRP is a superset of the classical traveling salesman problem (TSP), in which set of stops is organised optimally. As the TSP is a combinatorial problem, there is no straightforward way to find the best sequence and heuristics are needed to be used to find suitable solutions in a reasonable time. ArcGIS Network Analyst VRP solver was applied in this study and it operates on the basis of a fastest route origin-destination matrix and the heuristics used in this process are based on implementation of a tabu search metaheuristics which are further developed (ESRI 2012).

In this study, warehouses are supposed to be located within one or a few of the six hospitals of the region. Optimal delivery routes and related accessibility are computed by using all

$$n=2^T-1$$

combinations (n=63) of warehouses (T=6) which would potentially be applied. Effectiveness of different scenarios is considered on the basis of travel time needed for delivery routes connecting all accessible health centres to warehousing functions. Routes are generated via road network and by using travel speed estimated. Time budget for each route is nine hours of driving time and service time and 10 minutes penalty is given in the beginning and for every stop in a route.

### 2.3. GIS data

Accessibility analyses of the study are based on the leas cost path routes and road network data including speed limits for travel time estimates. Road network data consist of all regularly used roads including regional and local main streets, collector and feeder streets and private roads allowed for public use (Finnish Road Administration 2014). The speed limit based travel time estimates are highly accurate in Northern Finland, due to low effect of congestion in the area. However, travelling speeds in built-up areas are increased by 25 %. A few road ferry connections exist at the research area and estimated travel speeds of cable ferries are of 10 km/h and of larger ferries 20 km/h.

Data of Finnish health care facilities are maintained by the National Institute for Health and Welfare. Basic health care and hospital facilities were positioned by geocoding street addresses of facilities in relation to GIS data of road network. In Northern Finland there were six hospitals (being active in special health care, advanced surgery and births) and 92 health centres in the end of year 2014.

Population grid cell data of Statistics Finland consists of register based information of residential locations of Finnish citizens (Statistics Finland 2013). Originally 250×250 m grid cell data is aggregated to 2×2 km resolution grid cells to keep amount of observations (N=10249) suitable for computation power. The population of Northern Finland (734925 in habitants by the grid cell data) is included to the analysis. In accessibility analyses, locations grid cells are represented by their centroids.

## 3. Accessibility approach to rationalisation of health centre network

With the present, relatively dense, service network, accessibility to basic health care may be considered to be at relatively high level, as 78.4 % of population reaches the nearest service in 10 minutes and almost all citizens reach health care in 30 minutes (Table 1). Even though the population in Northern Finland can be characterised as dispersed, majority of population is located to cities and rural towns which are covered well by health centres. However, in rural and particularly in deeply peripheral areas travel times to services are high (Fig. 2), but correspondingly the amount of population living in these areas is low.

| Travel time threshold (minutes) | Health centres (N), Accessed population (%) | | | | |
|---|---|---|---|---|---|
| | *52* | *62* | *72* | *82* | *92* |
| 10 | 69.5 | 73.4 | 75.9 | 77.4 | 78.4 |
| 20 | 89.2 | 91.4 | 92.8 | 94.0 | 94.4 |
| 30 | 96.3 | 97.1 | 97.5 | 99.7 | 99.7 |
| 45 | 98.9 | 99.4 | 99.4 | 99.5 | 99.5 |
| 60 | 99.6 | 99.8 | 99.8 | 99.8 | 99.8 |
| 90 | 99.9 | 99.9 | 99.9 | 99.9 | 100.0 |

**Table 1.** Accessibility of basic health care. Share of population accessed by different size health centre service networks optimised by accessibility.

In the scenarios of considering the decreasing amount of health centres, accessibility effects of removing services strikes firstly to the populations in small towns in southern parts of the area and secondly to the sparsely populated northern and eastern areas (Fig. 3). A main reason to this is the relatively extensive service network in the south, where a majority of small towns have their own health centres. In the case of services would be withdrawn from a few these towns, services would still be available in neighbouring centres. However, even though the service level in general would remain in decent condition in these towns, the local effect would of course be notable. As the coverage of service network is already almost at the minimum level in northern and eastern parts of the region, location-allocation analysis saves mainly the service units at these areas. Thus, in the scenario where service facilities are reduced remarkably (from 92 to 52), population accessing services in 10 minutes decreases notable 8.9 %, but for population accessing services in 30 minutes suffer the decrease of 1.4 %, (table 1).

However, in the case of most sparse service network, travel times to basic health care increase very radically in remote areas and hinterlands having low populations (Fig. 4).

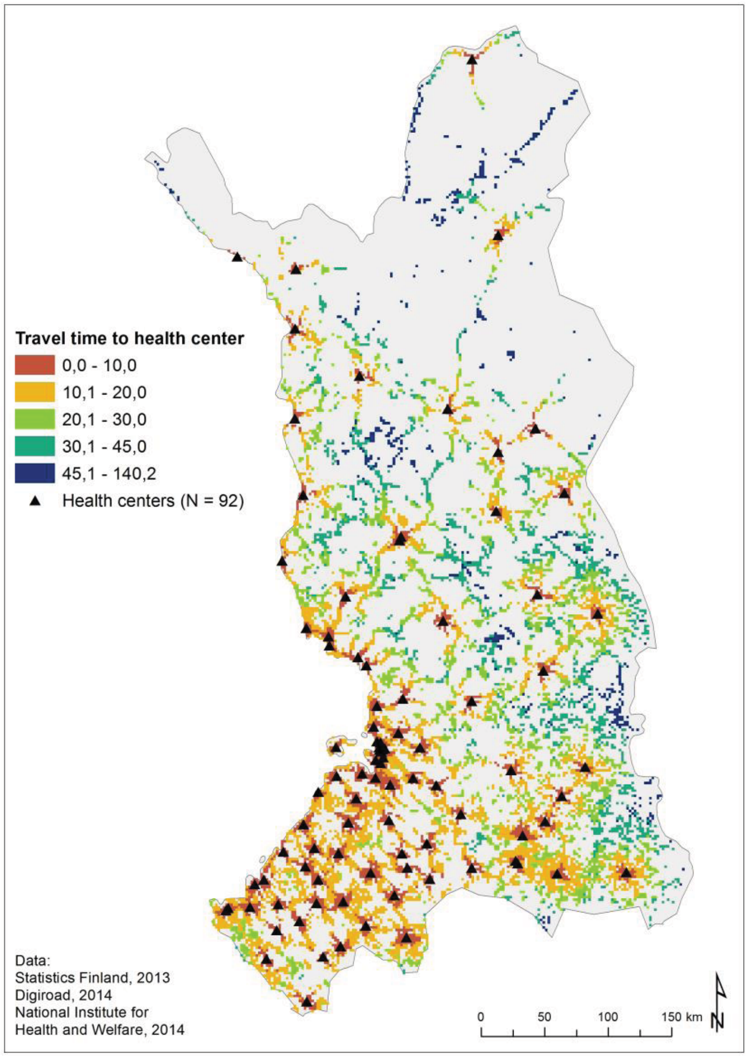


**Figure 2.** Accessibility to basic health care as estimated fastest route travel times by a passenger car.

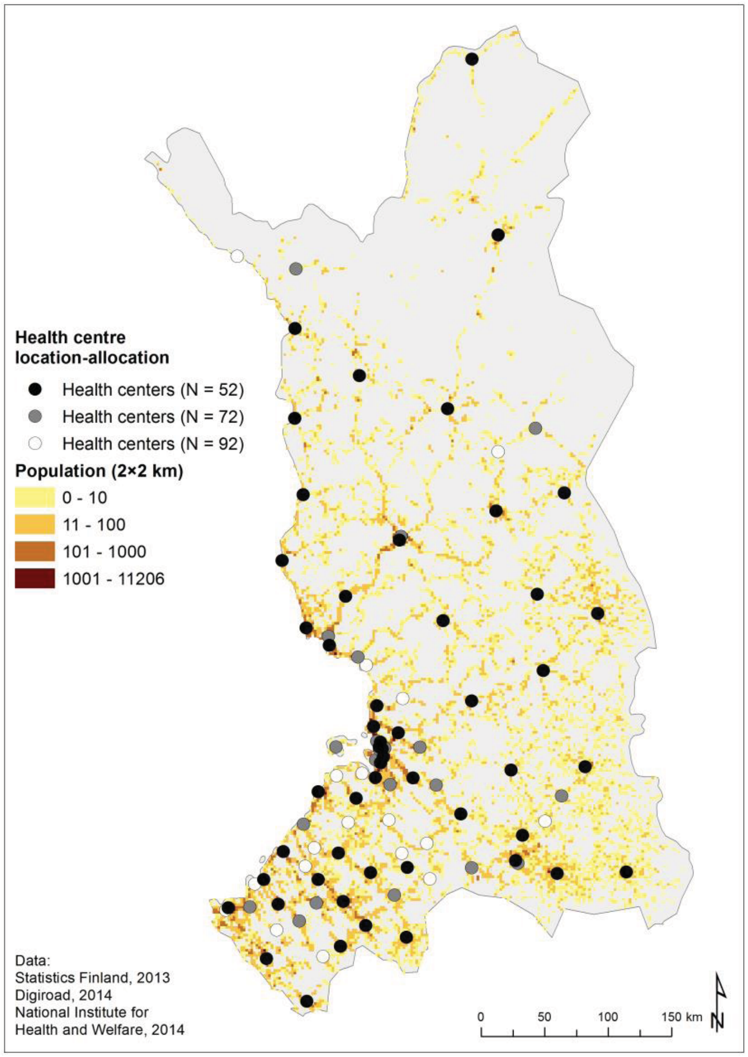


**Figure 3.** Health centre network with present coverage (N = 92) and examples of health centre networks with limited number of service units (N = 72 and N = 52) optimised in relation to the population structure by accessibility.

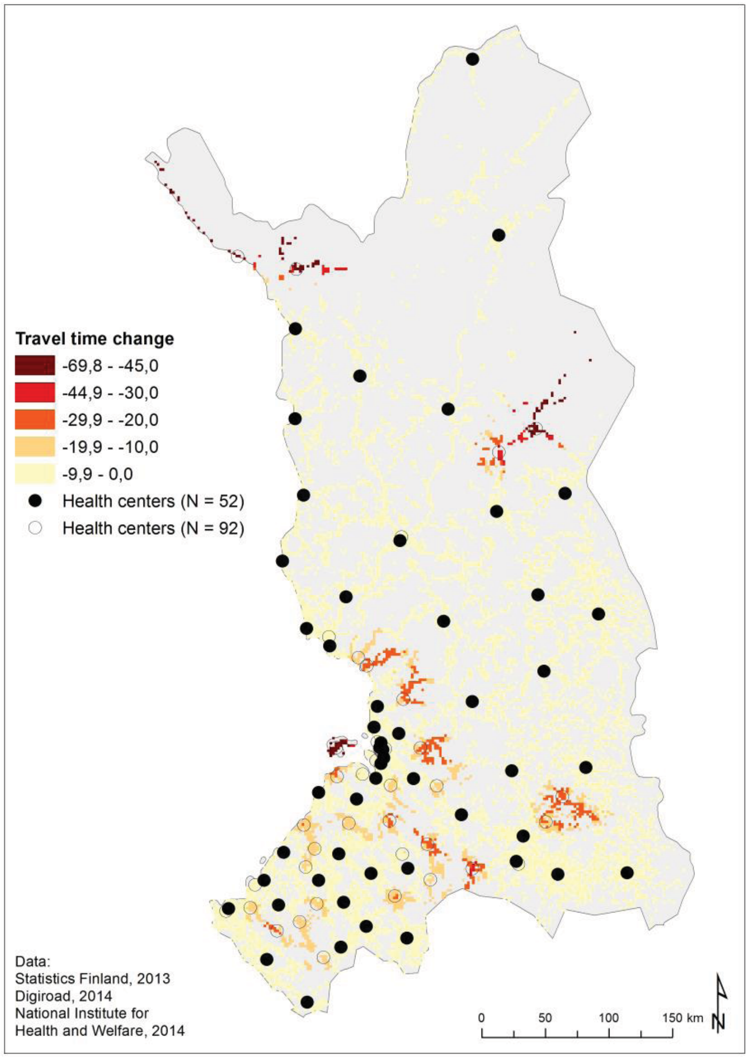


**Figure 4.** Travel time increase (minutes) in relation to accessibility of closest health care centre in present (N=92) and limited (N=52) service networks.

## 4. Optimizing centralised warehouse locations and delivery routes to health centres

Locating centralised warehouses serving health centres is considered by effectiveness of computational delivery routes. Analysis consists of 63 different warehouse location combinations, when one, few or all of the six hospitals of the Northern Finland are considered as potential site of a warehouse in turn. In each of these scenarios, delivery routes connecting warehouse(s) to health centres are established (Fig. 5). Five routes are allowed to be generated for each warehouse and each generated route is allowed to be continued until nine hours is reached with 10 minute time penalty in the beginning and during every stop. In addition, potential future health centre networks included to the analysis (see chapter 3).

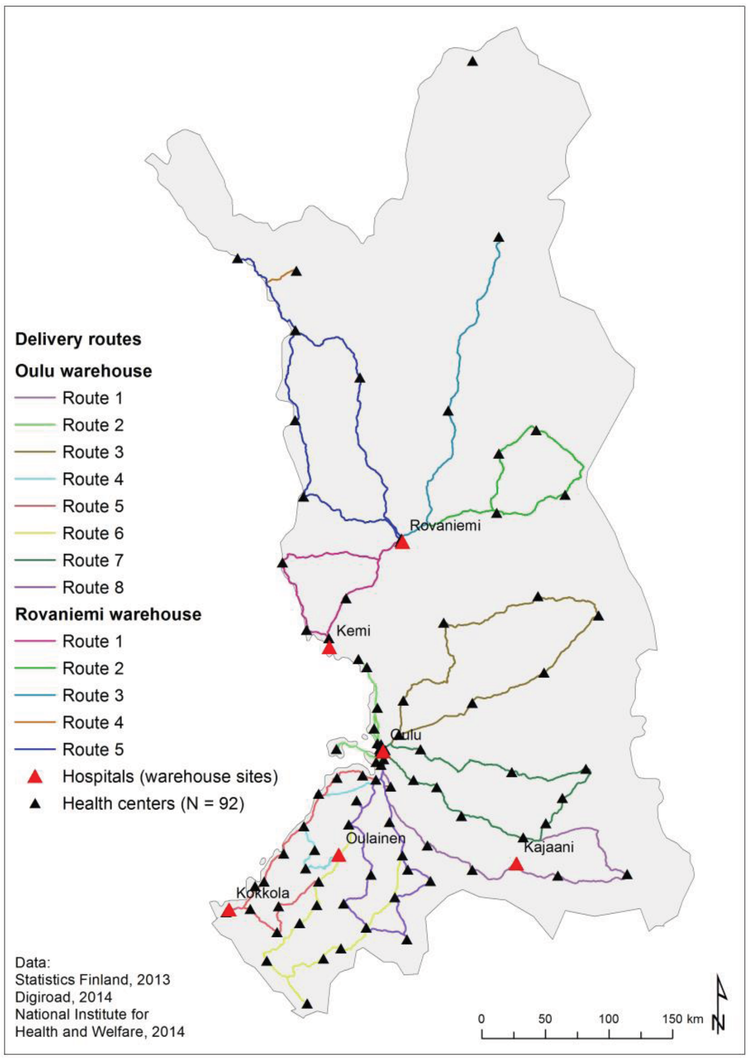


**Figure 5.** Delivery routes of the most optimal scenario of two warehouses, locations in Oulu and Rovaniemi.

For locating one warehouse on the basis of most efficient routes in reaching health centres, the location of Oulu university hospital would be clearly the best in sight of accessibility. Results are corresponding with scenarios of different size health centre network between 52 and 92 units. From warehouse located in Oulu, 87-90 % of health centres can be reached in all scenarios.

By locating two or more warehouses, all but one (the northernmost) health centres could be reached (table 2) by delivery routes, if one of the warehouse would located to Rovaniemi. In the case of locating two warehouses, minimum travel time in delivery routes is achieved by locating one warehouse to Rovaniemi and another to Oulu or Oulainen. Effectiveness in locating second warehouse to Oulu or Oulainen is almost similar when considered as travel time. Nevertheless, if the warehouse would be located to Oulu, it could be effectively integrated to warehouse facilities of Oulu University Hospital.

| **Number of health centres reached** | **Driving time (h)** | **Warehouses included** | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***Kok.*** | ***Rov.*** | ***Kemi*** | ***Oulai.*** | ***Kaj.*** | ***Oulu*** |
| 91 | 92.4 | 0 | 1 | 0 | 0 | 0 | 1 |
| 91 | 92.9 | 0 | 1 | 0 | 1 | 0 | 0 |
| 91 | 104.7 | 0 | 1 | 0 | 0 | 1 | 0 |
| 90 | 114.0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 88 | 86.1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 88 | 91.4 | 0 | 0 | 1 | 0 | 0 | 1 |
| 88 | 100.7 | 0 | 0 | 1 | 0 | 1 | 0 |
| 87 | 98.3 | 1 | 0 | 1 | 0 | 0 | 0 |
| 87 | 129.2 | 0 | 1 | 1 | 0 | 0 | 0 |
| 83 | 78.8 | 1 | 0 | 0 | 0 | 0 | 1 |
| 83 | 81.2 | 0 | 0 | 0 | 1 | 0 | 1 |
| 83 | 82.7 | 0 | 0 | 0 | 0 | 1 | 1 |
| 79 | 73.9 | 0 | 0 | 0 | 1 | 1 | 0 |
| 79 | 83.3 | 1 | 0 | 0 | 1 | 0 | 0 |
| 78 | 84.4 | 1 | 0 | 0 | 0 | 1 | 0 |

**Table 2.** Combinations of two warehouse locations, number of accessed health centres and total driving times of delivery routes.

With case of locating three warehouses, the result includes more options for variation, as efficiency of three different settings are within the marginal of 1.3 % in total driving time (table 3). Warehouses location setting including Rovaniemi, Oulu and Kokkola or Oulainen is almost as effective as setting with Rovaniemi, Kajaani and Oulainen.

| Number of health centres reached | Driving time (h) | Warehouses included | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Kok.* | *Rov.* | *Kemi* | *Oulai.* | *Kaj.* | *Oulu* |
| 91 | 85.6 | 0 | 1 | 0 | 1 | 1 | 0 |
| 91 | 86.7 | 0 | 1 | 0 | 1 | 0 | 1 |
| 91 | 86.7 | 1 | 1 | 0 | 0 | 0 | 1 |
| 91 | 89.7 | 0 | 1 | 0 | 0 | 1 | 1 |
| 91 | 91.2 | 1 | 1 | 0 | 0 | 1 | 0 |
| 91 | 91.6 | 0 | 1 | 1 | 1 | 0 | 0 |
| 91 | 91.7 | 0 | 1 | 1 | 0 | 0 | 1 |
| 91 | 93.7 | 1 | 1 | 0 | 1 | 0 | 0 |
| 91 | 98.1 | 0 | 1 | 1 | 0 | 1 | 0 |
| 90 | 104.4 | 1 | 1 | 1 | 0 | 0 | 0 |
| 88 | 80.0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 88 | 80.3 | 1 | 0 | 1 | 0 | 0 | 1 |
| 88 | 82.8 | 0 | 0 | 1 | 1 | 0 | 1 |
| 88 | 83.8 | 0 | 0 | 1 | 0 | 1 | 1 |
| 88 | 85.6 | 1 | 0 | 1 | 1 | 0 | 0 |
| 88 | 86.0 | 1 | 0 | 1 | 0 | 1 | 0 |
| 83 | 74.7 | 0 | 0 | 0 | 1 | 1 | 1 |
| 83 | 76.7 | 1 | 0 | 0 | 0 | 1 | 1 |
| 83 | 79.6 | 1 | 0 | 0 | 1 | 0 | 1 |
| 79 | 73.1 | 1 | 0 | 0 | 1 | 1 | 0 |

**Table 3.** Combinations of three warehouse locations, number of accessed health centres and total driving times of delivery routes.

Nevertheless, it is important to notice that the increasing number of warehouses do not decrease the total travel time remarkably (table 4). Total cost in reaching present health centre network or limited number of units in different scenarios by using six warehouses decreases travel time only 14–17 %, in relation to using two warehouses. When comparing the effectiveness of delivery routes of most efficient two and three warehouse settings, by adding a third warehouse, only 7–11 % of driving time could be saved. Increasing amount of warehouses from three to six, the total driving time reduces by 3–6 %.

| Number of warehouses | Number of health centres, total driving time (h) / accessed health centres | | | | |
|---|---|---|---|---|---|
| | ***52*** | ***62*** | ***72*** | ***82*** | ***92*** |
| 1 | 67.7 / 47 | 65.4 / 54 | 73.1 / 64 | 72.4 / 72 | 74.7 / 80 |
| 2 | 61.4 / 51 | 73 / 61 | 79.3 / 71 | 82.1 / 81 | 92.4 / 91 |
| 3 | 55.2 / 51 | 65.3 / 61 | 70.6 / 71 | 75.5 / 81 | 85.6 / 91 |
| 4 | 53.5 / 51 | 64.8 / 61 | 69.2 / 71 | 72.5 / 81 | 83.3 / 91 |
| 5 | 51.8 / 51 | 63.6 / 61 | 66.1 / 71 | 72.1 / 81 | 81.3 / 91 |
| 6 | 52 / 51 | 63 / 61 | 66.7 / 71 | 70.5 / 81 | 80.8 / 91 |

**Table 4.** Effectiveness of transports and number of warehouses and health centres

## 5. Discussion and Conclusion

This study gives a preliminary sight in optimising geographic aspects in core and supporting services of basic health in the Northern Finland. Findings of the study show that regional level accessibility is not harmed remarkably if 10–20 health centres would have to be withdrawn from areas having presently dense service network. However, local effect on accessibility might still be notable, particularly in the most sparsely populated peripheries. If health centre warehousing is wanted to be enhanced by centralised solutions, there are no remarkable geographic obstacles for this, even though the distances between health centres in the region may represent extreme in the context of the Europe. Only northernmost health centres of the study area are poorly accessed by generated delivery routes. Analyses indicate that Oulu is highly suitable site for centralised warehouse, and if two or more warehouses are aimed to be located, Rovaniemi shows as a very favourable location.

There are some opportunities to enhance this analysis in the future. Simple travel time estimates may be developed further by including real or estimated costs to analysis, in relation to travel time, distance, frequency as well as amount and quality of goods. Equally accessed nodes could be weighted by volumes in route generation. The effectiveness of route solver in designing routes may affect to the results in some extent. As vehicle route problem is solved by functions applying heuristics, only sub-optimal route setting is found. Thus, the differences between effectiveness of route solvers would be worthwhile to be compared, to increase the validity of results.

Finally, long distances are important factor that has to be taken into account in designing the health care services in northern context. In designing different level service networks, mobile services, warehousing functions or deliveries, locational analysis and GIS are an effective analytical framework to be applied in optimizing the spatial components of activities and facilities with motivation to design more effective services.

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