Mobile health care facilities vs. health centres – Comparing the service structure strategies in reducing CO₂ emissions

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Abstract

Societies are considering the accessibility of health services and its impact on environmental sustainability. The services are provided by both mobile and centralised solutions. This study compares the CO₂ emissions of these strategies by applying a geographical information system (GIS)-based route allocation that is referred to qualitative data from focus groups with health care management professionals. The results show that in the sparsely populated case area, the CO₂ emissions can be reduced 49% by applying a mobile health care facility model in primary health care. However, the presented model must be carefully considered to fit to the health service entity.

Keywords: Healthcare logistics, Mobile services, Sustainability, Carbon emissions

Introduction

Healthcare systems and organizations are facing challenges through the needed cost reductions, expected service improvements and also modern requirements for energy efficiency. These challenges are especially emphasised in sparsely populated areas due to the long distances and decreasing population. Proposed approaches to these challenges are managing the locations of health care service facilities HCF (see, e.g., Ahmani-Javid et al. 2017, Kotavaara and Pohjosenperä, 2018) and moving health care service facilities (see, e.g., Caires, 2017, Guruge et al., 2009; Gibson et al., 2014; Kojima, 2017). Both approaches heavily affect the accessibility of the health services and costs of the provided service entity. However, there still remains a gap in knowledge of how these different scenarios affect the total CO₂ emissions of the healthcare system.

This paper compares two service structure strategies for primary healthcare in a sparsely populated area in order to find the minimum level of CO₂ emissions of the system. The case area is Koillismaa, which is formed by the three most sparsely populated municipalities in the region of Northern Ostrobothnia in Finland. In the Finnish healthcare system, the municipalities organise the public primary healthcare services whereas hospital districts handle the special health care in larger geographical areas. The national
The case analysis is performed by calculating the outcome of two scenarios. The first is the ongoing strategy, where the primary health care patients travel to the healthcare centre to be treated and then back home. The second scenario applies a mobile healthcare model to offer new health care service locations for the population living far from the health centres. The accessibility and the back-and-forth travelling kilometres of both strategies are calculated by using Geographic Information Systems (GIS)-based transport accessibility methods (Miller and Shaw 2001) with actual road and healthcare facility data. Thus, the research utilises accurate location data of both inhabitants and the service network as well as the road infrastructure in the case area. CO₂ emissions are included in road network data as travel cost attributes in addition to minutes and kilometres (see Määttä-Juntunen 2011) by using average CO₂ emissions for different types of vehicles defined by the VTT Technical Research Centre of Finland (cited 19.2.2019).

The purpose of the study is to find an ecologically sustainable model for delivering primary healthcare service through health centres and mobile health care facilities. The empirical results from the case area reflect current literature about mobile health care facilities and were compared to the metrics that are used to estimate the influences of CO₂ reductions. Hence, this research aims to contribute to answering the following questions. How does implementing mobile healthcare facilities affect the CO₂ emissions of the healthcare system? Again, how does optimising CO₂ emissions influence societal sustainability goals? Overall, this study estimates and compares the CO₂ emissions of the two selected service strategies and, thus, opens up discussion about mobile health care facilities’ impact on societies’ reaching their goals concerning environmental sustainability.

Next, the paper presents overview of the literature of mobile healthcare facilities. Then the multidisciplinary research design of using both the GIS-method and qualitative case analysis is explained in Section 3, which also includes an overview of the case area. The case is further analysed in Section 4 and concluded in Section 5.

Mobile health care facilities

The Mobile health care (Caires, 2017) or Mobile health clinics (Guruge et al., 2009) represent transportable healthcare and can also be called Mobile medical clinics (Gibson et al., 2014; Kojima, 2017) or Mobile clinics (Lafuente et al., 2007; Pitt et al., 2012). ‘Mobile health care’ can also be understood in some cases to refer to wireless communications solutions such as health care applications in mobile phones and other wireless interfaces (Khazbak et al., 2017; Mangu, 2017). The mobility of health care professionals on the other hand means the movement of doctors and other health care occupant to provide the demand of health care services (Ribeiro, 2014).

Mobile healthcare clinics are an alternative solution to delivering care to people with transportable healthcare units that enable healthcare offsite from institutions and healthcare agencies to underserved populations that might be difficult to reach (Guruge et al. 2009). They are healthcare strategies that increase access to care by people with geographic, structural and social barriers, therefore decreasing inequality for marginalised groups by implementing the traditional, fixed healthcare media of healthcare (see, e.g., Gibson et al., 2014). Mobile healthcare clinics make it possible to deliver healthcare at a reasonable distance from groups that are restricted by location (Leese et al., 1993; Gibson et al., 2014) or other obstacles such as limited access to transportation (Hastings et al., 2007). They are sometimes described as non-traditional
health care strategies (Gibson et al., 2014). One study found that mobile medical clinics have been especially successful in delivering services to rural (Peritogiannis et al., 2011) and urban minorities (Daiski, 2005). Mobile healthcare can also be favourable for the populations that are vulnerable due to poor traditional healthcare. (Gibson et al., 2014.)

Mobile health care has been implemented for a large variety range of health-related services, including the increase of access to services for the elderly living in rural areas, screening at-risk-populations such as drug users and the homeless, providing maternal health care services, screening for sexually transmitted infections, preventive health care such as dental care, screening for breast and/or cervical cancers and providing crisis care for mental illness. (Guruge et al., 2009.) Mobile medical clinics can be a sufficient means of delivering health care, health promotion and health-related education. They have a tendency to use fewer operators for larger areas in comparison to traditional health care centres, which is extremely practical in areas where the geographical distribution of patients is widespread (Kojima et al., 2017).

One application for Mobile healthcare facilities is blood donation logistics. In these systems, cars and personnel drive to locations closer to donors to collect blood that is needed in health care operations. The bloodmobiles can attract more donors than fixed donation points by offering better accessibility by bringing the location closer to the donors, hence saving their time. These bloodmobiles can additionally be served by ‘shuttle car’, collecting the timely critical blood for the depot, allowing the mobile healthcare facilities more time to collect blood (Şahinyazan et al., 2015)

Of these mobile solutions presented above, this paper focusses principally on mobile health care facilities (mobile HCF) that provide primary healthcare for sparsely populated areas. The users of the service are selected by their home location in the case area.

Case area
The empirical case area Koillismaa is located in the Northern Ostrobothnia hospital district in Northern Finland. The region itself has 408,752 inhabitants in the area of 40,000 km², which works out to an average population density of 11.2 inhabitants per km². Most of the population is located in city centres, leaving the majority of the region sparsely populated. A total of 392,190 amongst the population (96%) have their home locations within 20 minutes car travel from nearest health centre. Thus, 16,562 inhabitants have over 20 minutes’ travel time to a health centre and the longest times reach 77 minutes or 82 kilometers.

Nearly half of these far distance inhabitants (7,805 people) live in three municipalities: Kuusamo, Taivalkoski and Pudasjärvi, which form the area of Koillismaa, located in the northeastern part of the region. The 27,261 inhabitants live in the area of 14,327 km², resulting in a very sparsely populated area (1.9 inhabitants per km²) which is also characterised by old age structure (28.2% are age of 65 or over) with high demand on health services.

Methodology
To find relevant empirical background for the study, a qualitative case approach is implemented as the issue is in the developmental stage, rather complex and alternates between the empirical field and different theoretical frameworks (Voss et al., 2002; Yin, 2009). The empirical data of the study is collected through various methods and multiple sources to add breadth and depth in understanding the phenomenon (Yin, 2009). By applying both the GIS and qualitative case methods, this study aims to increase both the research and managerial relevance of the research (see, e.g., Ketokivi and Choi, 2014).

Data collection methods contain interviews and forms of group discussions. Focus groups are especially useful in identifying important qualifiers or contingencies that may be associated with an answer to a structured question. Furthermore, focus groups offer an
opportunity for feedback from and response to the comments of others (Stewart and Shamdasani, 2014, p. 178).

The mobile health care facility strategies and their affect on CO₂ emissions are empirically discussed in focus group discussions with the research project ideating group (3) and steering group (3), which include professionals from both public and private healthcare organisations from the case region. Furthermore, the accessibility of primary healthcare services and mobile strategies are discussed in five focus group discussions/semi-structural interviews with health care professionals in the case region.

In this study, opportunities to reduce CO₂ emissions and increase service accessibility by extending health services close to rural areas with service vehicles were tested with Geographic information Systems (GIS)-based transport accessibility analyses (see Miller & Shaw 2001). Transport GIS-based analyses enable the measurement of travel distance, time and emissions for different types of vehicles routed from origins to destinations in a graph model of a road network. Analyses are executed with the ESRI ArcGIS Network Analyst extension, and are home to service site routes and customer potential which are generated with Location-Allocation analysis and a Vehicle Routing Problem method is applied to generate tour-based service routes. A passenger car travels from a home location to the closest health service locations, which are estimated to compare the service efficiency of different service scenarios in terms of accessibility. To produce a scenario for rural health services based on service vehicle, service routes were generated and optimised to satisfy service demand with minimised travel time.

In producing a service vehicle scenario, first a small rural population concentration which needs more than 20 minutes travel time to health centres cluster in the centres of built-up areas, villages, hamlets and commercial activity sites. Populations closer than 15 minutes are first allocated to these 66 local service points, resulting in customer potential levels between 333 and 11. Secondly, service vehicle routes were optimised to cover these service points. The maximum time of each route is limited to 9 hours due to EU driving time legislation. A weekly demand evaluated on the basis of estimated average service time consisting of population outside labour, an annual service which is used at a rate of 3.4 times per person (see Lankila et al., 2016) and 20 minutes’ average service time. Thirdly, service efficiency of health centres and service vehicles assessed by measuring driving and service time, travelled kilometres and CO₂ emissions.

Spatial data consists of Digiroad network data (Finnish Transport Agency, 2018) including all regularly used roads and speed limit data, locations of health centres, YKR population grid cell data (2017) and YKR data of built-up areas, villages, hamlets and commercial sites (2015). Road network data enables estimation of travel times (see Kotavaara et al., 2017), which were estimated for passenger cars and service vehicles, for which travel speeds were estimated at the level of a delivery van or smaller truck, and the maximum speed was limited to 80 km/h. Turn penalties are defined according to Jenelius and Koutsopoulos (2013), 10 seconds to left turn, 7 seconds to right turn and 30 seconds for a right turn when crossroads without a turn take 3 seconds. CO₂ emissions included road network attributes in addition to minutes and kilometres (see Määttä-Juntunen, 2011). The VTT Technical Research Centre of Finland (cited 10.4.2019) has evaluated CO₂-emissions for different types of vehicles and travel cost attributes for passenger cars and van with a full mass of 2.7 tonnes.

Case analysis
This study examines two scenarios for providing primary health care services in the case area. In the first scenario, the patients travel to health centres that are located in the centre of the municipals. Each trip is made using passenger cars. As a simplification, this case does not take into account the use of other transport modes as taxis, buses, motorcycles,
bicycles, walking, et al. as the distances are long and public transportation is very limited. The home locations and straight lines to health centres are illustrated in Figure 1.

In scenario 2, the same health centres serve the patients within a 20-minute time range. However, patients living more than 20 minutes away from the health centre are served through mobile service facilities, i.e., vans that drive the calculated routes once a week. The calculated locations for mobile facilities and their accessibility are illustrated in Figure 2. Some of the most distant locations are far from these mobile locations and are therefore calculated to use the health centres.
Figure 2 – Accessibility of the mobile health care facility locations

The van routes are calculated to cover the mobile facility locations once a week with maximum 9 hours working time per day. The van starts from a local health centre and returns to the same location at the end of each day. The 15 routes are illustrated in Figure 3 and are detailed in Table 1. All the routes can be covered within five working days with three vans, one per municipality. Each route requires between 1.5 and 4.2 hours of driving time, leaving 4.6-7.2 hours to operate as a mobile health facility.

Table 1 – Calculated routes

<table>
<thead>
<tr>
<th>Route</th>
<th>total h</th>
<th>driving h</th>
<th>km</th>
<th>CO₂ kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Taivalkoski</td>
<td>8.9</td>
<td>2.0</td>
<td>112</td>
<td>20.1</td>
</tr>
<tr>
<td>2. Taivalkoski</td>
<td>8.7</td>
<td>2.6</td>
<td>165</td>
<td>27.3</td>
</tr>
<tr>
<td>3. Taivalkoski</td>
<td>8.4</td>
<td>3.1</td>
<td>193</td>
<td>31.8</td>
</tr>
<tr>
<td>4. Kuusamo</td>
<td>8.7</td>
<td>1.5</td>
<td>94</td>
<td>23.7</td>
</tr>
<tr>
<td>5. Kuusamo</td>
<td>8.8</td>
<td>1.7</td>
<td>105</td>
<td>17.5</td>
</tr>
<tr>
<td>6. Kuusamo</td>
<td>8.4</td>
<td>2.3</td>
<td>136</td>
<td>22.8</td>
</tr>
<tr>
<td>7. Kuusamo</td>
<td>8.5</td>
<td>1.6</td>
<td>88</td>
<td>14.9</td>
</tr>
<tr>
<td>8. Kuusamo</td>
<td>8.9</td>
<td>3.5</td>
<td>192</td>
<td>32.6</td>
</tr>
<tr>
<td>9. Kuusamo</td>
<td>8.8</td>
<td>4.2</td>
<td>263</td>
<td>43.4</td>
</tr>
<tr>
<td>10. Pudasjärvi</td>
<td>8.6</td>
<td>1.9</td>
<td>121</td>
<td>20.1</td>
</tr>
<tr>
<td>11. Pudasjärvi</td>
<td>5.6</td>
<td>1.5</td>
<td>83</td>
<td>14.5</td>
</tr>
<tr>
<td>12. Pudasjärvi</td>
<td>8.7</td>
<td>2.4</td>
<td>139</td>
<td>23.6</td>
</tr>
<tr>
<td>13. Pudasjärvi</td>
<td>8.7</td>
<td>2.2</td>
<td>129</td>
<td>21.8</td>
</tr>
<tr>
<td>14. Pudasjärvi</td>
<td>8.3</td>
<td>1.8</td>
<td>112</td>
<td>18.6</td>
</tr>
<tr>
<td>15. Pudasjärvi</td>
<td>7.7</td>
<td>1.8</td>
<td>109</td>
<td>18.0</td>
</tr>
<tr>
<td>Total</td>
<td>125.5</td>
<td>34.0</td>
<td>2053</td>
<td>351</td>
</tr>
</tbody>
</table>
In scenario 2 most of the population (76%) live within 20 minutes accessibility from the health centres and, thus, uses the health centres as in scenario 1. The patients who live more than 20 minutes away from a health centre are now served through mobile HCF, which decreases the CO₂ emissions that they produce while using the service. However, scenario 2 also produces CO₂ emissions through the vans that drive the routes. The detailed driving time, kilometres and CO₂ emissions of scenario 2 with HC users, mobile HCF users and the routes is presented in Table 2. The digits are transformed to an annual scale by multiplying the weekly routes by 52 and by multiplying the hours, driving distances and CO₂ emissions by 3.4, which is the amount each citizen in Finland uses to reach primary health care services annually (Lankila et al., 2016).

Table 1 – Scenario 2 in detail (annual)

<table>
<thead>
<tr>
<th></th>
<th>Health centre users</th>
<th>Mobile HCF users</th>
<th>Mobile HCF routes</th>
<th>Mobile HCF total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>20,639 (76%)</td>
<td>6,622 (24%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours</td>
<td>18,928</td>
<td>3,975</td>
<td>1,770</td>
<td>24,674</td>
</tr>
<tr>
<td>Km</td>
<td>811,509</td>
<td>201,787</td>
<td>106,741</td>
<td>1,120,037</td>
</tr>
<tr>
<td>CO₂ kg</td>
<td>127,976</td>
<td>28,974</td>
<td>18,238</td>
<td>175,188</td>
</tr>
</tbody>
</table>
Table 2 presents an extreme scenario comparing the mobile HCF users’ trips to their mobile location and to the health centre. These users influence the largest savings, more than 80% in time, driving kilometres and CO₂ emissions.

<table>
<thead>
<tr>
<th></th>
<th>To health centre</th>
<th>To mobile HCF</th>
<th>Saving</th>
<th>Saving %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>25,141</td>
<td>3,975</td>
<td>21,166</td>
<td>84</td>
</tr>
<tr>
<td>Km</td>
<td>1,582,520</td>
<td>201,787</td>
<td>1,380</td>
<td>733</td>
</tr>
<tr>
<td>CO₂ kg</td>
<td>217,897</td>
<td>28,974</td>
<td>188,923</td>
<td>87</td>
</tr>
</tbody>
</table>

Finally, comparing both of the scenarios (Table 3), running scenario 2 with mobile healthcare facilities saves 44% in time, 53% in driving distance and 49% in CO₂ emissions. Annually, the 346 tonnes of CO₂ emissions can be reduced to 175 tonnes.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1 Health centres</th>
<th>Scenario 2 Mobile HCF</th>
<th>Saving</th>
<th>Saving %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>44,044</td>
<td>24,674</td>
<td>19,370</td>
<td>44</td>
</tr>
<tr>
<td>Km</td>
<td>2,392,475</td>
<td>1,120,037</td>
<td>1,272,438</td>
<td>53</td>
</tr>
<tr>
<td>CO₂ kg</td>
<td>345,658</td>
<td>175,188</td>
<td>170,470</td>
<td>49</td>
</tr>
</tbody>
</table>

Concluding discussion

This paper explores ecologically sustainable model for delivering primary healthcare service in sparsely populated area. The case analysis is presented to compare the centralised and mobile health care facility models. Our study thus illustrates how mobile health care facilities can be considered one method for achieving a decrease in CO₂ emissions by the primary health care system. The empirical results show 49% decrease in CO₂ emissions if the patients over 20 minutes driving time from the health centres are served through mobile health care facilities.

For the discussion of mobile health care facilities, this paper brings new methods of taking account of CO₂ emissions. The results show that strategic change from a centralised to a mobile model can have an impact on driving distances, driving time and CO₂ emissions. Managerially, this study offers a vision for developing health care systems that are part of societies that aim to achieve ecological sustainability. The reduction of 170 CO₂ is somewhat notable when considering the quite small population in the case area.

The presented model aims to minimise CO₂ emissions. Certainly, the results need to be further considered to fit the nuanced entity that the health care system is. Relevant questions include, for example, what kind of call-based system is required to manage the system and also whether the population in the area justifies the need for three mobile health care facilities with the needed personnel.

This research studies the service strategies in one particular geographical area (three municipalities), which puts limits on applying the results universally. However, on both a national and global scale, the case area is very sparsely populated, which intensifies the effects of the initiatives on reducing CO₂ emissions. Hospitals, hospital districts, city organisations and privately-owned healthcare services can use the results in developing their services to reach the set and aspired goals in environmental efficiency. Especially in Finland, the current healthcare reform offers momentum for renewing the health service structure to match the service needs as well as the goals of lower CO₂ emissions. Overall, this provides an example for societies aiming for environmental sustainability. Future studies can highlight the energy efficiency of other mobile health care solutions as the
mobility of health care professionals and using data connections in some parts of health services.

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