Web GIS for hjemmetjenesten

Ragnhild Angelsen

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This article reports the results of a project to demonstrate a web GIS developed to suit the needs of Home Care services. The web GIS contains comprehensive information on all home care recipients and nursing stations, and is available through the Home Care service's intranet. Queries can be easily performed on the client database both to identify clients of interest, and to aid in planning an efficient service route within a specified time frame. The application was developed using HTML, CSS, JavaScript API, and ArcGIS 10.

Key words: Home Care Services, GIS, ArcGIS, Vestvågøy, Development Center for Home Care Services, Municipality

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Introduction

In Norway, home-care services, community-based nursing and practical assistance are part of the local government statutory health and social services. It is the municipality's duty to provide necessary medical care, as well as practical and personal help, to people who because of illness, disability, age or other reasons are unable to cope with daily living activities. Home nursing is a free service, but practical assistance is paid for by the home care recipient (HCR). Nursing services include various nursing technical tasks, wound care, assistance with medication, personal care, help with meals, supervision and observation, and assistance in the home. Practical services include cleaning, laundry, food preparation, dishwashing, and changing linens. Prices depend on income level. Going forward, the cost of Home Care for the local government will increase drastically because of the baby boomers. This means that municipalities are now working to find ways to control future costs.

Vestvågøy municipality was chosen to participate in the research project Development and Maintenance of Qualitative Services in Open Care (ends 2014) directed by the Development Center for Home Care Services Nordland. One goal of the research project is to try out organization- and staff models to ensure satisfactory quality and efficient use of resources. Efficient use of resources requires knowing the extent of service routes for nurses in both time and distance, and the research project is interested in a GIS for this purpose. Solrun Holm, Associate Professor in Nursing Science, is the project manager and represents the research project.

The study area for the project was Vestvågøy, a 406 sq.km. island with 10,800 inhabitants located in the county of Nordland, Northern Norway. Home Care Services has 131 full- and part-time employees filling the equivalent of 88 full time positions. On average, 600 HCRs receive services per year.

The purpose of this project was to create a system to demonstrate how a geographic information system (GIS) could be used as a tool to calculate and visualize routes for Home Care services employees. A solution created for an intranet was most useful for the agencies using the product, as more users could access it from different computers, and the system was password protected. The final solution was a web application where the user could access a HCR database and perform a network analysis to plan routes through a map interface.

Problem statement

HCRs of the Home Care service (HCS) live throughout the entire island of Vestvågøy. The municipality has divided the island into five Home Care services sectors that manage

the HCRs within their area from a Home Care dispatch center. The road network on the island makes it easy to determine the route to reach the HCR, as the number of roads leading to each location is usually limited. Home Care services desires a system which can calculate the routes based on a work schedule, and supplement the routes with information regarding time and distance needed for each route. The system should also graphically display HCR locations and routes on a map and showing basic attributes. Each nurse has a given set of HCRs, and a service time. The required time of service is specified for some HCRs but is more flexible for others.

Proposed Solution

The proposed solution is to develop a web GIS application which will use information in a HCR database to help manage various services offered by Home Care services more efficiently. This is done by integrating HCR location information and the times required to both provide the service(s) and drive to and from the HCR's location. This project is intended to be a stand-alone demonstration of how GIS can be used for this purpose. Since actual HCR information for Home Care Services HCRs is confidential, a sample database will be constructed using fictitious HCR data. As the plan is to create a web-enabled application, the user will only require a web browser to display the desired output. The user will have the opportunity to upload a visit schedule and a nurse schedule, and a model will run in the background to calculate the routes and display them on the map. In addition, the web application will have basic functions for accessing the attributes for the HCRs and a search function.

Background and Literature Review

Planning service routes for Home Care is comparable to routing salespeople, school busses, waste collection, and street cleaning. They all deal with providing a service between depots and final users. This problem is generally known under the name 'vehicle route problem' (VRP) (Kallehauge, 2008) and is often illustrated by means of a graph with nodes representing clients/depots, and arcs representing the distance between them. Distance does not necessarily need to be the physical distance; it can be the travel time or the cost of traveling between nodes. Toth & Vigo (2001) say there are five main components for VRP: road network, clients, depots, vehicles, and drivers. These components can all have constraints that will influence the calculation for solving the routes. For instance, roads can be one-way only, which means that the distance from a to b is not the same as the distance from b to a. Clients may have a certain period of the day during which they can be served, a time window that will influence the order of visits. If they receive a product that must be picked up from another location beforehand, that will also impact the order of the visits. The capacity of the depots in terms of vehicles and drivers may differ, and the drivers are limited by their work schedules. Vehicles also can be limited by their capacity. Each of these constraints creates different problems when it comes to the algorithm used to solve the vehicle route problem. Toth & Vigo's book *The Vehicle Route Problem* (2001) presents in detail many models and algorithms that have been developed for solving vehicle route problems with different constraints.

VRP for Home Care Service is constrained by a time window when the service must start for each HCR, and the fact that the vehicle must remain at the HCR's location during service. Time windows can be hard or soft. Hard windows mean that the vehicle must arrive at the HCR's location within the given time period, whereas soft windows can be adjusted (Toth & Vigo, 2001).

In Sweden, for instance, "Vägverket" has created a specification for route optimization in Home Care services (Kravspecifikation för ruttoptimering) which is based on a project together with Orust and Marks municipalities (Vägverket, 2007). This specification was not used for this project, but it shows that municipalities are looking at methods to improve the logistic challenges in Home Care Services.

System Design

Through discussions with the Development Center for Home Care Services Nordland, it became apparent that two main functions were essential to meet the project's needs: a means to retrieve and display information about HCRs and Home Care dispatch centers, and a function to calculate and display routes according to HCR's location and the times required to both provide the service(s) and drive to and from the Home Care dispatch center.

When designing a system it is necessary to ensure that the proposed technical solution satisfies the established requirements. In the case of a web GIS it consists of three main components: data repository, server, and web client interface. The data repository refers to the GIS resources upon which the web application is built. For this project, the data repository consisted of a geodatabase and map documents. The server houses the services that handle requests from the web client. The web client interface is a web browser on a personal computer. Figure 1 shows these three main components.

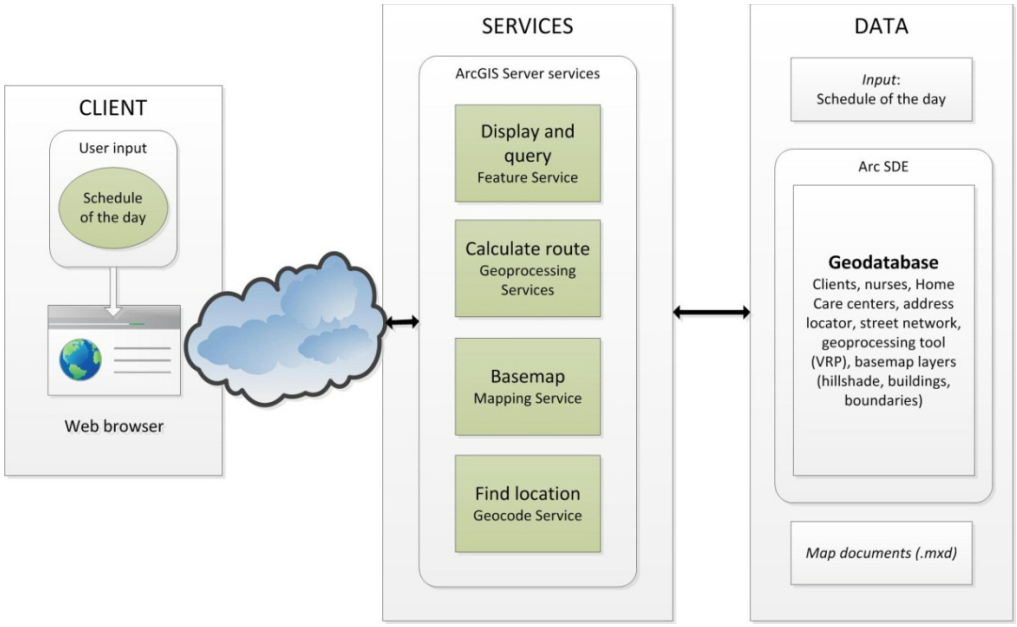

Figure 1 System design

The user runs the application through an internet browser such as Mozilla Firefox, Google Chrome, or Opera. Through the web page interface the user can zoom and pan the map; and by hovering the mouse over HCR locations, information about that HCR is displayed in a pop-up. Requested routes of the day are displayed graphically on the basemap when calculated. Figure 2 shows a screen capture of the web page displaying the locations of the different functions.

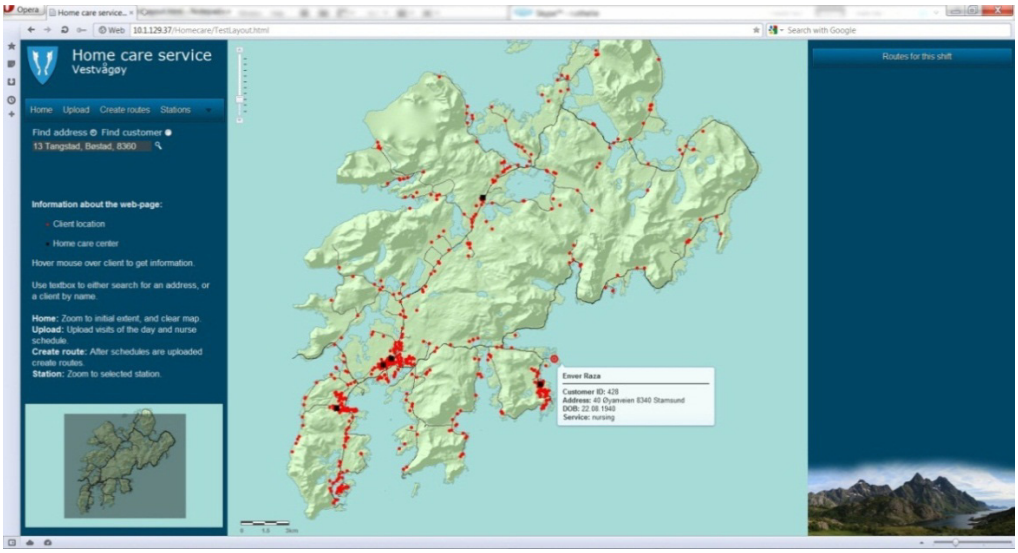

Figure 2 Web page interface

Conceptual Data Model

The conceptual model describes the relationship between the entities of the project in an abstract form. In Home Care Services, the main objects are clients and nurses. Additional objects are the service provided, the travel time between HCRs, addresses, and the visits. All of these entities culminate into a calculated route (Figure 3). A client refers to a home care recipient.

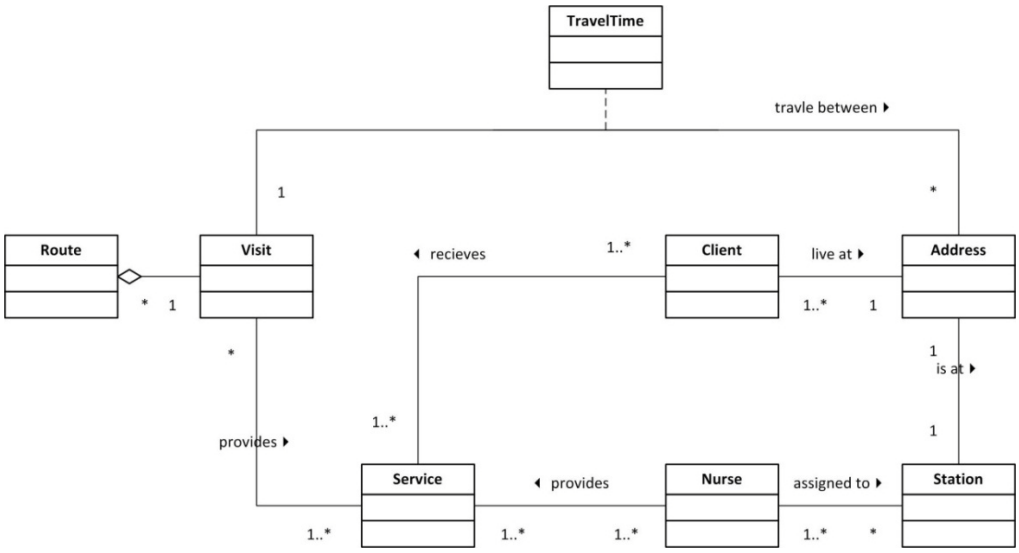

Figure 3 Conceptual model

A HCR lives at an address. Each HCR can have only one address, but multiple HCRs can live at the same address. Nurse stations (Home Care service dispatch centers) are also assigned an address, with only one address per station and vice versa. Each nurse works from a single station. A nurse will have certain skills that determine what services he/she can provide. Nurses can have the same skills and therefore provide the same services. Services are provided to the HCR by a visit, and more than one service can be provided at one visit. Each visit is composed of a visit and a travel time. The travel time refers to the time it takes for the nurse to drive from the previous visit to the current one, from one address to another. The order of the visits determines the route.

Logical Data Model

The logical model shows how the conceptual design was modified and organized so that it could be implemented in ArcGIS's 10.0 Network Analyst (Figure 4).

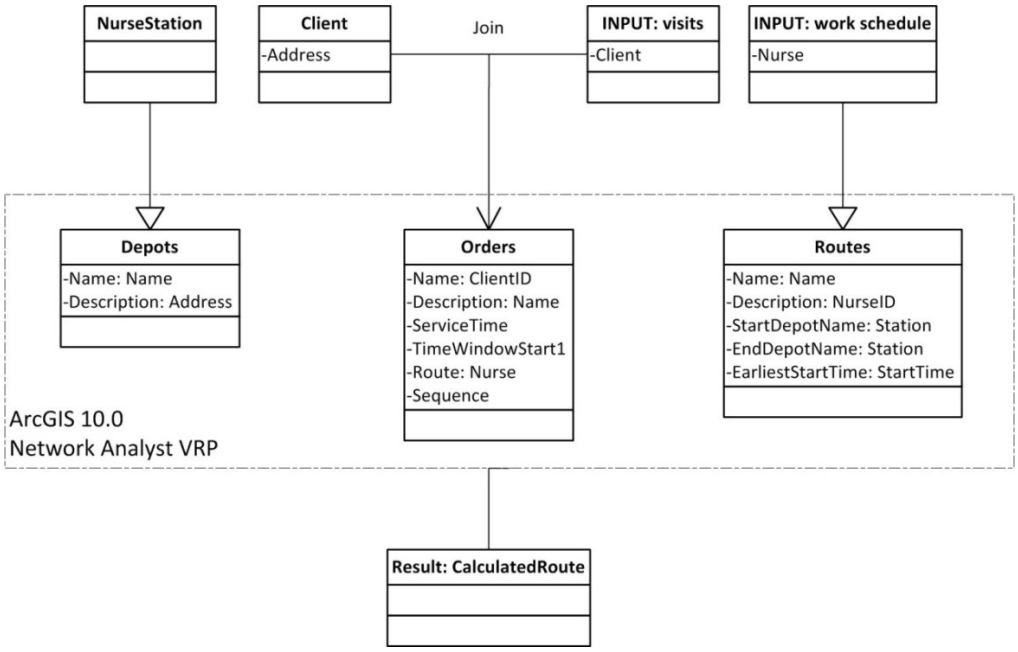

Figure 4 Logical model

To calculate routes, the software needs to know the start and end depots, orders, and routes. Routes in this context can be compared with vehicles. Each nurse will have one vehicle and is therefore one route. For this project, the depots were equal to the nurse stations. The location of each station was based on the address for the station. The orders cover the visits: which HCR, the service time, the nurse assigned, at what time if applicable, and the sequence number for the visit. The nurse assigned to the HCR relates to the route, since one route is equal to one nurse. The route's start and end depot depend on which station the nurse works at. The earliest and latest start time for the nurse is also included. All in all, this is sufficient information for the software to calculate the routes for each nurse based on his/her schedule.

Test of model

To date each of the five Home Care centers on Vestvågøy manually constructs routes to provide services in each of their service areas. The Center of Development for Home Care Services requested a method to calculate distances and times for pre-planned routes as well as a way to graphically display them on a map and present the results through a web solution. ArcGIS Network Analyst can create the manual routes using the Vehicle Route Problem solver ("solver"); the solver also has the capability to automatically compute routes and maximize route efficiency according to parameters set by the user. The analysis performed will compare the current system of manually constructed routes by nurses with those created automatically using the software. For the purposes of this test only about half of the parameters available in the solver are actually required to replicate as closely as possible a realistic Home Care daily schedule.

What follows is a description of the test that was performed including definition of terms, explanation of parameters, and an examination of results.

It should be noted that all data used in this analysis were constructed to simulate authentic data but were not based on actual data. Further, the test only calculates costs for actual time spent driving and providing services.

Terms used

Two solvers were created. It is useful at this point to define some of the terms that will be used when analyzing the two solvers. The solvers differ in the way they calculate service routes. In one the service routes are selected by the user ("manual routes"). The alternate model incorporates the capability of ArcGIS's Network Analysts Vehicle Route Problem Solver ("solver") to automatically create routes by using an algorithm to calculate the most efficient routes; these routes are identified as "VRP routes."

Efficient route planning must also take into account travel times and service times. This analysis will consider the following three significant time intervals: time window, wait time, and time violation. A time window is the interval during which a nurse is scheduled to arrive at a HCR's location. Wait time occurs when a nurse arrives prior to the beginning of the time window. A time violation is the interval between the end of the time window and the actual arrival time of the nurse (see Figure 5).

Figure 5 Wait time, Time window, and Time violation

Test parameters

There are two types of input parameters: inputs from the user and default values stored in the solver. User inputs are the visit and nurse tables that are uploaded from the daily scheduling calendar. To make a fair comparison of the two solvers, the following default values had to be set as constant in both models. Maximum Order Count sets the maximum number of HCRs allowed on one route to ensure that the solver does not create an unrealistic schedule. The value is set at ten based on the maximum number of HCRs in the manual routes. However, Home Care nurses may have anywhere from two to thirty HCRs per shift. Maximum Total Time is based on a typical work shift of 7–8 hours. It is estimated that a nurse will spend 7 hours, at most, visiting HCRs. The remaining time would be spent performing administrative tasks at the beginning and end of that day's shift.

Currently in Norway realistic costs in Norwegian Kroner (NOK) for a nurse per hour (Cost per Unit Time) could be NOK 240, and vehicle cost per km (Cost per Unit Distance) could be NOK 4.

Three parameters allow the user to switch from manual route planning to automatic route planning (VRP routes): assignment rule, route name, and sequence. When assigning manual routes, the Assignment Rule must be set to "preserve route and relative sequence," Route Name assigns the name of the nurse for that route, and Sequence must indicate the order in which the locations are visited. For automatic route planning, Assignment Rule must be set to "override" and the other two parameters are left blank.

One last input parameter used in this analysis rates the importance of honoring time windows without causing time violations, something that would have to be done by trial and error when manually determining routes. This value can be set to low, medium, or high importance, and can dramatically affect the result as will be shown later.

Vehicle Route Problem Solver

The purpose of utilizing the automated VRP solver is to achieve maximum route planning efficiency while minimizing overall cost. As presented in the previous section the costs in this project are hourly costs for nurses (NOK 240/h) plus the vehicle costs per km (NOK 4/km). The calculation of the overall cost is therefore:

$$Overall\ cost = total\ time \cdot {}^{NOK\ 240}/_{h} + total\ distance \cdot {}^{NOK\ 4}/_{km}$$

In the Home Care business the timing of some types of services is flexible, while other services must be provided at a specific time. ArcGIS allows the user to honor time windows by setting an importance level of low, medium, or high for the solver; however this level of importance is global and cannot act on individual records. When set to low the solver returns routes that minimize overall travel time, regardless of time windows. With medium, the solver balances meeting the time windows and reducing overall costs when computing routes. If set to high the solver's priority is to minimize time window violations even at the expense of increasing overall travel time. Similarly, the solver's algorithm also considers wait times, since they represent an inefficient use of resources. While the ideal route has neither wait times nor time violations, in practice wait times decrease only when increased time violations are permitted. Setting the appropriate importance level is therefore critical for the results.

Performing the test

Both manual and VRP route models were run in ArcMap 10.0. Each was tested with schedules for a morning shift (7 am–3 pm) and an evening shift (2 pm–10 pm). A typical morning shift has HCRs who may or may not have time windows for their services. Evening shifts typically have fewer HCRs, but all have scheduled time windows. Manual routes were run with the time windows importance level set at the default setting (medium), since manual routes are fixed and are not affected by changes in importance level. VRP routes were tested at all three time window importance level settings, low, medium, and high. The results of the three tests are referred to below as VRP low, VRP medium, and VRP high. It should be noted that the number of nurses at each Home Care center varies, and the model was not permitted to shift personnel between centers for the purpose of minimizing costs.

Results

The following figures and tables show the results of the comparisons of manual and VRP routes. The tables show the results for each center. Time is the total number of minutes required for all routes at all centers. Distance is the total number of kilometers driven by all nurses at all centers. Wait time is the total number of unproductive minutes for all nurses at all centers. Maximum wait time is the highest accumulated wait time that occurred on a single route. Time violation is the total number of minutes by which all nurses at all centers were late for appointments. Maximum time violation is the greatest number of minutes that a single nurse was late for an appointment on a single route. Cost is the total overall cost for all routes at all centers.

It is important to understand that since the VRP is not constrained by geographical area, it can assign any nurse to serve any HCR at any location, if that produces the most cost efficient service. Manual routes, on the other hand, are constructed by schedulers in each individual center who may choose to serve HCRs only in their own geographical areas (see Figure 6 below). The manual routes and VRP routes for a given Home Care Center may therefore not be comparable, since they may not serve the same HCRs. Time violations are illustrated by a red dot.

Manual Routes for a Morning Shift

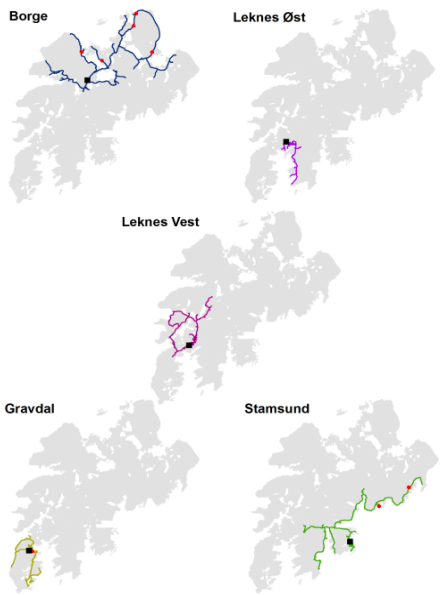

Figure 6 Manual Routes for a Morning Shift

	Borge	Gravdal\ Ballstad	Leknes Øst	Leknes Vest	Stamsund	Total
Time (min)	2,637	3,144	1,226	2,334	2,906	12,246
Distance (km)	408	144	79	152	305	1,088
Wait Time (min)	429	460	172	367	580	2,008
Max. Wait Time (min)	146	95	57	102	115	N/A
Time Violation (min)	99	5	0	0	193	298
Max. Violation (min)	72	5	0	0	136	N/A
Cost (NOK)	10,549	12,576	4,903	9,337	11,624	48,988

VRP low for a Morning Shift

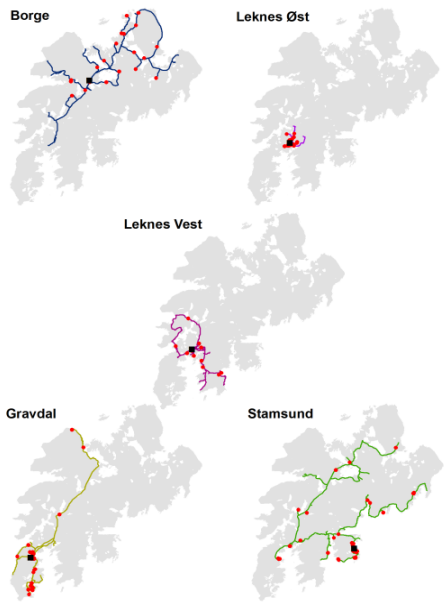

Figure 7 VRP Low for a Morning Shift

	Borge	Gravdal\ Ballstad	Leknes Øst	Leknes Vest	Stamsund	Total
Time (min)	1,760	2,873	1,071	1,485	2,981	10,171
Distance (km)	295	178	36	125	386	1,021
Wait Time (min)	0	0	0	0	0	0
Max. Wait Time (min)	0	0	0	0	0	N/A
Time Violation (min)	1,749	1,693	734	550	3,056	7,781
Max. Violation (min)	378	308	286	216	567	N/A
Cost (NOK)	8,220	12,206	4,427	6,442	13,469	44,765

VRP Medium for a Morning Shift

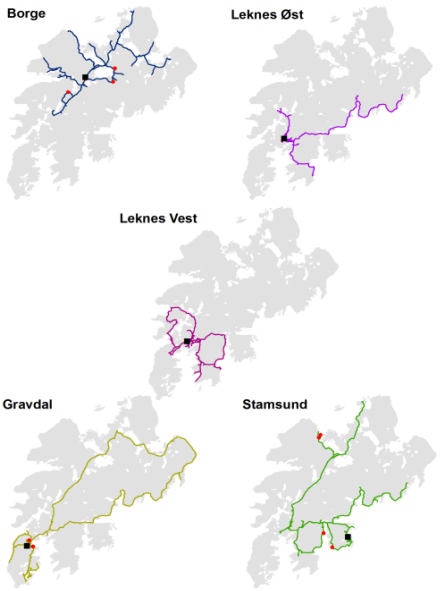

Figure 8 VRP Medium for a Morning Shift

	Borge	Gravdal\ Ball-stad	Leknes Øst	Leknes Vest	Stamsund	Total
Time (min)	2,063	3,049	1,152	1,788	2,380	10,432
Distance (km)	375	259	137	133	361	1,264
Wait Time (min)	8	0	0	0	9	17
Max. Wait Time (min)	8	0	0	0	4	N/A
Time Violation (min)	27	7	0	0	34	68
Max. Violation (min)	11	4	0	0	24	N/A
Cost (NOK)	9,753	13,235	5,154	7,682	10,961	46,785

VRP High for a Morning Shift

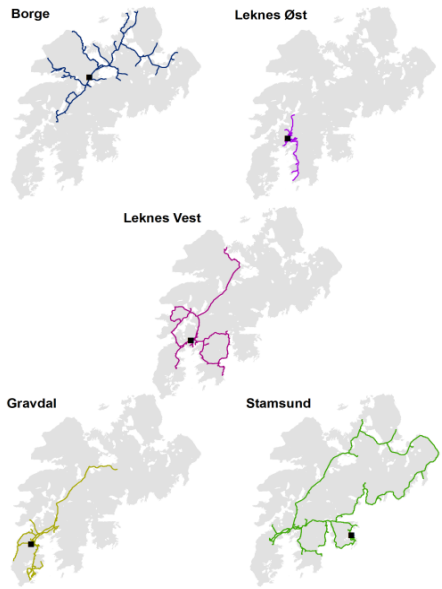

Figure 9 VRP High for a Morning Shift

	Borge	Gravdal\ Ballstad	Leknes Øst	Leknes Vest	Stamsund	Total
Time (min)	2,132	2,787	1,026	1,789	2,828	10,562
Distance (km)	395	211	66	189	513	1,373
Wait Time (min)	17	2	0	10	10	38
Max. Wait Time (min)	7	2	0	5	7	N/A
Time Violation (min)	0	0	0	0	0	0
Max. Violation (min)	0	0	0	0	0	N/A
Cost (NOK)	10,105	11,992	4,366	7,911	13,366	47,740

The following tables (Tables 1 and 2) summarize the data presented above and the result of a similar test for the evening shift.

Table 1 Results morning shift (all Home Care Centers)

		Manual	VRP low	VRP medium	VRP high
Time	[min]	12,246	10,171	10,432	10,562
Distance	[km]	1,088	1,021	1,264	1,373
Wait Time	[min]	2,008	0	17	38
Max. Wait Time	[min]	146	0	8	7
Time violation	[min]	298	7,781	68	0
Max time violation	[min]	136	567	24	0
Cost	[NOK]	48,988	44,765	46,785	47,740

Table 2 Results evening shift (all Home Care Centers)

		Manual	VRP low	VRP medium	VRP high
Time	[min]	9,130	5,922	6,589	7,111
Distance	[km]	888	671	1,058	1,144
Wait Time	[min]	3,002	10	291	727
Max. Wait Time	[min]	163	7	33	81
Time Violation	[min]	200	13,003	418	12
Max. time violation	[min]	72	1062	119	9
Cost	[NOK]	36,525	26,372	30,588	33,021

The tables above confirm that utilizing the time window importance level setting to reduce time, distance, wait time, and cost is done at the expense of time violations. Conversely, minimizing time violations to keep more closely to a schedule results in increases in time, distance, wait time, and cost.

The VRP low produces so many time violations that the routes would be unacceptable for Home Care services. While VRP medium and VRP high generally produce more efficient routes than were produced manually, one anomaly is apparent in the tables above. The manual routes resulted in a shorter overall distance because the nurses were each limited to a certain area, which then resulted in higher costs, largely due to increased wait times. VRP routes minimize this issue by not restricting nurses to specific areas. It should be mentioned that many HCRs on the morning shift have no time windows, whereas all HCRs on the evening shift have them and are therefore subject to more time violations, as seen in the tables above.

Summary of Test Cases

The test results indicate that savings could be achieved by removing geographical constraints when planning Home Care service routes. A more realistic test would compare the results calculated by the solver with those developed by an experienced Home Care services scheduler, and would use actual Home Care data to achieve a more accurate comparison. Analysis of such a test would allow one to conclude whether or not the VRP solver is an efficient planning tool for Home Care services. If the VPR solver was determined to be a promising alternative to manual route planning, it would certainly be reasonable to also consider using more of the additional capabilities available in the solver than were used in this test.

One potential limitation of using the solver is that cost may not be the only, or even the most important, consideration. Nurses who work at each Home Care center may not be interested in having the entire island as a service area since that may require longer

drive distances each day. Figure 10 illustrates this issue. The map shows the VRP medium routes for Gravdal/Ballstad's morning shift. Each dot represents a HCR, and they are color coded by which nurse the client has been assigned. Home Care Gravdal/Ballstad normally visits HCRs who live at the southwest part of the island (see Figure 6 above). As seen in Figure 8 the VRP solver calculated it to be most cost efficient for one nurse from Gravdal/Ballstad to visit HCRs on the northeast side of the island, despite the fact that these HCRs all live closer to other Home Care centers. The nurse, who is used to short driving distances in Gravdal/Ballstad's service area, might not appreciate the additional driving.

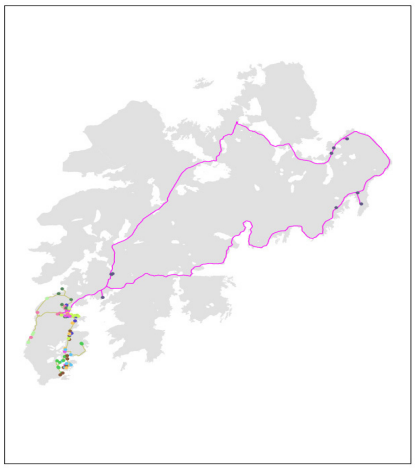

Figure 10 Nurse route outside Gravdal\Ballstad Service Area

Also, HCRs often appreciate seeing the same nurse for regular visits, which is more likely to occur when nurses are assigned to a single service area.

The Development Center for Home Care Services Nordland requirements were the ability to graphically display pre-planned service routes in a web solution, and access to the times and distances for each route. Enabling the use of the solver in the web application would require greater functionality than requested by the project client. This is beyond the scope of this project because it would require at a minimum the ability to display time violations and route sequences. Also, the user would need the option to adjust the importance level for time violations. A solver created to automatically generate routes is therefore more useful in a desktop environment like ArcMap, where these capabilities are already present.

Conclusions

The primary goal of this project was to create a web application for demonstration purposes with the functionality of displaying HCRs on a map, and calculating and displaying routes for a work shift based on a given schedule. To accomplish the goals of the project, necessary data were organized in an ArcSDE geodatabase, a basemap was created, and a tool for a vehicle route problem solver was designed in ArcGIS ModelBuilder 10.0. A web application was created using ArcGIS Server 10.0 and the ArcGIS API for JavaScript (See Figure 2 above and Figure 11 below). The functionality of the web page encompasses geocoding, searching, uploading files, and a geoprocessing tool. The user of the web page can upload a daily visit schedule and a nurse schedule. With the uploaded data, a Vehicle Route Problem solver creates routes and displays them on the map, listing them by name. In addition, the web application has the functionality to find an address, search for a HCR by name, and find contact information for a Home Care center. This application satisfies the functional and non-functional requirements of the Development Center for the Home Care Services Nordland by providing a system that demonstrates how GIS can be used for Vestvågøy Home Care Services.

Future work

In future development, several improvements could be made which would allow the user to easily change input parameters for the routing model. Some additions could also be made to the application itself. Home Care services has various software for HCR database management in which routes can be created based on when a visit takes place, regardless of HCR's location. The ideal solution would be to

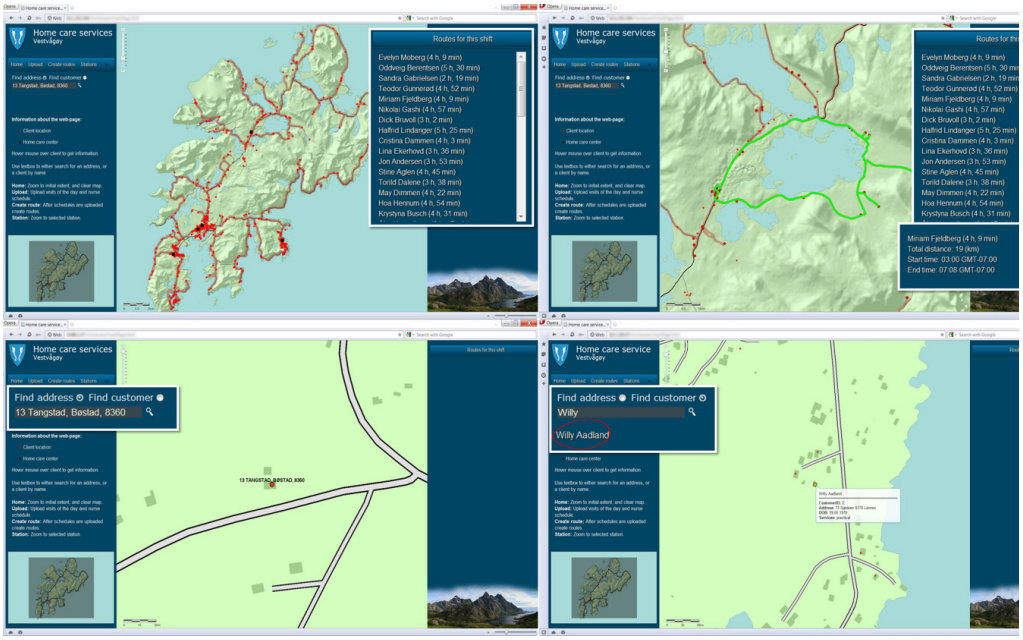

Figure 11 Application screenshots. (Some elements are made bigger for the purpose of this illustration).

integrate a GIS application like the one presented here with HCR database management software, allowing the user to add and delete HCRs through the map interface as well as calculate and visualize routes. GIS can be used for more than just calculating and visualizing routes. It is a powerful tool that can be utilized in planning and organizing Home Care services, and gives a clearer picture of where resources are needed.

Local government entities run Home Care in Norway, determining the operation standard in each municipality. A web application similar to the one described here could be used as a template for each municipality by changing map data, data, images, and some titles. To make it easier to adapt the template for different municipalities, all inputs (like images, map data, and titles) could be defined as variables in a configuration file that could be called up by the main web page. By doing so, there would be no need to go through the code itself to find each variable and change it according to the municipality.

Summary

Even though the web application can be improved, this prototype gave the Development Center for Home Care Services Nordland insight as to how GIS could be used for Home Care on Vestvågøy, and possibly in other municipalities. The web application is easy to use and allows the client to experience the tools and ability of a GIS and web page. When applying the project to real data, the user can better understand how the application works and can specify any desired changes.

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