

# Integrated location-allocation of private car and public transport users – Primary health care facility allocation in the Oulu Region of Finland

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## Abstract

The Finnish healthcare system is currently under significant reorganization, and new service providers are accessing emerging markets. Easy and equal accesses to services are key factors for good-quality health care. Locally available services will also reduce the need for passenger car travel, if public transport may be easily used. Network accessibility-based location-allocation analyses are commonly applied to locating services in a normative manner with travel distance or car travel time attributes. Again, multimodal accessibility is often measured in a positive context. However, location-allocation analyses including simultaneously two or more separate travel mode layers are rarely conducted. This paper applies p-median type location-allocation analysis in geographic information systems (GIS) with network data including integrated public transport and car-user routing. The aim is to find new optimal sites for primary health care services by taking potential public transport travels into account, in addition to passenger car travels. A key part of the analysis is the time estimates of bus and walking routes, which are based on the General Transit Feed Specification (GTFS) and walkable road network. For location-allocation, potential bus users are routed from home locations to all potential service locations via the fastest available transit connections within a defined time period. By connecting this connectivity matrix to car travel estimates, public transport and car travels may be integrated in the analysis. By integrating public transport and car travelling in location-allocation, the coverage and the efficiency of the service network in the Oulu and Kempele city regions may be developed in a way that is more favourable to public transport users.

*Keywords:* Accessibility, General Transit Feed Specification (GTFS), Health care, Location-allocation, Private car, Public transports.

## 1 Introduction

In Finland, healthcare systems and organizations are facing challenges through needed cost reductions and expected service improvements. Especially in sparsely populated areas, long distances, decreasing population and modern requirements for energy efficiency put an extra challenge on the healthcare system and urban form, in general. One of the most important strategic approaches to these challenges is the locations of the service facilities (see e.g. Ahmani-Javid et al., 2017). These healthcare facility (HCF) location decisions, indeed, affect heavily the accessibility of health services and costs associated with the provided service entity.

Hence, new solutions have been sought to develop and re-structure healthcare systems. Until now, the municipalities in Finland have organized public primary healthcare services, whereas hospital districts are accountable for specialized health care in larger geographical areas. A new reform (to be implemented by the year 2019) will centralize all public healthcare into regionally managed organizations. In addition, the volume of privately provided health services will grow as the reform increases patients' right to choose their health service providers.

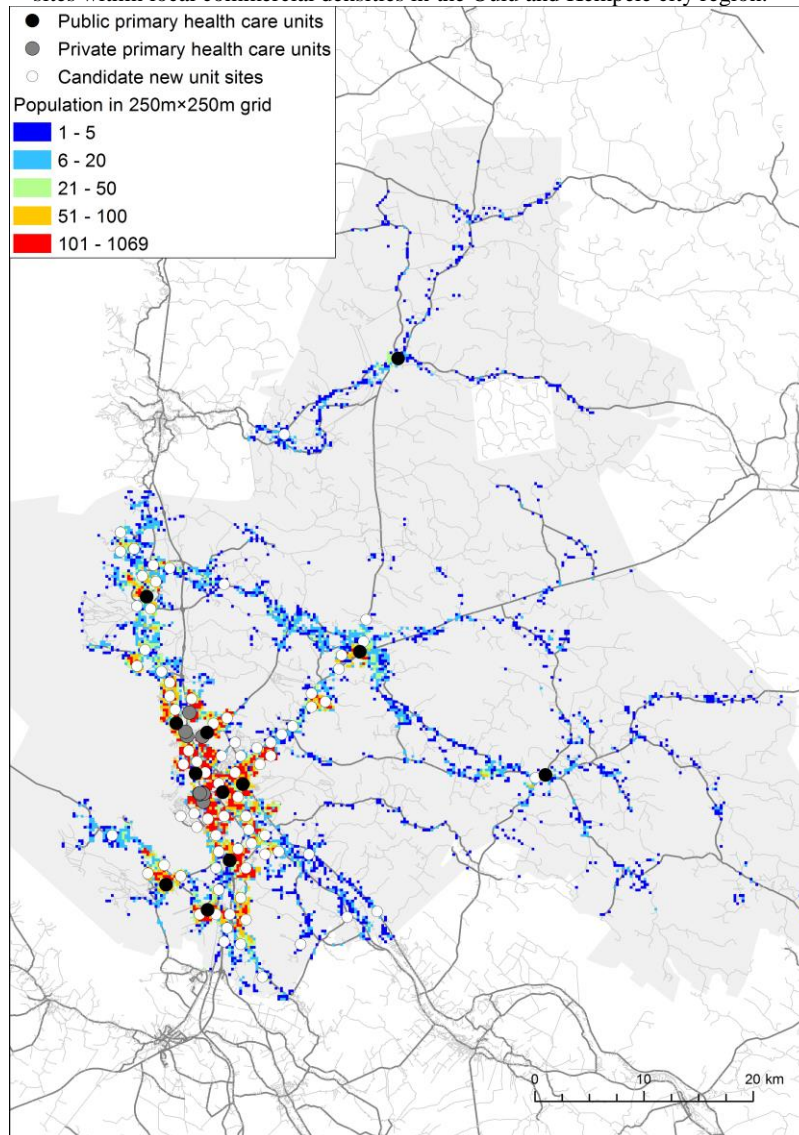
This paper focuses on HCF location scenarios in the Finnish city region of Oulu and Kempele (Figure 1) in Northern Finland, more precisely in the Northern Ostrobothnia region. The reform calls for GIS-based HCF location information as

the new models are researched to produce health services in new regional entities without relying on earlier service production or municipal and administrative borders. This gives new opportunities that affect service offering in the matter of quality, better accessibility to population, service and cost efficiency, equality in access, as well as promoting an environmentally friendly urban structure.

A great deal of location-allocation analyses have been developed for different analytical purposes (see Polo et al., 2015; Lei et al., 2016). The p-median type location-allocation is a common subtype of graph-based facility location problems (see. Rodrigue et al., 2013: 176-179, 306-317). Geographic information systems (GIS) are applied widely to solve spatial location problems (Miller & Shaw, 2001; Tong & Murray, 2012) having relevance also in the field of health care (Cromley & McLafferty, 2011).

In this paper, we seek to answer the question: How could local-level primary health care service networks be developed to be more efficient, equally accessible and public transport friendly? Potential new unit locations were surveyed by location-allocation analysis and transport accessibility by public transports and passenger cars. The aim is to find the most suitable locations for new 1-10 complementary HCF service points. Energy efficiency and environmental aspects are important considerations in the aim to increase the usage of public transport and decrease the need for owning and using personal vehicles in the region.

Figure 1: Population structure at 250m×250m grid, public and private primary health care units and candidate unit sites within local commercial densities in the Oulu and Kempele city region.



Source: Geography Research Unit, University of Oulu.

Data: Digiroad (Finnish Transport Agency 2016), the Monitoring System of Spatial Structure and Urban Form (YKR) (Finnish Environment Institute SYKE), HCF data (The National Institute for Health and Welfare (THL) and University of Oulu).

## 2 Societal geospatial data

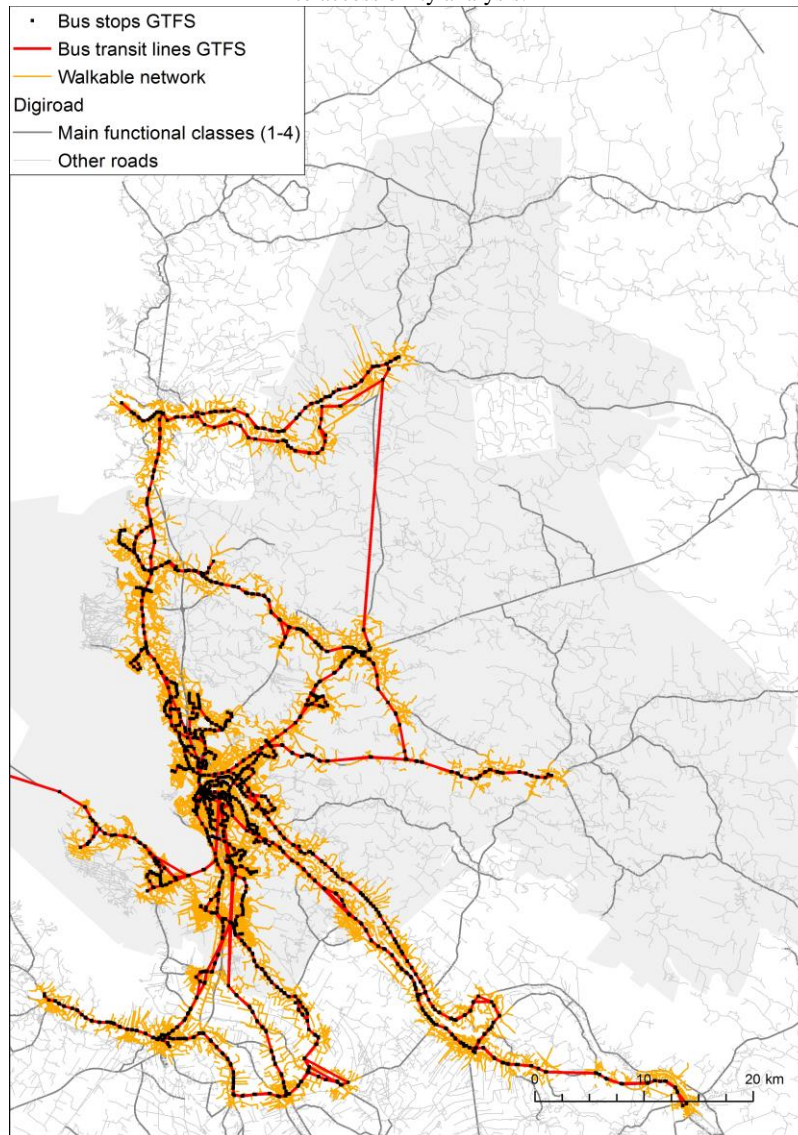
GIS data used in the study consist of 1) routable transport network data including time table-based public transport travel chains with shifts and walking network as well as car travel network with speed limit attributes, 2) population structure and household-specific car ownership data and 3) primary HCF and commercial activity site datasets.

### 2.1 Transport network and transit data

Transport network data includes the Digiroad model of the Finnish road network and the General Transit Feed Specification (GTFS) of Oulu Region public transports

(Figure 2). GTFS data of Oulu Region public transport is dated on 20.11.2017 and Tuesday 16.1.2018 9:00–10:00 AM was applied as a reference date and time for bus travels (Oulu Public Transport transit data 2017). GTFS data was transformed into a form compatible with the ArcGIS network analyst using the Add GTFS tool set. Road network data consisted of all roads including regional and local main streets, collector and feeder streets and private roads allowed for public use and walkways (Finnish Road Administration 2016). In the road network, travel speed estimates were formulated on the basis of the speed limit data. 40 km/h was used for missing information and 4 km/h was applied for walking. Thus, travel time estimates are highly accurate in the mainly uncongested traffic of Northern Finland.

Figure 2: Public transport GTFS data, walkable network within bus stops and drivable road network data integrated into accessibility analysis.



Source: Geography Research Unit, University of Oulu.

Datasets: Digiroad (Finnish Transport agency 2016), GTFS (Oulu Public Transport transit data 2017).

## 2.2 Population and car ownership

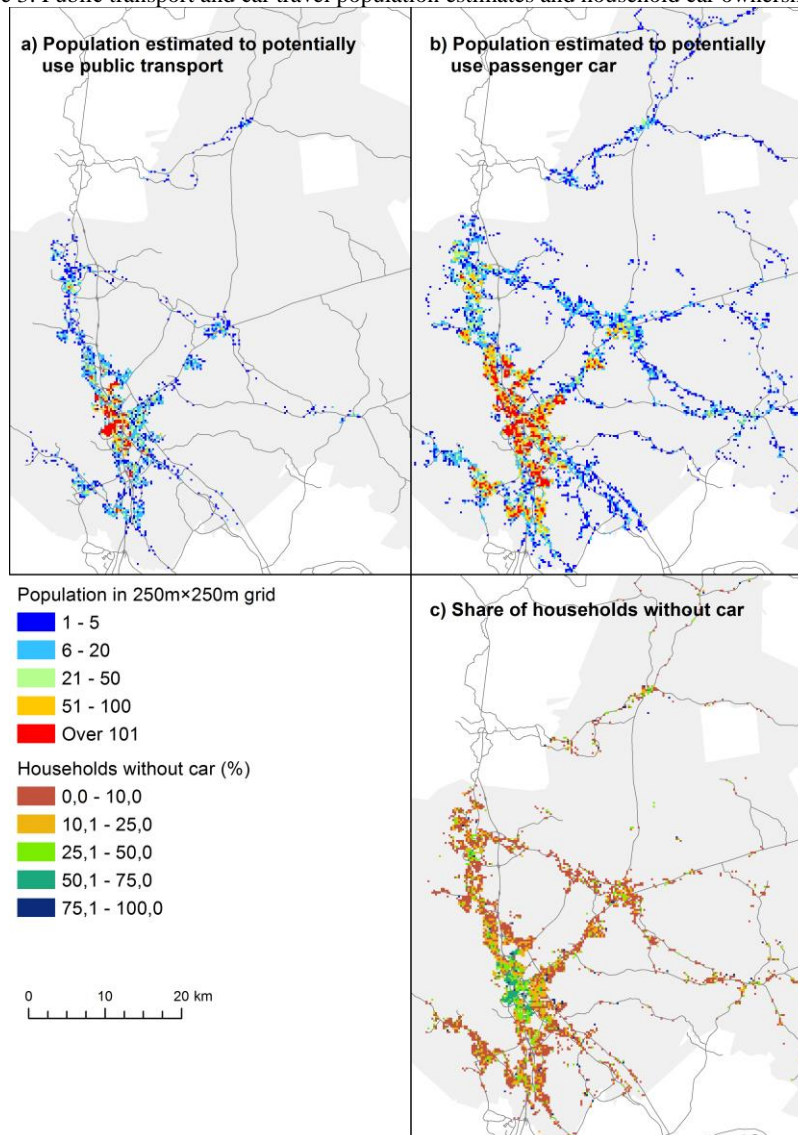
Population data includes year 2016 population structure at 250m×250m grid cells. Car ownership data from 2015 was applied to produce raw estimates for the spatial distribution of potential public transport users. Both datasets are obtained from the Monitoring System of Spatial Structure and Urban Form (YKR), and they are produced by the Finnish Environment institute. The share of households having no car ownership was applied as a ratio to produce a raw estimate of the public transport-using population. Thus, the region's 216,322 inhabitants were divided to 53,159 public transports users and 163,163 car users. However, 408 inhabitants having no car, but living further than 1,000 m from the nearest bus stop were also considered as car (or taxi) users. In the

analyses, locations of grid cells are represented by their centroids shifted to the nearest road segment.

## 2.3 Health care facilities and candidate locations

Primary HCF location data is based on the HILMO register of the National Institute for Health and Welfare including the "Topi" health care unit register. Unit locations were geocoded and cross-checked (Lankila et al., 2016) and thus, year 2016 public (N=12) and private (N=11) primary health care units with two reviews in 2018 were applied as facility location data. For surveying new unit sites by allocation analysis, commercial activity sites were applied as candidates. The Monitoring System of Spatial Structure and Urban Form (YKR) includes the amount of retail units at 250m×250m grid cells. The local maximum of the cells with 1200 m range was

Figure 3: Public transport and car travel population estimates and household car ownership data.



Source: Geography Research Unit, University of Oulu.

Datasets: Digiroad (Finnish Transport agency 2016), the Monitoring System of Spatial Structure and Urban Form (YKR) (Finnish Environment Institute SYKE)

selected to candidate sites (N=78). Thus, the most-dense agglomeration of retail units in centres and a single retail unit in periphery areas represent candidate unit sites with suitable density and coverage.

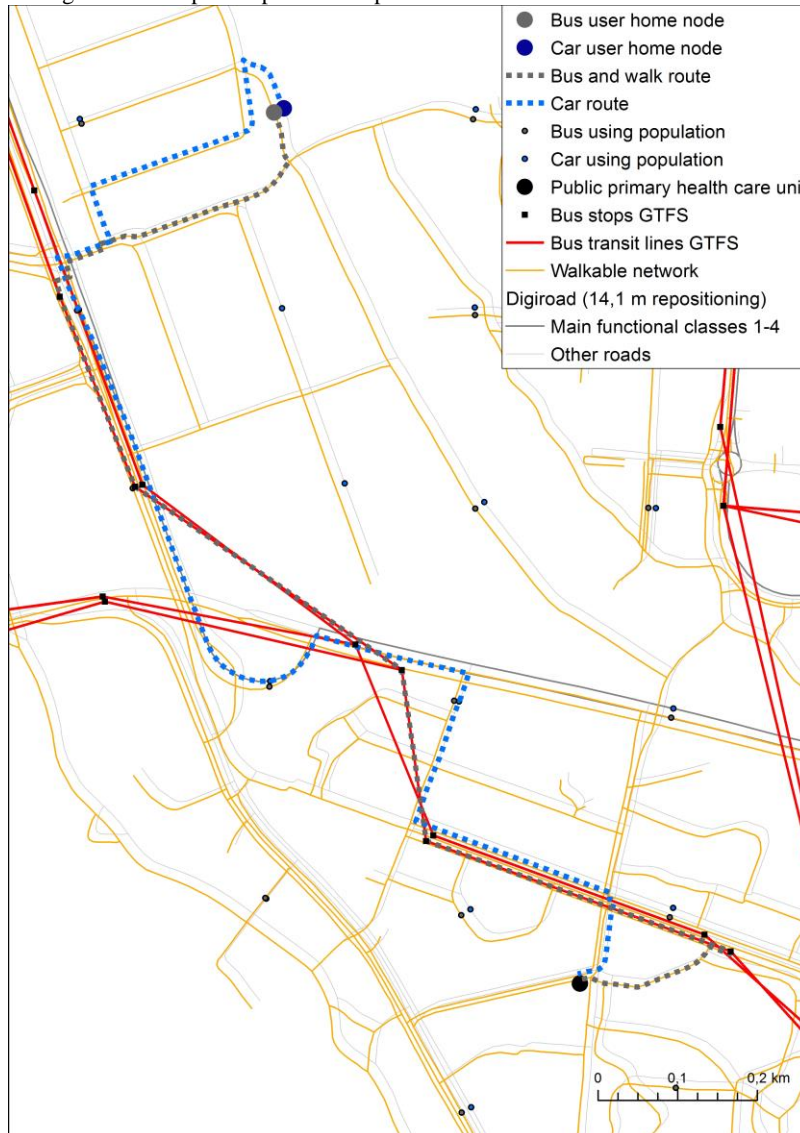
### 3 Accessibility and location-allocation analysis in HFC design

GIS offer a highly applicable framework in analysing accessibility with transport network data of transport networks, supply and demand (Páez et al., 2012, Rodrigue et al., 2016). P-median location-allocation is one of the several network-based location optimization methods applicable in the geographic context, and it is widely available in GIS

(Miller and Shaw, 2001). By p-median allocation, it is possible to locate a defined set of service facilities within a limited amount of candidate sites by minimizing the sum of population weighted travel costs between supply and demand locations (see e.g. Baray, J., and Cliquet, G., 2013). In addition to accessibility positive measuring, normative location-allocation methodology is applied to HFC design in various studies (McLafferty, 2003). To mention some recent examples, Kotavaara et al. (2016) have analysed opportunities of accessibility-based HCF optimization in Northern Finland and Huotari et al. (2017) have applied travel time-based location-allocation to define optimal catchment areas for Finnish tertiary hospitals so that their spatial accessibility is as equal as possible. With a Portuguese study case, Mestre et al. (2015) applied and developed models to reorganize hospital



Figure 4: Examples of public transport and car travel user route formulation.



Source: Geography Research Unit, University of Oulu.

Datasets: Digiroad (Finnish Transport Agency 2016), GTFS (Oulu Public Transport transit data 2017), the Monitoring System of Spatial Structure and Urban Form (YKR) (Finnish Environment Institute SYKE), HCF data (The National Institute for Health and Welfare (THL) and University of Oulu).

networks under future uncertainties, when hierarchical network and units providing multiple services is under consideration and there is a desire to improve geographical access while minimizing costs. In this study, ESRI ArcGIS Network analyst-based location-allocation analysis was applied with minimized impedance, i.e., p-median optimization ESRI (2012).

### 3.1 Public transport routing

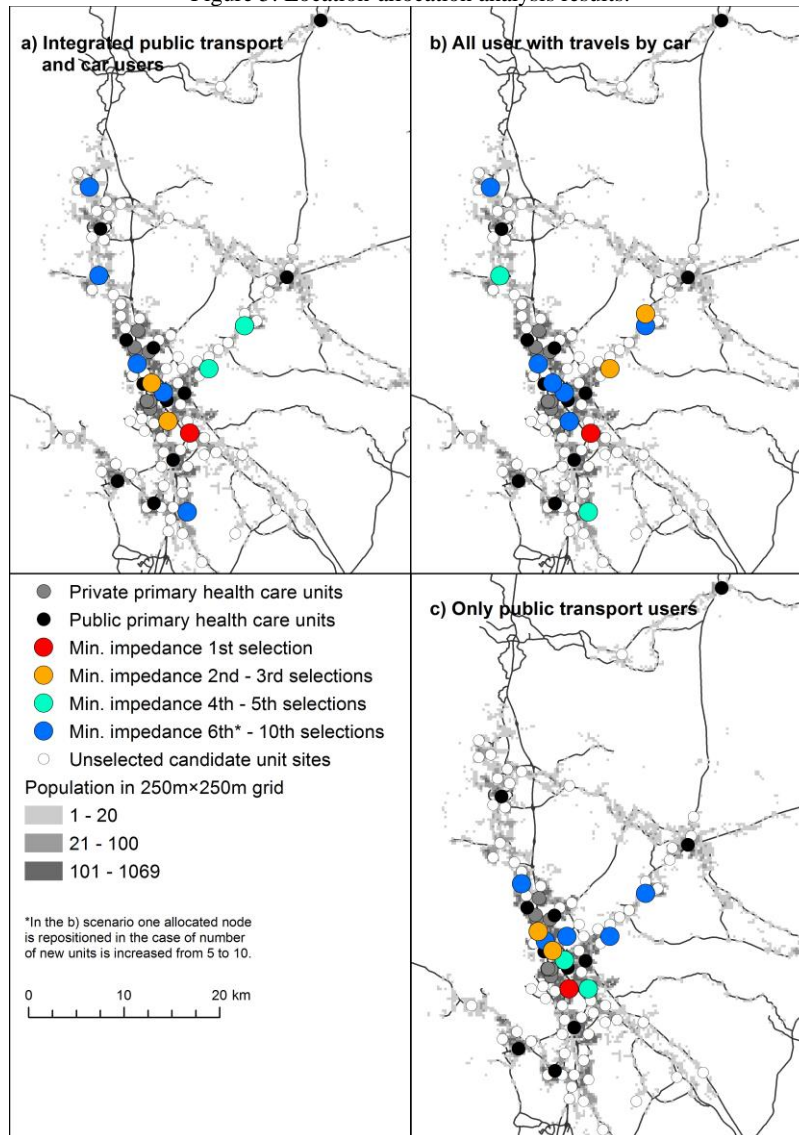
Public transport users connected to the nearest walkable road network segment and they were routed via scheduled transit connections. The fastest connections between each residential and service location were obtained on Tuesday 16.1.2018 when trip starting time iterated between 9:00–10:00 AM with

one-minute intervals. The fastest residential and service location connections with realistic travel chains formulated to a travel matrix for location-allocation analysis. Temporal route sequencing was carried out with Python scripting.

### 3.2 Car travel routing

For routing passenger car users simultaneously with public transport users, the drivable road network shifted 14.1 m northeast, which enabled the use of similar network geometry and topology, but different time attributes. Again, car travellers connected to the nearest drivable road network segment and they routed from residential to service locations via Digiroad road network data including travel time estimates based on speed limit attributes.

Figure 5: Location-allocation analysis results.



Source: Geography Research Unit, University of Oulu.  
 Datasets: Digiroad, GTFS

#### 4 Results

All executed location-allocation scenarios were analysed adding one, three, five or ten new HCFs to Oulu and Kempele city regions, by applying widely used p-median location-allocation analysis with time-based travel cost estimates (see Huotari et al., 2017, Polo et al., 2015). Three different traveling scenarios were conducted (Figure 5): a) public transport and passenger car users were integrated into the same analysis, b) the whole population of the region routed by passenger car travels and c) only the population estimated to be potential public transport users routed via public transport.

The main finding of the study is that when one to three new units are added optimally to the region, the most suitable locations are found within the main transit lines outside the centre of Oulu. Results indicate that at least from one to three

new sites, accessibility of the service network would increase notably. However, due to the relative high coverage of the present network, the benefit gained by allocating over five new units is rather low.

In more detail, the public transport user segment in scenario a) draws complementing service sites outside urban districts within reasonable connectivity to the bus network, whereas passenger car users draw other service sites towards distant suburbs in following stages of allocation. The latter trend is strongly visible also in scenario b) considering car users purely, however, the first allocated site corresponds to the scenario a) result. When considering the public transport user segment in scenario c) sites near and in urban districts within reasonable public transport connections are clearly emphasized.

Car users benefit more from a southeast targeting network, which has the sparsest service coverage. Adding a fourth and fifth unit would spread the service allocation also to more distant locations, all within entry roads. When locating the 6<sup>th</sup> to 10<sup>th</sup> units, also more dispersed unit sites are included in the service locations in the case when public transport and car users are included in the analysis. Interestingly, only a few of the scattered larger population settlements within commuting distance are able to draw a service unit. The results refer indirectly to the idea that the present HCF network has relatively good coverage, but all units are not well connected to the public transport travel chains.

## 5 Discussion

Location-allocation analysis integrating public transport and passenger car users opens new opportunities to design service networks in a more public transport-friendly way. When applied, the key services in the urban structure enable increasing public transport use as well as efficiency and equality of service accessibility.

Equality in this case refers to the goal of having corresponding distances to service points, but also the segmented use of public transportation. In short, by enabling better accessibility via public transportation, HCF accessibility may be improved especially for young and female residents.

Again, increasing public transportation usability for trips to and from healthcare facilities may reduce the need for a car or second car ownership and decrease transport-related CO<sub>2</sub> emissions to some extent. Of course, primary health care facilities represent only one service type, but clearly one needing efficient and equal accessibility.

The public service network based on concrete service centre buildings is not rapidly changeable. However, the results of this case study may be used in evaluating privately provided health service points, as healthcare reform raises their position also in public health service offering.

Widely available GTFS transit data format enables easy options for public transport routing with real-world travel chains. However, managing temporal dynamics is essential and the sequenced fastest route time matrix is needed for the basis of allocation analysis. Even though the GTFS data enables including scheduled public transport allocation analysis, the recently expanded sharing economy taxi services and other developing call bus services, may benefit service network accessibility in terms of time cost and time.

Research focusing on these services is needed for making energy-efficient HCF decisions to benefit more sparsely populated areas of the region where traditional public transportation does not offer adequate opportunities for trips between home and health care facilities. Finally, it seems that integrated public transport and passenger car location-allocation analysis seem to yield promising results for HCF decisions in situations where public transportation can offer real travel alternatives to private car travels for accessing health care or other key services.

## Acknowledgements

The study was carried out in the project “Low carbon logistics in local social and health care services”, which is funded by the European Regional Development Fund (ERDF) for the period 1.3.2018–29.2.2020. The work for this paper is supported also by the project “Improving the information base and optimising service solutions to support social welfare and health care reform (IMPRO)”, which is funded by the Strategic Research Council (SRC), for the period 1.1.2018–31.12.2020.

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