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Pentti J. E. Nakari

Potential and Challenges in Home Care Service Process Optimization

A Route Optimization Approach

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ABSTRACT

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Aging of the population is an increasing problem in many countries, including Finland, and it poses a challenge to public services such as home care. Vehicle routing optimization (VRP) type optimization solutions are one possible way to decrease the time required for planning home visits and driving to customer addresses, as well as decreasing transportation costs. Although VRP optimization is widely and succesfully applied to commercial and industrial logistics, the home care is a relatively new application area for it. This thesis examines what kind of distance and time savings would be possible to achieve if daily home care operations are optimized in the similar manner as typical VRP optimization cases. In order to plan the optimization cases, a detailed analysis of the target organization (Home Care of the City of Jyväskylä in Finland) is conducted. The optimization results and other findings are compared to the experiences of 98 Finnish home care organizations (all organizations in Finnish municipalities with at least ten thousand inhabitants) that answered a detailed survey concerning home care optimization. Both the optimization experiments and the answers by the home care organizations support the conclusion that operational home care work is difficult to optimize by typical route optimization solutios as it is fully customer oriented work and the schedules of the home care staff change continuously as the needs of the customers change. This often breaks the detailed schedules created by optimization. Despite the perceived incompleteness of many the currently available home care route optimization solutions, most organizations that answered the survey had a positive outlook of the research and future development of new solutions. Also some possible methods that could be incorporated into home care optimization to improve it are discussed.

Keywords: Optimization, Combinatorial Optimization, Computational Science, Data Analysis, Home Care, Health Care, Service Process Optimization, Workforce Planning

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I thank several persons in the management of the Social and Health Services and the Home Care of the City of Jyväskylä and all those other people who gave me aid and support. Specifically I thank the staff working in the field of home care for collecting the data sets used in this study. I thank also the communities and organizations for their data.

LIST OF FIGURES

LIST OF TABLES

CONTENTS

1 INTRODUCTION

Aging population is an increasing challenge in many countries, particularly in Europe and Japan. Finland is one of the Europe's aging societies. This leads to an increasing demand of home care and home health care services for the elderly. Especially in countries where the citizens are entitled to social and health services provided by a national health care system, providing the elderly and the disabled assistance and medical care at home is estimated to be more cost-effective solution than long term treatment at nursing homes. Aging of the society and the challenges it poses has been one incentive for this study. This matter is discussed in detail in Chapter 2.

Improving and developing the productivity, effectiveness, quality and economics of home care requires new measures and innovations. Developing home care route optimization solutions further can be one practical measure. Still the Home Health Care Problem (HHCP) and the Home Health Care Crew Scheduling Problem (HHCCSP) are both relatively little studied in comparison to other optimization problems. The majority of the research on routing and scheduling problems deal with commercial logistics, such as truck and delivery car routing. Although the routing of home care workers is superficially similar, it also contains much more complex constraints than delivery logistics.

When the home care problem is oversimplified to be a variant of a vehicle routing problem (VRP) of delivery vehicles, optimization often fails to take into account the complex and ever changing nature of home care operations. Also the contents of and operational model of home care may vary from country to country, ranging from basic help at home to a much wider array of tasks that the home care workers do. Nevertheless, some VRP based optimization methods have been developed especially for home health care use as well. [HLP16]

In Finland often more than half of a home care workers' work shifts contain other duties than actual home visits. The home care workers take care of their customers' matters also elsewhere than at homes. Many of these other duties are difficult to plan in advance. Also a part of home visits are unplanned responses to sudden needs of the customers and even pre-planned visits can often take more time that was anticipated, leading to a constant change of plans and schedules.

Although the home care content and operations differ in some extent between different home care organizations, it always has the basic duties. Home care as a part of the services for the elderly is discussed in Section 2.2 and more detailed analysis of the home care organization of the City of Jyväskylä in Finland is represented in Chapter 4.

1.1 Objective of the study

The objective of the study is to examine to what extent vehicle routing problem optimization approach is applicable to real life home care operations and what kind of improvements at maximum can be expected if most real life constraints are left out. In this study the term *home care* refers to home service and home health care by trained home care workers at the home of the customer (private homes and home-like sheltered housing apartments), organized by the public sector social and health care organizations.

In order to compare the optimization experiment results to real life home care the home care process of the City of Jyväskylä in Finland is also analyzed in detail using various data analysis and visualization techniques. These analyses are also meant to show the possible methods that can be utilized in planning and development of home care processes.

Finally the optimization experiment results are compared to the results of a survey sent to and answered by 98 Finnish home care organizations. The results of the survey describe what kind of attitudes and plans home care organizations have about route optimization, and also what kind of experiences those organizations have had that have piloted optimization systems or are already using them. The detailed research tasks are represented in Chapter 1.5.

1.2 Research methodology

The study is done in the context of society. The main purpose is to examine concrete home care route optimization problem by utilizing computational science methods, particularly route optimization. The study tries to increase knowledge how these tools could be used in maintaining and developing the effectiveness, the efficiency and the quality of home care services.

A powerful route optimization software is used to route workers in a real operational data collected by the City of Jyväskylä home care organization. Optimization results (kilometers driven by the workes, time needed for transportation, and the number of workers required to handle all the home visits) are compared to the actual data.

The optimization experiments are conducted by using real life operational service data, thus cooperation with the target home care organization was necessary. Planning the optimization experiments required analysis of the daily operations of the target home care organization. The study is not an action research because the researcher did not participate in the activity and development of the target organization. The study contains some features of an case study because it describes and analyzes detailed real life data for the purpose of developing optimization scenarios. In the case study the results can have general value also elsewhere.

The concrete research methodology used in this study comprises of empirical data collection, robust and exploratory data analysis, statistical testing and modelling of home care procesesses, and routing combinatorial optimization experiments to evaluate what level of savings and improvements could be possible to achieve by route optimization.

Also the current situation of utilizing route optimization solutions in Finnish home care organizations is examined in the form of a survey that contains the answers of all Finnish home care organizations that serve areas that have population level of at least 10 000. [1]

The following data sets (City of Jyväskylä, Finland) are used in the analyses and optimization experiments:

- One week home care operations data
- Overall statistics of both home health care and other home care daily customer and home visit numbers and total home visit times
- Home visit content data
- Transit delay data
- Queueing to computers data
- Additional data sets from other home care organizations in Finland

Optimization experiments based on the home care operations data set:

- Optimization experiments with one week data and different optimization scenarios

1.3 The cooperation and research permits

The study was conducted in cooperation with the City of Jyväskylä Department of Social and Heath Services and its home care unit. The home care provided the data used for optimization experiments and analysis of the home care operations. The data contained home addresses of the home care customers. As all information about the customers of social and health services is confidential, the data was received and handled under a research permit granted by the City of Jyväskylä Department of Social and Health Services.[2]

[1] 2013–2014 situation, a total of 98 organizations. These comprise 87.5% of Finnish population excluding Helsinki and 56% of the municipalities in Finland.

[2] The Ministry of Social Affairs and Health (26 July 2006) has given instructions how the organization can give this kind of data for research purposes.

Map based visualizations in the following chapters are scaled sufficiently to conceal home care customer addresses to maintain patient confidentiality. In similar manner home care staff headquarter locations are approximate for security reasons.

The Department of Social and Health Services also received the results of the study. The City of Jyväskylä granted also a permits to use the maps of the street network and home care service areas.

1.4 Contribution and structure

After the introduction (Chapter 1) the Chapter 2 provides background information for the empirical part and discusses about the challenges for social and health services posed by the aging of the population. Chapter 3 provides a brief introduction to combinatorial optimization, particularly route optimization which is applied to the City of Jyväskylä home care data. A review of literature of the latest research on the home health care optimization problem is also presented. The detailed research tasks are in the Chapter 1.5. Chapter 4 describes the target organization and contains a detailed analysis of the City of Jyväskylä's home care organization, its functions and processes. Chapter 5 contains route optimization experiments and their results, based on the City of Jyväskylä home care data. Chapter 6 describes some common challenges in home care optimization as well as results of two surveys that were answered by Finnish home care organizations. Chapter 7 describes briefly some possibilities to utilize home care data to overcome some of the challenges described in the previous chapter.

1.5 Research tasks

To solve each research objectives mentioned in the introduction the study:

(a) **describes home care operations in the target organization and analyzes the home care process in team headquarters and the transportation to customers' home addresses**

- data:
  - one week home care operations data collected in November 2011
  - Transit delay data collected in June 2012
  - Queueing to computers data collected in 2010
  - Overall statistics of both home health care and other home care daily customer and home visit numbers and total home visit times during tears 2010–2013

(b) **describes and analyzes the home care work content**

- data:
  - Home visit content data collected in May 2013

(c) **conducts route optimization experiments**

- data:
  - One week home care operations data collected in November 2011

(d) **demonstrates what kind of improvements can be expected in home care if most real life constraints are left out (approximate upper limit of improvements in terms of driven kilometers and time needed for transportation)**

- data:
  - One week home care operations data collected in November 2011

(e) **examines what kind of attitudes and experiences Finnish home care organizations currently have concerning route optimization in home care and compares the answers to the optimization experiments conducted in the study**

- data:
  - 2009 survey to Finnish home care organizations
  - 2013–2014 survey to Finnish home care organizations serving areas with population of 10 000 or more

2 AGING POPULATION AND CHALLENGES FOR SERVICES

The aging society has been increasingly common problem in Europe during the past two decades and in Finland the aging of the population has been noted even earlier. Finland belongs to the group of aging societies. In 2013 in Finland 18,8% of the population was elderly (65 years or older) and in EU 18.2%. Similar or higher levels are in Bulgaria, Latvia, Italy, Greece, Portugal, Sweden and Germany. Although the level of the elderly is not on the highest in Europe, the number of elderly is rising and the structure of the age pyramid is changing. This is already placing stress on the public services. The estimate for year 2020 in Finland is that 22.6% of the population will be 65 years old or older and 9.9% 75 years old or older. [Sot16] [EVA06] [1]

Aging population leads to an increasing demand of social and health services like home care and home health care services for the elderly. The challenge the aging poses to the society can be represented by old age dependency ratio. The indicator gives the number of people aged 65 and over in relation to hundred people aged 15–64 on the first of January according to the population projection for 2020. The age dependency ratio has continuously increased in Finland. It was 28.9% in year 2013 and is projected to increase to 35.8% by 2020. [Sot16]

Another similar indicator is demographic total dependency ratio that is estimated to increase from 2013 level of 55 to 69.6 by 2030. The ratio is the number of people aged under 15 and over 64 per hundred working age people aged 15-64. The greater the number of children or retirement age people, the higher the dependency ratio is. [EE14]

The increasing number and proportion of the elderly population does not necessarily increase the demand of social and health care services linearly because changes can happen in many factors such as in population health and func-

1 Aging development has been compared in 11 countries by calculating time frame during which the percent of 65 year olds and older doubles from 7 percent to 14 percent. This level was reached in Finland and Japan already in 1994 (36 years in Finland and 24 years in Japan required to double from 7% to 14%). In other seven European countries included in the comparison and in the US the time frame varied from 41 to 115 years. [EVA06]

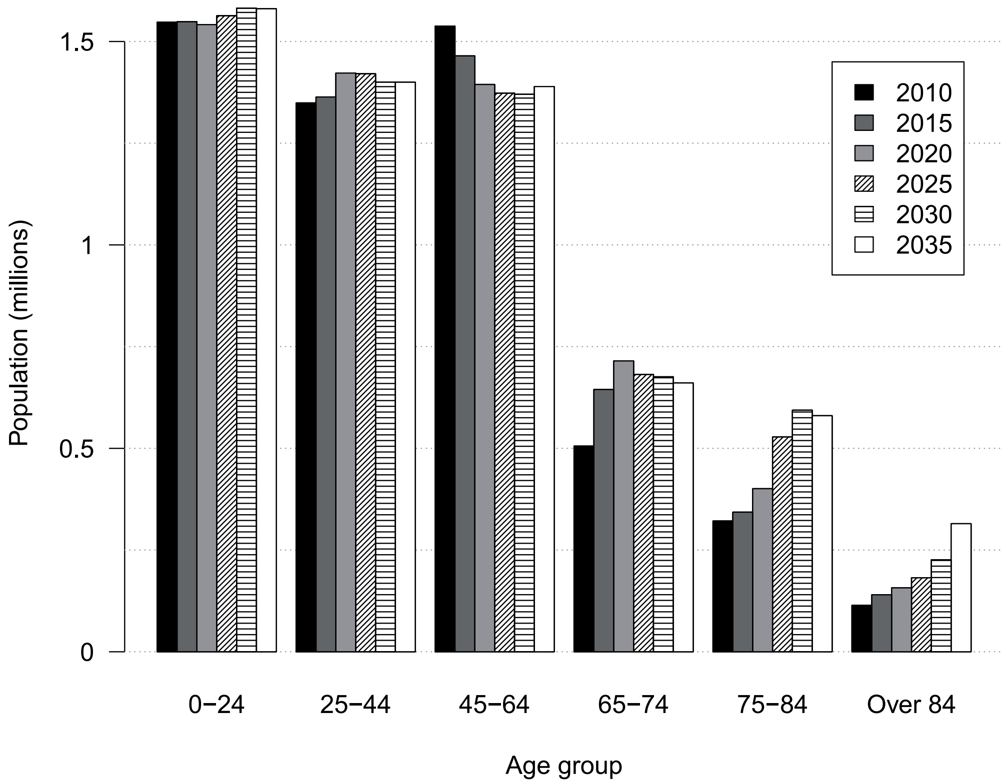

FIGURE 1 Aging population in Finland during the next two decades. 2010 level and estimates for years 2015–2035 in five year increments. In the last three age groups the increase of population from 2010 level is estimated to be 30.7% (65–74 years, the young old), 80.5% (75–84 years, the aged) and 175.5% (over 84 years, the oldest old). The total number of elderly citizens (65 years or older) is expected to rise 65.3%, from 941 041 to 1 555 713. [TK13]

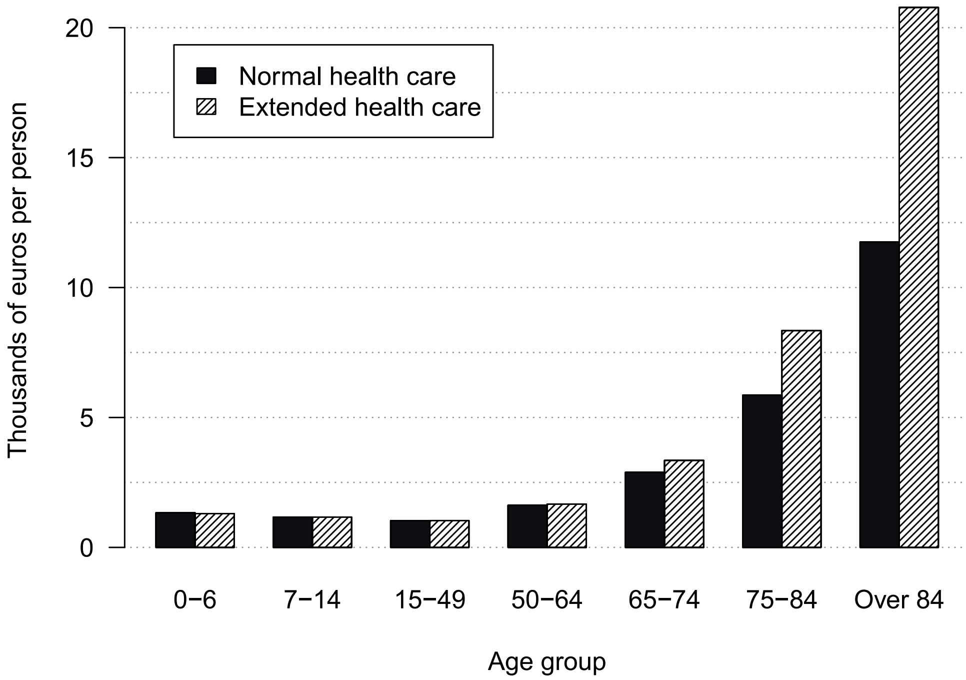

FIGURE 2 Normal and extended health care expenses per person by age group in big cities in 2011. [SKL12]

tioning. However, aging will still eventually increase the demand of services and the increase of demand is high especially in the oldest age groups. [VTTV10]

The Association of Finnish Local and Regional Authorities (Suomen Kuntaliitto) report contains normal health care expenditure and health care expenditure extended with home care, institutional care and intensified shelterd housing (24h assistance) for the 11 biggest cities in Finland. The expenditure is age standardized and gives a good picture of the economic challenges that the services for the elderly pose. The effect of the age to the expenditure is represented in Figure 2. [SKL12]

The expenses of home care are not known in detail on the national level. [VTTV14] There is an ongoing process of developing social and health services to be more efficient. Changes are slow to implement and it is difficult to measure the effects and benefits of the changes. However, in smaller service provider organizations and on municipal level the operations and expenses are usually known in more detail. This makes it possible to monitor the development of the services and their expenses. Thus it is also possible to get meaningful results from research and development projects during a relatively short time interval. Research and development projects are common in social and health care sector. The Association of Finnish Local and Regional Authorities and the National Institute for Health and Welfare encourage social and health care providers to develop new practices and also collect and distribute experiences and results produced by development projects. Also the route optimization of home care is practically oriented and needs to be done in a real operational environment.

2.1 Social and health services for the elderly in Finland

One of the duties of the public sector is to take care of the health and wellbeing of the population. This is done in part by arranging social and health services. The responsibility for organizing such services lies with local government, the municipalities. They can provide basic social welfare and health care services alone, or form joint municipal authorities with other municipalities. Municipalities may also purchase social welfare and health care services from other municipalities, organizations or private service providers.

Most important social and health care services used by the elderly are regular health care, sheltered housing, intensified sheltered housing with 24h care, nursing homes, home care and different types of support services. Informal care by family members is also supported and utilized to make it possible for the elderly to live in their own homes as long as possible. The society's obligation is to develop the participation and agency of the older people and the living environment. [STM16a]

In Finland everyone is entitled to publicly funded universal health care. The health care system is decentralized and working on three levels. Health services are divided into primary health care and specialized medical care. In primary health care the municipality arranges monitoring of the health of the population, the promotion of health, and various services in health centres.

Specialized medical care refers to specialist health examinations and treatment. Most specialized medical care is performed in hospitals (secondary care).[2] Some specialized medical care services are organized on the basis of special responsibility areas of university hospitals (tertiary care).[3]

Primary health care consists of local health centers, hospitals, home care and other day-to-day medical and other services. More specialized care is available in district or regional hospitals that are often shared by several municipalities. Tertiary care is provided by five university hospitals that provide the most advanced medical care. The public social and health services are funding mainly by taxes.

Fees paid by social and health service clients account for about 9% of the funding of social and health services. The maximum fees charged for municipal social and health services are stipulated in the Act and Decree on social and health care client fees. Municipalities may choose to use lower rates or to provide the relevant service free of charge. Municipalities are not permitted to collect fees for

2 Central Finland Central Hospital in Jyväskylä provides secondary health care to Jyväskylä and other municipalities in Central Finland.

3 In cities of Helsinki, Turku, Tampere, Kuopio and Oulu which all have universities with medical faculties.

services above the amount that the production cost of the services.[4] [STM16b]

Public social and health services and the citizens' right to them are based on various laws.[5] The Social Welfare Act (1301/2014, Finlex) secures the access of people aged 75 and older to a social services needs assesment within seven days of contacting their municipality. Each municipality has the duty to arrange home service, home care, institutional care and services supporting transportation. The elderly are the largest but not the only group of people utilizing these services. Sheltered housing is arranged for people who need care and an apartment suitable for their needs. Intensified sheltered housing is available for people requiring assistance every day around the clock. Services for the elderly include also regular nursing homes.

According to The Social Welfare Act (1301/2014 Finlex) home service refers to assisting in everyday living, health and other care, maintaining physical function, running errands and chores. Support services include meal, clothes maintenance and cleaning services as well as services supporting social life. Home care is the combination of home service and home health care (1326/2010 Finlex). Home health care is multi professional health care given at the customer's home or at a location comparable to home. It can be regular, based on personal care and service plan, or temporary.

Previously the term home care was not included in the legislation and in practice the workers visiting customers homes were often from various types of social and health care organizations. Recent development has lead to specialized home care units or organizations and in public strategies, plans and quality recommendations home care is nowadays defined as the combination of home service and home health care. These recent changes were based on a temporary law that defined that the services organized by different units should be combined to function seamlessly.

The official monitoring of the home care services is not fully implemented on a national level which makes it more difficult to make decisions. National monitoring and statistics collection is done at different sectors and service providers may interpret regulations differently.

Home service and home health care visits are logged separately in health care but in social care only home service visits are logged. The exact number of customers in regular home care is available only once a year at the end of November. [Sot16] Expenditure reports of home care contain also support service costs. Home health care expenditure is included in non-institutional health care statistics. Expenditure reports are assembled and published by Statistics Finland and the Association for Local and Regional Authorities publishes the classification instructions. Because of this the National Audit Office of Finland has pointed out

4 In 2015 the fee for a visit to doctor or treatment in primary health care in Jyväskylä was 16.10 € and 32.10 € for first aid during night time, weekends and public holidays. The fee is charged at maximum three times per year per health care center. The yearly maximum payment limit is 679 € after which health care is free.

5 The Constitution of Finland 731/1999; Health Care Act 1326/2010, The Act on Specialized Medical Care 1062/1989, The Social Welfare Act 1301/2014, Finlex 2016-04-13.

that the exact national home care expenses are not known. [VTTV10] This also makes it difficult to compare different home care organizations. Municipalities and other service providers maintain their own statistics that can be used for decision making and development projects. However, long term development is often affected by occasional internal organizational changes.

2.2 Home care in the social and health service delivery structure

An elderly citizen may end up to be a customer of many separate service provider and administrative unit at the same time.

Act on care services for the elderly to ensure high standard of quality nationwide (980/2012 Finlex) is intended to ensure that elderly people will receive care and treatment according to their individual needs and on an equal basis nationwide through high-quality social welfare and health care services. New services were not created by the legislation.

According to the act current services should be developed to be more coordinated and especially rehabilitating and home care services should be improved further. Long term care should be given primarily at private homes or at long term sheltered apartments. Long term institutional care should be utilized only when absolutely necessary.

The quality recommendation concerning the care of the elderly sets the target that as many elderly person as possible can continue to live in his or her own home as long as possible. By 2012 91–92% of the 75 year old or older people should be able to live at home independently or with support services, and 13–14% should receive regular home are. The quality recommendation 2013 sets the same targets for 2017. [STM13, STM08]

The content of home care work has changed during the past decades to be more customer oriented instead of simply maintaining the home of the customer. The coverage of home care has remained on the same level since the year 2000 although the number of the elderly is rising. This has led to the situation that some customers feel that they do not receive all the help they need. [VTTV14, YP08]

The physical and mental condition of the home care customers has been decreasing and the need for care has been increasing. The proportion of memory ill customers has increased 4 percentage points between 2007 and 2013. Customers receiving more than 30 or 90 home visits per month has been increasing as well. [Sot16]

Table 2 represents how the service expenditure is divided between different age groups in 11 largest cities in Finland.

The age distribution of the customers in different service types varies. In the age group of 0–49 year olds outpatient health care and institutional special health care is more common, but institutional health care is more common in the case of older age groups. Home care is more common in the older age groups, but

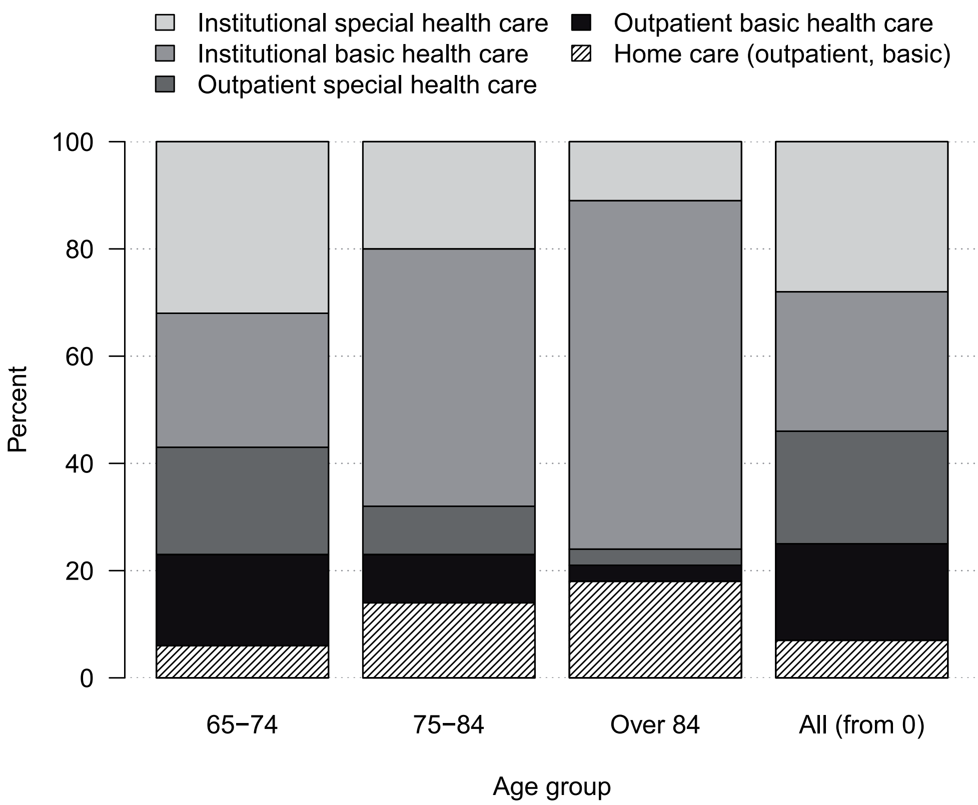

FIGURE 3 Health care expenses by types and age groups in big cities in 2011. Percents represented in detail in Table 2. [SKL12]

Figure 3 also demonstrates how institutional care expenses increase when home care and noninstitutional care expenses decrease. Institutional care is still more common in the older age groups. The better evaluation of the service structure needs more information about the coverage, availability, effectiveness and quality of the services.

Table 1 demonstrates the expenditure of different services in Finnish municipalities and the change compared to the year before. The home care contains home service and support services but not home health care services.

The expenditure of the home care services was 3.9% of the social and health services and institutional services services for the elderly and disabled used 5.6% of the expenditure. The proportion for non-institutional services like day center and group homes was 12.8%.

2.3 Service structures reform in Finland

During 2015–2016 there is an ongoing social welfare and health care reform in Finland. Its main objective is to restructure Finlands public social and health services in order to safeguard high-quality social and welfare services throughout the country and to improve the efficiency of the services.

Still at the moment the services are organized and provided by approximately 200 municipal organizations. In the new proposed model there would be only five social welfare and health care regions, and at most 19 joint municipal bodies within them. The new model is planned to start operating in 2016–2017. The proposal for the new service structures model was passed to the Finnish parliament in 4th of December 2014. After the proposal was found to contain legal difficulties, is was moved to the new parliamentary season starting in mid 2015. Furthermore, in March 2015, the current proposed model was deemed to be unconstitutional as in the five big planned regions smaller municipalities would not have enough voice concerning their own social and health care matters. The latest objective of the government is to create 18 provinces that have the responsibility to arrange social and health services. In the beginning the state funds the services. Also the customers should have more freedom in choosing services. [STM15, HS15]

TABLE 1 Social and health service expenditure in Finnish municipalities in 2011 (in millions of euros) and percentual change compared to 2010. Municipal enterprises are not included in the table. Expenditures include operating expenses, deprecation and reduction of value. Incomes inlude operating incomes. (Tilastokeskus 2016). [SVT11]

	Expenditure				Income			
	Total M€	Change %	Salaries M€	Change %	Total M€	Change %	Fees M€	Change %
Total	**20 087**	**5.6**	**4 648**	**4.7**	**2 658**	**3.7**	**1 181**	**3.2**
–of which:								
Childrens' day care	2 814	6.5	1 220	5.1	359	4.9	318	6.3
Child protection, institutional and family care	659	7.7	86	2.8	48	7.2	14	13.1
Other childrens' and family services	390	7.7	160	7.8	34	-18.7	2	-13.9
Institutional services for the elderly and disabled	1 132	-4.2	386	-4.8	234	-4.7	185	-6.5
Home care services	*782*	*3.4*	*364*	*1.4*	*161*	*0.4*	*100*	*0.4*
Other services for the elderly and disabled	2 578	11.7	514	12.2	384	9.5	234	9.9
Basic health care	4 037	5.0	1 350	4.0	684	6.1	278	1.2
Special health care	5 575	6.0	177	14.2	112	7.5	22	19.6

TABLE 2 Expenses by health care types in largest cities in 2011. [SKL12] Home care is one type of outpatient basic health care. The expenses are also visualized in Figure 3.

	Age group			
	65–74	75–84	Over 84	All (from 0)
Home care	6	14	18	7
Outpatient basic health care	17	9	3	18
Outpatient special health care	20	9	3	21
Institutional basic health care	25	48	65	26
Institutional special health care	32	20	11	28
Total %	100	100	100	100

3 COMBINATORIAL OPTIMIZATION

Combinatorial optimization is a typical topic in applied mathematics, theoretical computer science and computational sciences. It consists of finding an optimal object or combination of objects from a finite object set. For many practical applications exhaustive search—systematically examining all possible solution candidates—is not feasible due to a *combinatorial explosion* (Figure 9) that often produces more solution candidates than even supercomputers can evaluate in a reasonable time. This makes combinatorial optimization one of the hardest fields in optimization. From the point of view of the home care optimization both the *Traveling Salesman Problem* (TSP) and its derivatives, different types of the the *Vehicle Routing Problem* (VRP) on a mathematical graph are of key interest.

3.1 Graph theory

The Vehicle Routing Problem and different route optimization methods to solve it utilize mathematical *graphs* that are used to represent the street network in which the routed vehicles travel. Mathematical *graph theory* is one example of the methodology used in computational sciences and forms the basic model on which also many other combinatorial optimization methods operate. Due to its diverse application possibilities it is increasingly important in a modern world. Since the pioneering Swiss mathematician and physicist LEONHARD EULER (1707–1783) laid its foundation it has been applied to model systems and phenomena in a multitude of scientific and engineering fields. Typical examples include computer networks and electrical engineering, computer science, organizational structures, biochemistry and genomics, biological systems, pure mathematics, operations research and complex transportation systems. Car navigators and map applications in GPS enabled smart phones are just one example of technology utilizing graph theory which is generally considered to have begun (with topology) in 1735 when Euler presented, and later in 1741 published his famous paper "Solution of a problem in the geometry of position" concerning the *Seven Bridges of Königsberg*[1] problem and it's negative resolution:

> "This problem, then, which was described to me as quite well known, was as follows: At Königsberg in Prussia there is an island *A* called *der Kneiphof*, and the river around it is divided into two branches, as shown in the figure; and the branches of this river are crossed by seven bridges *a*, *b*, *c*, *d*, *e*, *f*, and *g*. The following question was now raised concerning these bridges: whether someone could arrange a walk in such a way as to travel over every bridge once and not more than once. Some people (I was told) deny that this is possible, and others doubt it; but nobody asserts it. From this I set myself the following quite general problem: whatever the form of the river and its distribution into branches, and whatever the number of bridges, to find whether it is possible for each bridge to be crossed only once, or not."
>
> Translated Latin quote from "Solutio problematis ad geometriam situs pertinensis" by LEONHARD EULER in *Commentarii Academiae Scientarum Imperialis Petropolitanae*, 8 (1741), 128–140. Figure from Plate VIII represented in Figure 4. [Eul41, Beh]

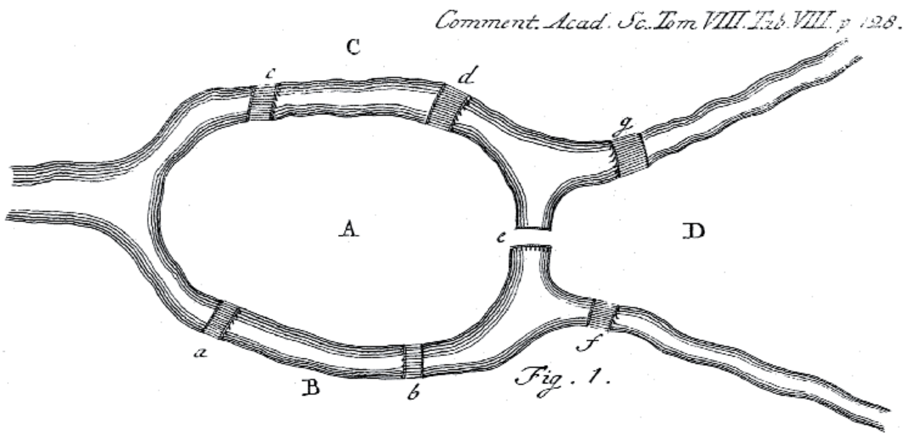

FIGURE 4 The bridges of Königsberg in a paper by LEONHARD EULER, 1741. [Eul41]

3.2 Graphs as a mathematical model

Graph theory studies mathematical structures constructed of *vertices*, or *nodes*, and *edges* connecting pairs of vertices. A graph can also be *directed*. In this case the edges are called *directed edges* or *arcs*. The bridges in Figure 4 is represented as an undirected graph in Figure 5, where the edges *a*–*g* represent the bridges and the vertices *A*–*D* represent the land areas that the bridges connect.

The Königsberg bridge problem, travelling through each edge of the graph, is an example of an *Euler cycle*. Visiting each vertex of a graph exactly once starting and ending the tour at a specific vertex is known as a *Hamiltonian cycle*. The

1 Königsberg became the Russian city of Kaliningrad and the river Pregel was renamed Pregolya. After their destruction during the Second World War, five rebuilt bridges exist today.

problem of minimizing the tour lenght of a Hamiltonian cycle is known as the Travelling Salesman Problem (TSP), one of the most intensely studied optimization problems. The Vehicle Routing Problem is closely related to it.

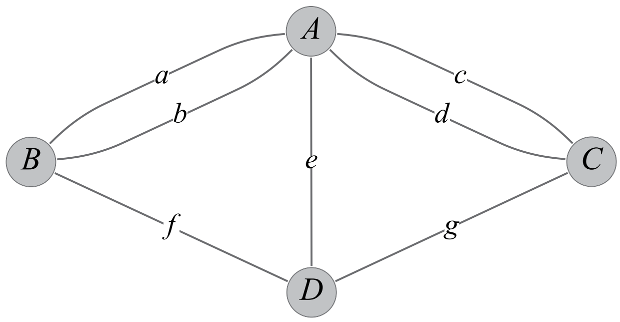

FIGURE 5 The bridges of Königsberg as a modern graph representation.

3.3 Travelling Salesman Problem (TSP) and its variants

The Travelling Salesman Problem (TSP) is an NP-hard[2] problem in combinatorial optimization and one of the most intensely studied optimization problems.[3]

It can be divided into three widely studied main categories. These are Symmetric (STSP), Asymmetric (ATSP) and Multiple TSP (MTSP). These are defined as follows.

STSP on a complete undirected graph $G = (V, E)$: Let $V = \{1, 2, \ldots, N\}$ be a set of vertices (e.g. cities), $E = \{(i, j) : i, j \in V, i < j\}$ be the edge set connecting the vertices and $d_{ij} = d_{ji}$ be a cost measure (i.e. route length) associated with edge $(i, j) \in E$. The distances between all combinations in E are known. Thus cost matrix $C = (c_{ij})$ is defined on E. The STSP object is to find a minimal length closed tour that visits each vertice exactly once. If the vertices in V are given in coordinate pairs (x_i, y_i) and d_{ij} is the *Euclidean distance* $\sqrt{(x_i - x_J)^2 + (y_i - y_J)^2}$ between i and j the problem is also known as Euclidean TSP, one type of Metric

2 *NP-hard* is a complexity class of decision problems. E.g. the question whether there is a shorter Hamiltonian cycle than one with length k is *NP-complete*. It is easy to check if a proposed cycle has length less than k, but the optimization problem of finding the shortest cycle is thus NP-hard as there is no easy way to determine if a proposed solution is the shortest possible.

3 TSP has been mentioned (without mathematical definition) in a 1832 handbook for salesmen with example tours in Germany and Switzerland. It was defined mathematically by the Irish mathematician Sir William Rowan Hamilton and the British mathematician Thomas Penyngton Kirkman in the 18th century. The general form of the TSP have been first studied in the 1930s by Karl Mengar in Harvard and Vienna and later promoted by Princeton scientists Hassler, Whitney and Merrill. [ABCC07, MSM10]

TSP or Δ-TSP. Although still NP-complete, in some cases it is slightly easier to solve than general metric TSP. The cost matrix C is said to satisfy the triangle inequality when $c_{ij} + c_{jk} \geq c_{ik}$ for all i, j and k.

The decision variable x_{ij} is defined as:

$$x_{ij} \triangleq \begin{cases} 1 & \text{if the edge } (i,j) \in E \text{ is included in the tour} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

and the problem can be formulated as

$$\min z = \sum_{i<j} c_{ij} x_{ij} \tag{2}$$

subject to

$$\sum_{i<k} x_{ik} + \sum_{j>k} x_{kj} = 2 \qquad k \in V \tag{3}$$

$$\sum_{i,j \in S} x_{ij} \leq |S| - 1 \qquad \forall S \subset V, 3 \leq |S| \leq n-3 \tag{4}$$

$$x_{ij} \in \{0,1\} \qquad \forall j, i \in \{1,...,N\} \tag{5}$$

The problem becomes more complex ATSP on a asymmetric directed graph $G = (V, A)$ if $d_{ij} \neq d_{ji}$ for at least one (i, j), e.g., if the arcs (directed edges) are streets that can be also one-way only. Thus $A = \{(i, j) : i, j \in V, i \neq j\}$ is an arc set and the cost matrix $C = \left(c_{ij}\right)$ is defined on A.

The decision variable x_{ij} is defined as:

$$x_{ij} \triangleq \begin{cases} 1 & \text{if the arc } (i,j) \in A \text{ is included in the tour} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

and the problem can be formulated as

$$\min z = \sum_{(i,j) \in A} c_{ij} x_{ij} \tag{7}$$

subject to

$$\sum_{i=1}^{N} x_{ij} = 1 \qquad \forall j \in \{1, ..., N\}, j \neq i \tag{8}$$

$$\sum_{j=1}^{N} x_{ij} = 1 \qquad \forall i \in \{1, ..., N\}, i \neq j \tag{9}$$

$$\sum_{i \in S} \sum_{j \in S} x_{ij} \leq |S| - 1 \qquad \forall S \subset V \tag{10}$$

$$x_{ij} \in \{0, 1\} \qquad \forall j, i \in \{1, ..., N\} \tag{11}$$

The total distance is to be minimized (2) and each node must be visited exactly once (3). In (4) $|S|$ denotes subtours (disjoint loops) and the constraint eliminates them. Also a large number other formulations of the problem exist (e.g. [MSM10, KB06, Bek06]). 24 different ASTP formulations are presented and compared in [ÖAL09].

The problem becomes even more complex MSTP if there are m salesmen located at a single vertice defined as the depot node and the rest of the vertices are defined as intermediate nodes. The object is to find tours for each salesman so that each intermediate node is visited exactly once, the total cost of visiting each node is minized and all salesmen start and end their tours at the depot. Different variations exists, such as multiple depots (individual salesmen can return to any depot keeping the number of salesmen in each depot the same), the number of salesmen can be fixed or a bounded variable, different cost factors and time windows. Different formulations for the MSTP can be found e.g. in [Bek06, KB06, Jou07, Dia10, MSM10]. If there are no vehicle capacity constraints involved the MTSP is similar to relaxed Vehicle Routing Problem (VRP) which is discussed in Section 3.4.

3.3.1 TSP routing examples

Optimizing even a basic TSP tour is hard as there are $\frac{1}{2}(n-1)!$ different route combinations for a problem with n vertices, assuming that the tour can be executed either way around.[4] E.g. if there are 31 points in the problem, there are $30!/2$ (that is $(30 \times 29 \times 28 \times \cdots \times 1)/2 = 1.326264 \times 10^{32}$) possible combinations. If, for some reason, it makes a difference which way the tour has to be executed, the number of possible route combinations is $(n-1)!$, twice as many as in the previous case.

Figure 6 produced by a R language program written for the example shows a set of 30 random points approximately normally distributed around a depot

4 Strictly speaking this is not the only reason, other problems exist that are easier to solve although the number of solutions grow even quicker, e.g. finding the *minumum spanning tree*, a subgraph that connects all the vertices in a graph by exactly one simple path between each pair of vertices without cycles. [Die05, CLR99]

point at coordinates (21, 20), a total of 31 points (Figure 6(a)). Figure 6(b) shows a randomly routed tour between this points, yielding a total route length of 249.16 calculates as an Euclidean distance. Figures 6(d–l) show nine different manual routing attempts (mean 95.37, standard deviation 2.72 and median 94.98, see also Figure 7). Optimal solution, route length 86.46, is shown in Figure 6(c). The optimized solution is 10.3% shorter than the mean route length of the manually created solutions. This example is very small when compared to real life problems and serves as an example how humans have a natural ability to solve simple routing problems relatively well [ABCC07]. When the number of points increases, manually solving the routing becomes increasingly harder. Eventually computational solving becomes the only viable option. Taking into consideration the fact that the number of combinations includes the factorial of the number of the vertices, the number of different combinations will be 31 times bigger if one more vertice is added to to the problem, and so forth.

A slightly larger problem of 61 points is shown in Figure 8. In this case there are $60!/2$ (that is 4.160494×10^{81}) possible combinations.[5] The manually routed lengths are 239.95, 241.94 and 243.79 (Figures 8(a–c)) compared to the optimized length of 214.51 (Figure 8(d)), which is 11.6%, 12.8% and 13.6% shorter respectively.

In both examples the number of points is still relatively small. In many scientific and technical applications the number of points can easily span from thousands (e.g. drilling holes and placing components on a printed circuit board) to hundreds of thousands (e.g. moving and positioning a detector in X-ray crystallography). [MSM10] In large problems it is no longer obvious how the route should be planned and it will not be feasible even to try to do the routing manually, thus computational optimization becomes necessary.

3.4 Vehicle Routing Problem (VRP)

In practice many routing problems are asymmetric, e.g. street level routing with one-way streets and need to be optimally divided into several separate TSP tours making the problem a Multiple Travelling Saleman Problem (MTSP). In most cases also a wide array of other constraints may need to be included, such as vehicle capacity (Capacitated Vehicle Routing Problem, CVRP), time windows, worker related training and working time constraints, worker or vehicle related standing and running costs etc. When each visiting point has a defined time window during which the stop by has to happen, also time becomes a new dimension in the problem. Street network data has to contain information about speed limits and possibly also rush hours. The optimization software has to calculate also driving speed on each part of the route in order to be able to ensure that each point is served within the defined time window and allowed margins.

5 This is roughly as many or more combinations than the estimated number of atoms in the observable universe, $10^{78} - 10^{82}$.

3.4.1 Vehicle Routing Problem with Time-Windows (VRPTW)

Vehicle Routing Problem With Time Windows (VRPTW) is a variant of the TSP problem that contains also time windows during which each address must be visited. In home care optimization each home care customer has a specific schedule that often contains home care staff visits ranging from several visits per week to several visits per day around the clock. Each visit has a time window during which the visit needs to either start or be completed. In order to optimize the routing so that the time windows can be honored requires also driving time calculation and in more advanced solutions details such as rush hours and typical driving speeds on different round types can be taken into account. [TV14]

3.4.2 Multi-Day and Periodic Vehicle Routing Problem (PVRP)

Multi-day and periodic (PVRP) vehicle routing problem incorporates multi day schedules to the VRP problem. In the classical VRP the planning period is single day but many real life applications require multiple day planning. In PVRP the deliveries or visits have a multi-day service horizon. The customers are visited during specific days and in addition to clustering the customers into tours and routing the vehicles or workers, also the visiting days are selected by the optimization algorithm. [TV14, DCG+16]

3.5 Deterministic optimization algorithms

Deterministic algorithms always produce the same output with the same input. In some cases deterministic optimization algorithms can be used in the optimization problem is simple. In practice combinatorial optimization problems are computationally hard and require other approaches, such as heuristics methods.

3.6 Heuristic optimization algorithms

In many cases it is not practical to try to find the most optimal solution. When computational resources and time are limited or background data is imperfect, heuristic techniques are preferred. Heuristic techniques are different kinds of approaches for optimization and other problem solving that do not try to find the absolute optimum solution, but a solution that is good enough for the practical requirements. Metaheuristics are higher level procedures used to select a suitable heuristic technique for the given problem. The following sections describe some heuristic and AI method techniques that are suitable for routing and allocation problems. [Haa04, HHL+02, Jou07, BG05b, Pur11]

3.6.1 Genetic Algorithms (GA)

The underlying TSP problem itself have been studied from biological perspective as well. E.g. *Physarum* slime molds are shown to able to route themselves optimally between nutrient sources and have been experimentally used for motorway network design. [ABD12, ALS13, AS12, Bon13]

Also many optimization algorithm groups are nature inspired. Genetic algorihms belong to evolutionary computing and they simulate natural selection. When using a GA algorithm, a population of candidate solutions is created. Each candidate solution contains a set of parameters (chromosomes or genes). The starting population is created either by randomly or by other algorithms that try to create a reasonably good candidate solutions. The fitness of each candidate solution is evaluated and the chance that the solution is passed to the next generation of solution is based on the fitness value–this is usually the objective function of the optimization problem. When a new generation of solutions is created, new solution candidates may be generated by recombining high quality solution candidates (parents) to form new solutions (offspring) that inherit traits of its parents. Also random mutations can be introduced to the new generation. The simulated evolution is continued until a satisfactory solution is found or the computational resources reserved for the optimization run are exhausted.

3.6.2 Ant Colony Optimization (ACO)

Ant colony optimization (ACO) algorithms are also one example of nature inspired optimization methods in routing problems. ACO techniques are a part of swarm intelligence methods and are used for finding paths through graphs that can represent a road network. ACO techniques can be divided to many types. The basic priciple simulates pheromone trails laid down by ants travelling between food sources and ant colonies. When the ants find a new better route, the pheromone trail will gets enforced by ants using the route. At the same time older longer routes will be discarded as the pheromone evaporates. Eventually the positive feedback generated this way leads to shorter and more optimal routes between resources and the ant colony. [VFV13, ZZZ+13] Also several other types of particle swarm optimization (PSO) methods can be used, such as the improved particle swarm optimization (IPSO) method developed for periodic vehicle routing problem. [NSA15]

3.6.3 Simulated annealing (SA)

Simulated annealing (SA) techniques take their inspiration from cooling and heating materials such as glass and metal in order to reduce defects and to increase the crystal size of the material. SA methods are metaheuristics that are used to approximate global optimization in a large and often discrete search space such as VRP tours. SA algorithms generally start from a high temperature value which is gradually cooled down to zero state. Random changes are made to the solution and the cooling of the temperature lowers the probability of accepting new worse solutions. Also the scale of the random change made to the solution may depend on the temperature.

3.6.4 Variable Neighborhood Search (VNS)

Variable Neighborhood Search (VNS) is a metaheuristic method for combinatorial optimization problems. One of its applications is vehicle routing optimization. It works by evaluating neighborhoods of the best solution and jumps to a new solution only when a new and better solution is found. It attempts to maintain those charasteristics of the solution that are already optimal. A local search method is also applied in order to find the local optimum of the current neighborhood. The details of the metaheuristic depend on the implementation. [BG05a, HM01b, DJV15]

3.6.5 Large Neighborhood Search (LNS)

Large Neighborhood Search (LNS), a particular heuristic in the Very Large Scale Neighborhood Search (VLSN) class of heuristic algorithms, is another metaheuristic that can be used to solve route optimization problems with Constraint Programming. It works by improving the currently best solution by destroy and repair principle. The destroy step breaks the solution by removing a part of customers either randomly or by some specific method. The repair method rebuilds the solution by inserting the customers back. The exact insertion principle depends on implementation. [BG05b, LQZ+16, PR10]

3.6.6 VRP optimization operations

Optimization algorithms used in commercial VRP optimization softwares are usually trade secrets and detailed information is not publicly available. Some common basic operations used and refined in more complex TSP and VRP optimization procedures are described below. These and similar operations are also used also in the optimization experiments (SPIDER optimization software) described in the following chapters.

2-Opt, 3-Opt, and Or-Opt

2-Opt is a local search algorithm dating back to 1958. It takes a route that has a crossing arcs and reorders them so that the crossover is removed.

3-Opt works by deleting 3 arcs in a network or a tour and then reconnecting them in all possible ways. Each reconnection is then evaluated and the shortest one is selected. The process is repeated for different arc sets.

Or-Opt relocates customers between other customers by replacing edges and preserves the orientation of the original route. [BG05a]

Lin-Kernighan heuristic

Lin-Kernighan heuristic is a generalization of 2-opt and 3-opt algorithms and works by swapping pairs of sub tours instead of switching paths.

Exchange, relocate, and cross

Also other procedures are used in solving TSP tours. Exchange (swap) operation moves a node from first route to second route and a node from the second to the first. Relocation (insertion) refers to removing a node from its current position and changing it into a new position. Cross operation exchanges two segments between two different routes. Also variations such as CROSS-Exchange and GENI-Exchange exist. [GT10, BG05a]

3.7 Application of combinatorial optimization in home care

A typical problem in home care is to allocate customers to workers. This allocation needs to be done every day and real life constraints such as driving times, visit times at customers' homes, planned home visit durations, workers' special skill requirements needs to be incorporated in the allocation. These problems can be solved by different types of combinatiorial optimization.

3.7.1 Vehicle Routing Problem in home care

A major part of the home care optimization is routing the workers through different locations in a city. This kind of optimization problem is knows as the Vehicle Routing Problmen (VRP). Solving it requires visiting address or coordinate data as well as a map data that contains available streets and all other relevant information (such one-way streets, street types with different maximum driving speeds, and rush hour information).

Different types of the VRP problem utilize the Travelling Salesman Problem, especially the MTSP variant. The TSP problem is defined as finding the shortest possible tour through a specified number of cities when the distances between all cities are known, each city should be visited exactly once and the tour must start and end at the same specified city. In the case of home care more advanced VRP variants are needed.

3.7.2 Work shift optimization

Work shift optimization is a common combinatiorial optimization problem in almost any kind of organization. It involves finding optimal work shifts for each worker of the organization so that all requirements concerning work shift durations, free days, weekends, public holidays, overtime etc. are followed. Manual work shift allocation can be extremely time consuming when the work contracts of the workers include complex requirements concerning details such as maximum number of consecutive work shifts at different times of the day, minimum number of consecutive days off, maximum number of work shifts during public holidays per year and many other similar constraints.

3.8 Optimization in home care

Relative few optimization systems are available specifically for home care operations compared to the number of software available for commercial logistics such as optimizating the routes and loading of trucks, delivery cars, tanker and container ships, and airplanes.

3.8.1 Review of literature

Human Resource Planning Process for Home Health Care (HRPHHC) has been increasingly popular research topic during the recent years. It has been studied from optimization perspective and operations research and management perspective. Typically the proposed solutions can be divided into route optimization, worker to customer allocation (including capacity and skill constraints, service areas etc.) and assignment & scheduling optimization (e.g. making weekly schedules) types. More developed systems and solutions combine these all by first assigning the workers to the customers and then solving the routing problem. Separate algorithms have been developed for different kinds of staff scheduling problems that can be applied to home care as well. [MCS+14, SM14, KVM11, BMW97, BQB11, CDB+05, CGS13, LAR13, LMS12, SOI13]

The home health care planning problem has been solved as a multi-depot Vehicle Routing Problem with time windows (MDVRPTW) in the late 1990's. This solution formulated the problem as a mixed integer linear program and included already many of the necessary constraints such as maximum work shift lengths and lunch breaks [CR98]. During the last decade there has been many improved solutions that incorporate more constraint possibilities and preferences to the optimization through different methods (also non-VRP related). Most of them utilize different kinds of heuristics. [EFR06, Tho06, AYD07, BR08, TGH11, RJD+12, BR07, CS13] Some proposed solutions include also weekly planning functionality. [NSS12, BMB+06, CS15, GJ12, CHG+12, THH14] Different proposed solution methods take different approaches such as stressing patient's preferences [BMB+06], walking workers [FH15], continuity of care (patient-nurse loyality) [NSS12], multi-objective optimization [KPG15], visiting patterns [CS15], periodic logistics [LXG14], optimal management of care [KVM11, LMS10], worker skills [THH14], flexible visiting and working times [GJ12], and minimizing the number of different operators visiting a customer. [CHG+12]

As combining all these may be impractical, a recent research [YCS+16] proposes a new kind of method, namely two-phase method utilizing patterns. In this method the home visits are based on a set of visiting patterns (i.e. the week-days when the patient receives home visits are fixed depending on the number of visits per week). The optimization is divided into to phases in which the worker assignment and scheduling decisions are made first before the second phase containing the routing decisions. The assignment and scheduling decisions are not fixed but can be reconsidered in the second-phase when the routing solution is created.

This approach assumes that each patient requires only one visit per day, but the authors note that the pattern definition can be modified to work with multiple visits per day as well.

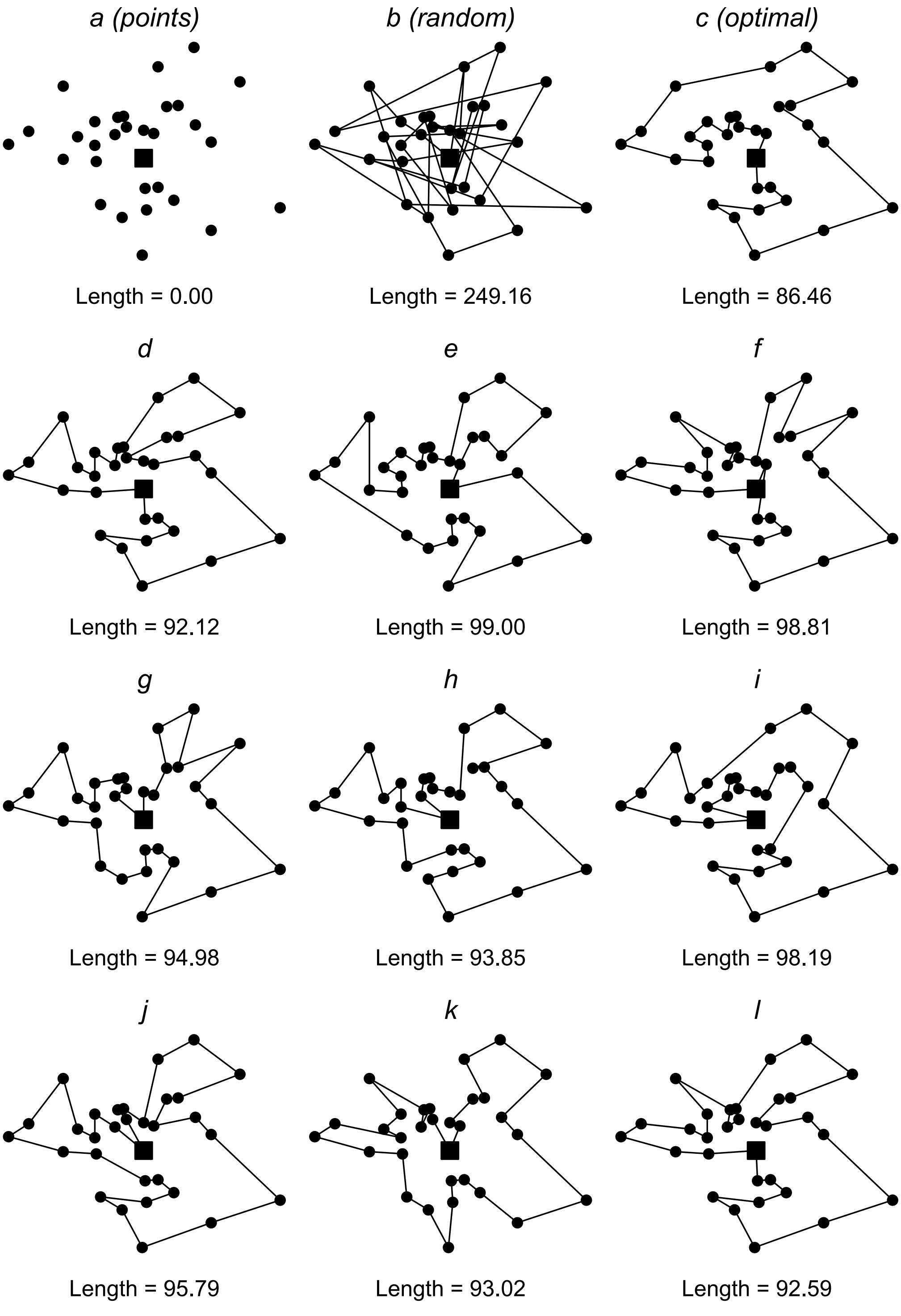

FIGURE 6 Small TSP example. Optimized route (c) and manual routing attempts (d–l).

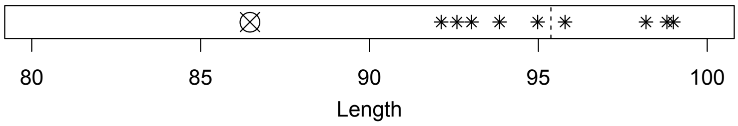

FIGURE 7 Small TSP routing example (Figure 6) results visualized. Route lengths of nine manual routing attemps marked with stars, mean manually routed length with dashed line and optimal solution marked with crossed circle.

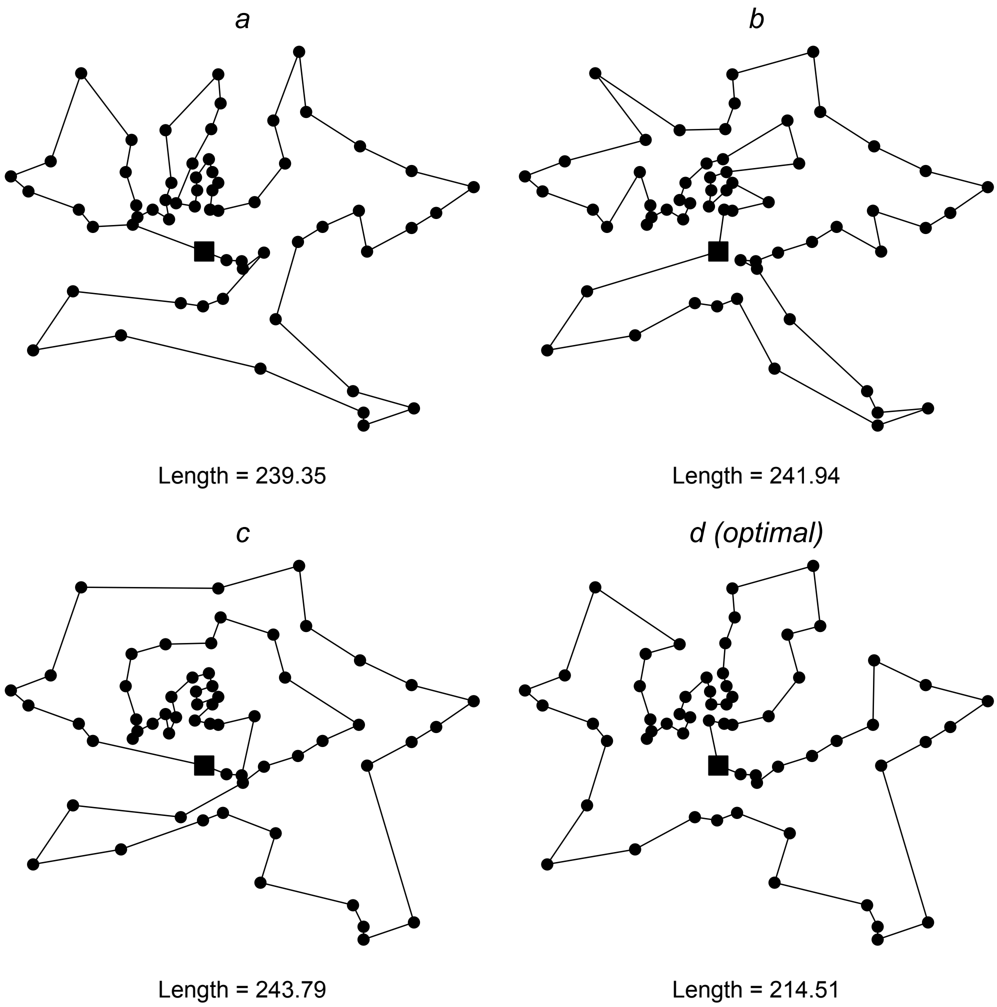

FIGURE 8 61 point TSP example. Optimized route (d) and manual routing attempts (a–c).

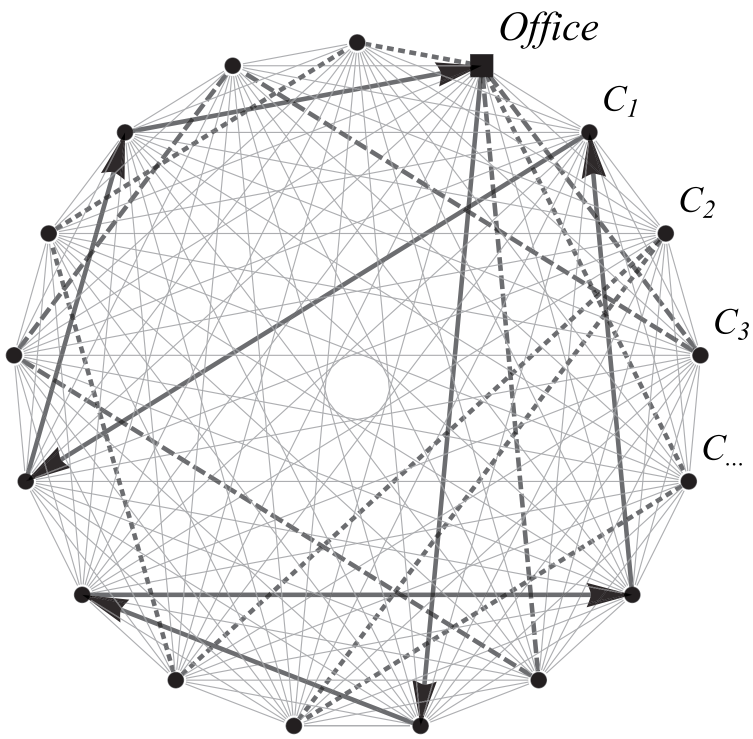

FIGURE 9 Multiple possible routes example (e.g. individual workers moving between customers, visualized in different types of black lines). Grey lines represent all possible routes between the points. Increase of the number of points quickly leads to *combinatorial explosion*, so many possible route combinations that the optimization problem becomes very hard to solve.

4 ANALYSIS OF HOME CARE IN JYVÄSKYLÄ

The target organization of the study is a part of the social and health services of the City of Jyväskylä. This section decribes the home care organization of the City of Jyväskylä and its operations. Then the following sections explore and represent the main points of the home care process in Jyväskylä that should be taken into account when planning optimization.

4.1 The City of Jyväskylä

The city of Jyväskylä is the largest city and municipality in the region of Central Finland which belongs to the province of Western Finland. In 2009 the municipality of Korpilahti (and the Rural Municipality of Jyväskylä were consolidated to Jyväskylä. With its current population (2015) of 137 780 (179 760 in Jyväskylä region) Jyväskylä is the 7th largest city in Finland. Geographically Jyväskylä is located in the Finnish Lakeland area and covers 1 171 km^2 of land and 295 km^2 of water.[1] The population density is 114 km^2 which in practice varies between the more densely populated city area and more sparsely populated rural areas merged to Jyväskylä.[2] Jyväskylä is divided into 14 wards which contain smaller areas for statistical purposes. The age distributions (2011 and 2015) and estimated increase of the elderly population in Jyväskylä is represented in Figures 10, 11, and 12. Jyväskylä belongs to the big cities and the percentage of 65 year olds and older is less than the mean of other big cities in Finland (Figure 13).

The socioeconomic structure varies between areas or suburbs. The proportion of people aged 64 or older varies between 11–24% (2014 situation) within different suburbs. The health of the population can be described with THL's age

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1 By area Jyväskylä is the 7th largest municipality in Finland and the geography includes 328 lakes.

2 Approx. 66 786 dwelling units, of which units with aged 65 and over was 23.2%. Living alone population aged 75 and over was 48.8% of total dwelling population of the same age. [Sot16]

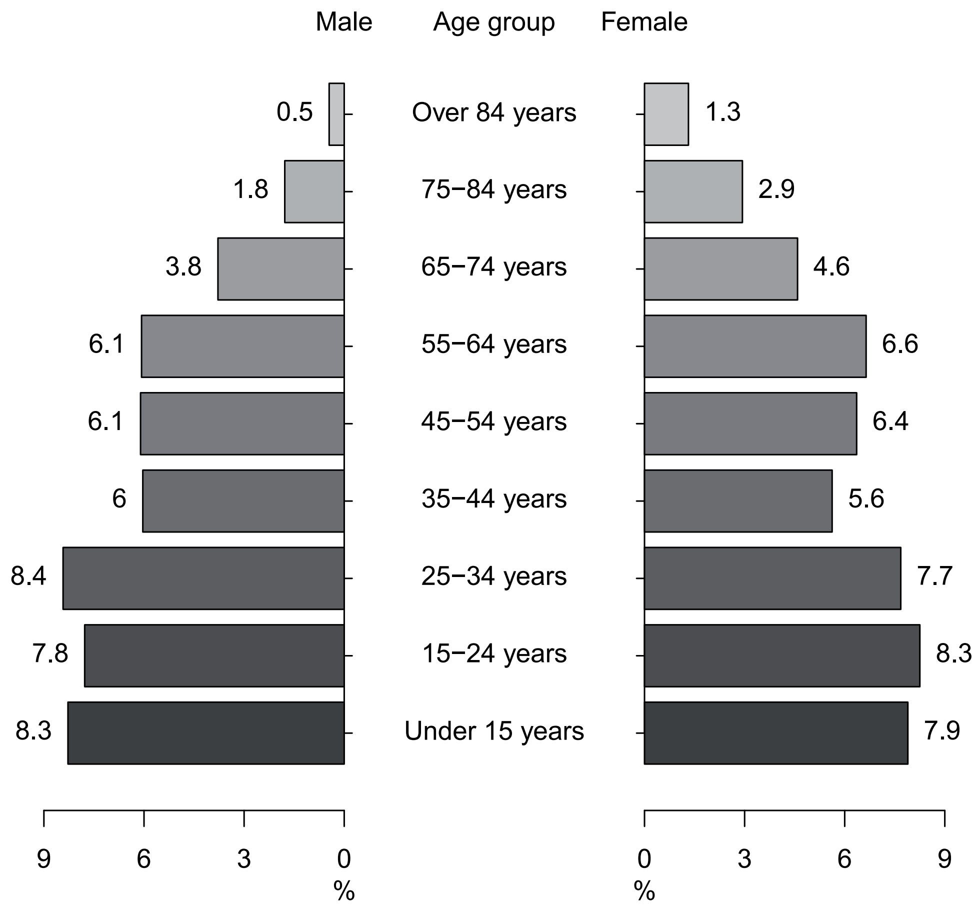

FIGURE 10 Age group distribution during 2011 in Jyväskylä. 14.9% of the population was 65 years old or older. [JKL13b]

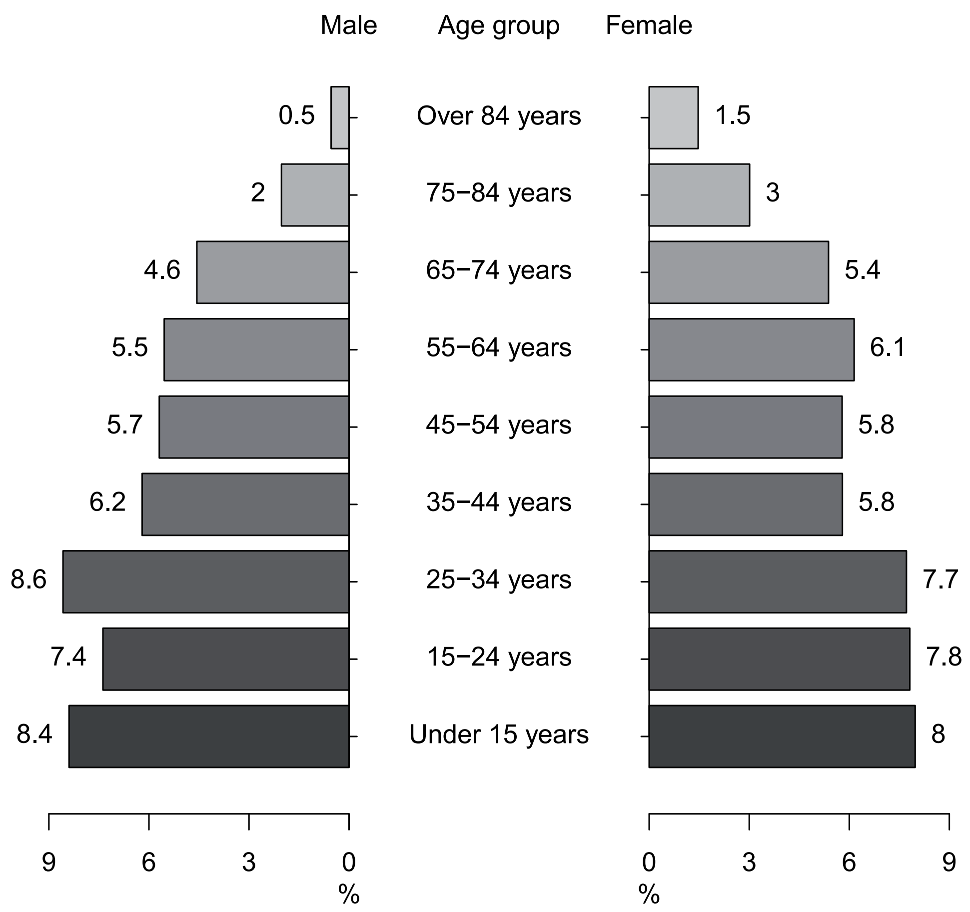

FIGURE 11 Age group estimate for 2015 in Jyväskylä. The proportion of the elderly (65 years or older) was estimated to be 17% in 2015 (official percentage was not yet available in 2016). [JKL13b]

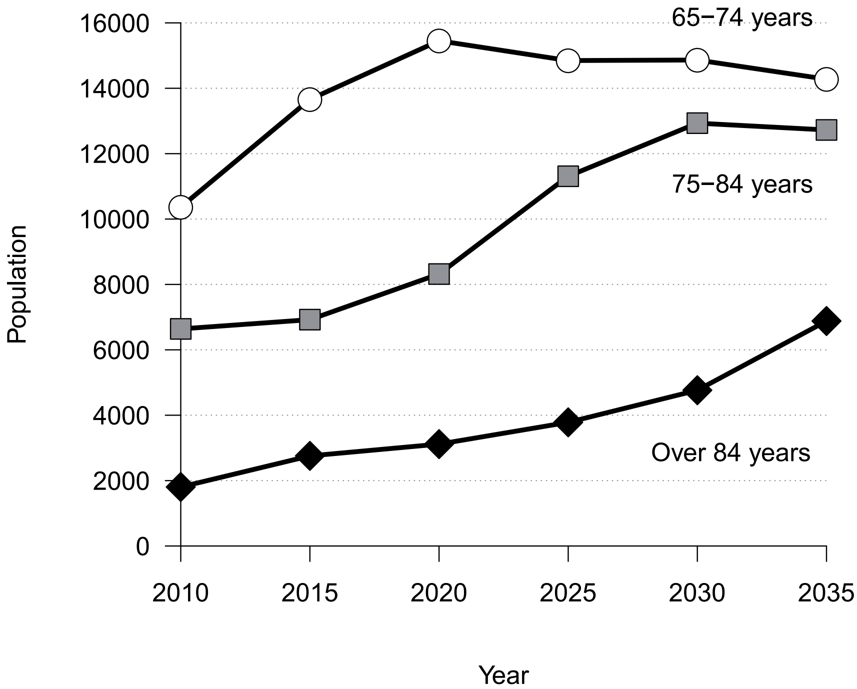

FIGURE 12 Estimated increase of the elderly population in Jyväskylä. 2010 level and estimates for years 2015–2035 in five year increments. The increase of population from 2010 level is estimated to be 37.8% in the age group of 65–75 years (white circles), 91.6% in the age group of 75–84 years (grey squares) and 281.2% in the age group of over 84 years (black diamonds). The total number of elderly citizens (65 years or older) is expected to rise 80.1%–from 18 810 to 33 834. [JKL13b]

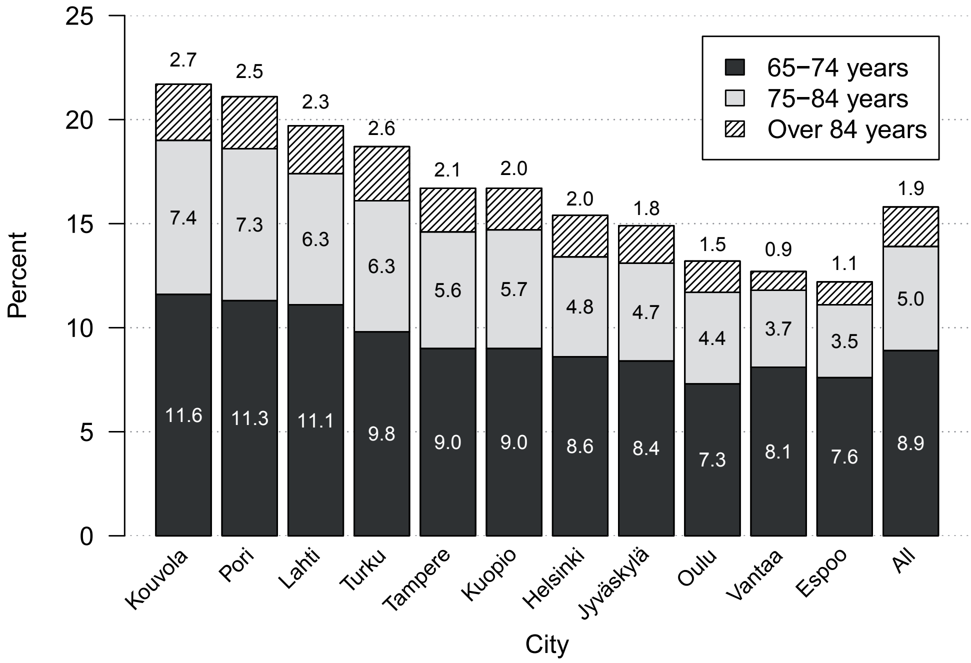

FIGURE 13 Percentage of elderly age groups in big cities in 2011. [SKL12]

standardized health morbidity index. The value of the index is 100 for the whole country. In 2011 the index for the City of Jyväskylä was 104.4. The value of the index increases as the morbidity in the region increases. The disease groups included in the index are cancer, coronary heart disease, cerebrovascular diseases, diseases of the musculokskeletal system, mental health problems, accidental injuries, and dementia.[3]

The City of Jyväskylä is the biggest (7 000 employees) and the Central Finland Health Care District owned by 23 municipalities is the second biggest employer in Jyväskylä (3 100 employees), followed by the University of Jyväskylä (2 600 employees) in the third place.

4.1.1 Social and health services in Jyväskylä

In the City of Jyväskylä health and social services are administered by the Centre for Social and Health Services which provides services for all age groups starting from childrens' care to treatment and care of the elderly. Other examples of the services provided are maternity clinics, dental care, hospital care, school health care, rehabilitation and patient transportation. In addition to secondary health care hospital Jyväskylä has also a smaller healthcare centre hospital maintained by the city. The city also provides different types of social services.

The budget of the City of Jyväskylä and different services during the data collection period are represented in Table 3. Childrens' day care was moved to a separate organization in 2012. Considering this change, social and health services were 48% of the city's gross expenses and 62% of net expenses. Services for the elderly were 16% of the city's total net expenses and home care was 3.4% (19 million €).

In 2015 the total expenditure in social and health services was 437 million €/374 million € (gross/net) of which the services for the elderly and disabled was 87 million €/65 million €. Services for the elderly and disabled were 14% of the net expenses and the services for 65 year olds and older cost approximately 2800 €/person per year. The sum has decreased significantly during past few years. Exact costs can not be calculated because of organizational changes. [JKL12a, JKL16b, JKL16c]

4.1.2 Home care

Home care operations can be organized in many ways. It is common that multiple service areas and teams form a joint bigger unit. The staff typically has three work shifts around the clock. [LTV05] During the collection of the data (2011) used for the optimization experiments the home care organization of the City of Jyväskylä was divided into 9 areas (Figure 25) and 33 teams. The number of teams within each area varied between 1 and 6, and all teams had both home service and home health care staff.

[3] Sotkanet.fi Statistics and Indicator Bank. © National Institute for Health and Welfare 2005–2016.

TABLE 3 The City of Jyväskylä's social and health services budget in 2011 from top level to detailed expenditure in home care. The Center for Social and Health Services is responsible for arranging a wide array of services, including services for the elderly and disabled. Home care is one of the service types provided under the elderly and disabled services. Home care field work (home visits) belongs to the home care service areas category. Numbers are in thousands of euros. [JKL12a, JKL12b, JKL12c]

	In 1 000 €		
Description	**Expenditure**	**Income**	**Net exp.**
City of Jyväskylä, total	**843 280.9**	**286 816.9**	**556 464**
Social and health services, total	**483 532.9**	**70 560**	**412 972.9**
Administration and development	16 048.6	4 164.3	11 884.3
Health services, Jyväskylä	80 941.3	9 682.9	71 258.4
Health services sold to other municip.	10 800.2	10 841.9	+41.7
Special health care services, Jyväskylä	128 823.7	35.9	128 787.8
Childrens' day care	75 766.9	8 150.1	67 617.7
Elderly and disabled services	*110 731.3*	*22 705.9*	*88 025.4*
Social and family services	60 420.9	14 979	45 442
Elderly and disabled services, total	**110 731.3**	**22 705.9**	**88 025.4**
Home care	*23 718.4*	*5 018.7*	*18 699.7*
Family care	6 076.5	47.7	6 028.8
Assisted living and group homes	30 062.3	9 665.3	20 397
Long term care retirement homes	21 474.4	5 451.1	16 023.3
Services for the disabled	28 982	2 511.4	26 470
Administration	417.6	11.6	406
Home care, total	**23 718.4**	**5 018.7**	**18 699.7**
Home care service areas	*18 056*	*2 779*	*15 277*
Home care support services	2 196.4	1 485.9	710.5
Home care day centers	2 759.7	753.6	2 006.1
Administration and shared expenses	706.3	0.2	706.1
Home care service areas, total	**18 056**	**–**	**–**
Staff expenses,	15 670.6	–	–
of which pension related fees	1 479.5	–	–
Purchased services,	1 677.9	–	–
of which travel expenses	158.8	–	–
Supplies,	224.6	–	–
of which leasing car fuel expenses	65.6	–	–
Other expenses,	482.9	–	–
of which leasing cars	154	–	–

Social and health services required approximately 40% of the city's total staff man-years in 2014. [JKL16a] Details of the home care staff titles and numbers are represented in Table 5.

The home care staff has a large number of sick leaves and work stress. [Nak03] In 2012 the average number of sick leave days was 29.3 days per person and in 22.5 days in 2014. [JKL13a, JKL15]

Some indicators of home and elderly services are represented in Table 4. [JKL12b, JKL13a, JKL15] The indicators vary in different years. Several numbers have decreased during the past few years but the proportion of outsourced services has increased.

The Figure 16 shows the development and variation of daily numbers of home visits during years 2010–2012. The raw data was extracted from EFFICA information system (Tieto Corporation) used in social and health services.

TABLE 4 Home care and elderly services indicators in the City of Jyväskylä.

	2010	**2011**	**2012**	**2013**	**2014**
Number of different customers	2 930	3 046	2 420	2 143	2 217
Number of visits	652 633	676 670	717 953	828 904	
of which outsourced services %	6.8	7.7	7.7	19.9	
% of 75 years old or older					
–in home care during the whole year	25	25.9	20.3	19	18
–in regular home care in the end of November			10.7	9.8	10.3
–in sheltered housing	7.1	7.7	6.2		
–in long term care	5.4	4.1	3.8		

4.2 Data acquisation methods and evalution of accuracy

Optimization experiments and analyses of the home care operations are based on empirical data that was collected from 30th of October to 6th of November in 2011. Each home care worker recorded all duties with predefined codes and all corresponding task start and end times to a paper forms (Figure 68). The form also included fields for additional information such as visit type, information whether the visit could have been done at another time or not, transit type, information whether the visit length was a planned or shorter/longer than planner, and driven kilometers.

4.2.1 Data collection

For practical reasons the data collection had to be done manually. Even though digital systems such as EFFICA information system were in use during the data collection period, it was confirmed that extracting information from EFFICA and combining it to other manually collected data would have not been possible in practice. Also recording the data directly to a spreadsheet by each worker was not possible because not all workers had access to computers and also ensuring the quality of the data would have been difficult. Using optically read forms was discussed but due to practical difficulties and costs they were not used. During the the planning phase of the data collection also a simple iOS app prototype for Apple iPhone and iPad was developed by the author to demonstrate how the data collection could have been done more easily if the home care organization would have had mobile devices in use. During the data collection period all workers did not have work phones or smart phones and the organization was in the process of acquiring mobile devices in the future so using mobile devices for recording the visits was not a viable option. [JKL12b, JKL13a, JKL15] [4]

4.2.2 Accuracy of the data

Everything practically possible has been done during the saving process to ensure that the data is accurate. As a data of this type and scale (approximately three quarter million cells) cannot be one hundred percent accurate, most tables and figures use kilometer and hour sums rounded to nearest full hour or kilometer even though the actual computations used higher precision. In some figures and optimization scenarios a small number of outlier or otherwise abnormal values may have been left out if necessary for various computational reasons. Due to the size of the data, this should not have any practical effect to the results.

All results should be interpreted as estimates of the scale of the improvements that are possible to achieve. In most cases optimization solutions contain only order of visitation addresses. Selecting the shortest or fastest driving routes are left to the drivers' discretion and thus not included in optimization results. GPS based car navigators can often suggest similar point to point routes that route optimization software used in routing computations but random events and decisions may force drivers to select different actual driving routes.

As the increase in driving kilometers and times when the proportion of fixed time-critical home visits increases is linear, most of the scenarios have been computed with 0%, 50% and 100% proportions and the results for other proportions between have been derived from linear regression formulas.

True kilometers include only those trips that have been made by cars, not those made by walking, bicycle, bus or other means of transportation. Thus in reality the true kilometers is higher than represented in the following figures and tables and the savings in kilometers is a bit higher as well. True working hours

[4] Piloting of the mobile devices started in the end of 2011, in 2012 mobile devices were in use in some home care areas. Logging the visits at customers' homes by mobile devices increased the time used at customers' homes about 0.5% (1077 hours) by decreasing the time needed for manual logging of the visits. More home care areas started using the mobile system in 2013 and in 2014 interfaces to ERP, work time management and other systems were added. In 2015 the contract for the ERP system in use was discontinued. The procurement process for a new system was started in 2015 is still ongoing in 2016.

may be slightly higher or lower in the optimization scenarios for various technical reasons. The advantage in the kilometer difference and this should cancel each others out. Still to be on the safe size, extra hours and work shifts are added to the results in some figures and tables.

4.2.3 Sources and levels of possible inaccuracies in data

Some level of error will always be inherent in this type of data collection and optimization. Although all reasonable ways to ensure the precision of the data has been utilized, the following points remain:

1. Manually collected data and paper forms. Each worker was personally responsible for following instructions and writing down precise information. Some forms were very detailed, some did not include everything asked. The data was primarily collected for the City of Jyväskylä's internal work time analysis use and it is used for optimization experiments as secondary data.

2. Manually typing the data from paper forms to digital format. As much error detecting and correcting was conducted in this phase, but in a dataset this big, naturally some error may remain.

3. Data conversion to optimization software format. Some outliers and otherwise abnormal tasks had to be left out and adjusted manually in order to optimize the scenario. In most cases the number of these changes is not bigger than e.g. 0–10 individual entries per day in the case of work shifts 1 and 2. In other words, a couple of per milles of the whole. This should not have any visible effect to the results.

Some details were intentionally left outside of the data collection, such as random phone calls in transit. These cannot be anticipated and included in operational optimization so they were left out. The number of them is very small, a few cases per day.

Special tasks, such as 8 hours training. In reality each worker will arrive to training places directly from home and will depart directly to home. As the optimization software handles these cases as home visits, it will assume that the worker will leave from office address and return there after the task. In order to optimize these tasks the 8 hour task length had to be shortened in order to fit it and the transit time to 8 hour work shift. This should not have any visible impact to the results. Hours spend to work tasks may be slightly smaller than in actual data, on the other hand driving kilometers may be slightly higher. In a large whole the effect is minimal.

Despite these inaccuracies, the level of improvement brought by optimization in the results can be used a reasonably accurate estimate.

4.3 Methods and technical details

Exploratory data analysis (EDA) can be defined as an approach to summarize complex data sets in clear and understandable form without using statistical models and formulated hypothesis. This is often achieved by visualization, which was promoted by the american mathematician JOHN W. TUKEY[5] (1915–2000) in order to isolate patterns and features in the data [Tuk77]. EDA can be used as a basis for suggesting hypothesis concerning the features discovered, assessing assumptions concerning statistical interference, planning of further data collections or experiments and selecting appropriate statistical techniques for analyzing new data. Exploratory analysis is usually followed by confirmatory analysis that assesses reproducibility of the observed patterns and provides statements of significance and confidence [HMT83]. Generally the same data used for EDA should not be used for confirmatory use, but new data is collected for further analyses after hypotheses have been formed based on detected patterns.

EDA inspired the development of statistical computing packages and languages, such as the Bell Laboratories[6] S, which was the first programming language specifically developed for creating analytical prototypes. [BL16b] Its descendants are S-PLUS [TS13] and the Open Source programming language and computing system R [RP13], which is the main tool used in the analyses and visualizations in the following sections. Despite its sometimes steep learning curve, R language has an advantage over simpler tools by allowing complete command and control of the analysis, and a work flow that can be hard to achieve with point-and-click type statistical softwares. It can be used for deep data exploration and discovery in a highly interactive manner by inputting command lines through integrated development interfaces (e.g. RStudio IDE [RS13]) or for writing interpreted computing and visualization programs. It also contains interfaces for directly tapping to database servers, for parallel computing, and accessing high performance programming languages such as FORTRAN.[7] As a freely available and modifiable (mostly GPL licensed [FSF07]) Open Source tool it has become the *de facto* standard in statistical and scientific computing. With modules covering a wide array of scientific and engineering fields, it offers a highly advanced and cost effective alternative to proprietary softwares.

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5 Also known as the (re)inventor of the *Cooley-Tukey fast Fourier transform (FFT)* algorithm originally developed for detecting Soviet nuclear experiments (and before that used by CARL FRIEDRICH GAUSS in 1805 to calculate the trajectories of the asteroids *Pallas* and *Juno*) and the box plot visualization method used e.g. in Figure 15. [PT01, IA84]

6 Nokia Bell Labs since 2016, Formerly known as AT&T Bell Laboratories and Bell Telephone Laboratories (New Jersey, USA). Credited for development of e.g. *the transistor*, *the laser*, *the charged coupled device (CCD)* used in digital cameras, the UNIX operating system, the C programming language, and eight Nobel prizes awarded for work done at Bell Laboratories. [BL16a]

7 The *de facto* standard programming language of supercomputing and the programming language with the longest continual active development history, first version being published by IBM in 1957 and the latest FORTRAN standard, ISO/IEC 1539-1:2010 (informally FORTRAN 2008) being approved in 2010. [Nak06b, ISO10, RF12, HRR01, HM01]

4.4 Operational details and analysis of Jyväskylä home care data

The following sections describe the details and operations of the home care during the time period of the data used in the optimization experiments.

4.4.1 Overview of long term statistics of home care

Daily statistics for years 2010–2012 in Jyväskylä home care is represented in Figure 14. The figure shows the increase of the frequency of home visits to 2012 and the different visit frequencies between weekdays and weekends. Also effects of national holidays are visible. Further analysis of the data also shows that the frequency of home visits is smaller in Fridays. More details are represented in Appendix Figures 48–52 and 62–65.

Daily total number of home health care and other home care visits, individual customers and total hours for years 2010–2012 are represented in Figure 15. The figure shows how in the home health care the time spend at users' homes decreases towards the end of the week. In other home care services the values of the indicators are smaller only during the weekend. Figure 16 shows that the increase in the frequency of home health care visits in 2010-2012 has been lower than in other home care.

The number of home care visits per day was between 1100 and 2000. The number of different customers per day varied between 100 and 400. The average number of home visits and customers increased between years 2010 and 2012, but the time used for home visits did not increase significantly. Home visit frequencies decreased in home health care. The average duration of home visits also decreased. This development is visualized in Appendix Figure 53.

In 2012 weekends differ from weekdays but differences can also be found when comparing weekdays. Kruskal-Wallis test[8] indicates that levels for indicators differ between weekdays for other home care customers numbers and other home care visit numbers, but not for other home care visit hours. In the case of home health case the number of customers, the number of visits and the given service hours differ significantly. All weekdays differ from each other in home health care and in some cases in other home case visits. Kruskal-Wallis test results are represented in Table 6. As the data was limited to one week only, the results should be considered suggestive. A larger scale data sampling would be needed to confirm the differences.

The majority of the customers receive regular home care based on a preplanned personal care plan. Known reasons for the detected differences during weekends are smaller number of staff and work shifts during weekends, and the principle that only necessary care is provided during weekends. The data also reveals a noticeable difference between different weekdays. The variation of the customers' need for care between weekdays cannot be explained.

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[8] A non-parametric statistical method for testing if independent samples originate from the same distribution by evaluating if the population medians are the same.

The challenges that aging poses to public services were discussed in the introduction. These challenges can be seen in the target organization of this study. The analysis of the home care organization of the City of Jyväslylä shows that the number of home care customers and home visits has increased in 2010–2012 as the population ages. However, the duration of home visits and the total time used for home visits has decreased. The proportion of home health care services has not increased significantly and there are less service during the weekends than during weekdays.

4.4.2 Work shifts and titles

The home care operates in three shifts around the clock, every day around the year. Different staff titles are represented in the Table 5. For all practical purposes the staff can be divided into two main groups: home health care staff (B.Sc. level registered nurses and public health nurses) and other home care staff (vocational level licensed practical nurses and other staff with varying education). Only the latter group works in three shifts, home health care being provided only during office hours in weekdays. Limited health care can be provided by licensed practical nurses during weekends. In the case of emergency the customer is always transported to primary care.

Work shifts are based on flextime system. Actual work shift lengths for individual workers vary within certain limits, the typical work shift length being approximately 7–8 hours. Work shifts switch approximately around 7:00 in the morning, 14:00 in the afternoon and 21:00 in the evening without fixed hard limits. The night shift (shift 3) has lower staffing than earlier shifts (shifts 1 and 2) and it contains only certain task types, mainly visits to customers requiring assisting around the clock. For safety reasons the night shift staff usually operates in pairs. Shift 1 and 2 staff usually works alone but exceptions exist such home visits requiring lifting of heavy or otherwise harder to care customers. Other field tasks and office tasks are normally done only during shifts 1 and 2.

Figures 17, 18 and 19 represent how different home care task are distributed during a 24h period and weekdays in the 2011 one week data. A peak of other tasks is visible in the morning, which is followed by home visit rush during the morning shift (Figure 19). Figure 17 represents the frequencies of the tasks but does not include task hours. The frequencies show that the work days are relatively similar between tasks although different tasks can have different frequencies and durations. The start time distrubution of different task groups are represented in Figure 22.

4.4.3 Task types and duties

The data collection form used in November 2011 used 16 different task types as represented in Figure 20. One additional task type (17, phone calls during transit) was added afterwards based on written additional notes in the forms. Description of the tasks are as follows:

Examples of typical work shifts are described below based on interviews and written descriptions provided by the staff.

Morning and afternoon shifts, other home care

- Short meetings concerning the details of the previous night's night shift and sudden changes, e.g. workers absent due to illness and making changes to customer's care plan. Collecting and preparing supplies, medication and keys. Briefing workers returning to work after vacation or sick leave.
- Morning home visits. Morning chores such as helping customers out of bed and to wheel chair, bathroom assisting, hygieny, changing diapers, dressing customers, giving medication, preparing breakfast, basic cleaning of environment (doing the dishes, taking trash out, cleaning bathrooms, making up beds). Possibly taking blood or urine samples.
- Coffee and lunch breaks at office, practically often elsewhere.
- Office tasks such as ordering supplies for customers, phone calls and emails with customers' famililies, doctors and other care takers.
- Day home visits. Day chores such as assisting in dining, giving medication, bathroom assisting, hygieny, laundry, shopping and cleaning to those customers who receive support services.
- Possibly taking customers to see a doctor or to other appointments when family members aren't available.
- Afternoon workplace meetings at offices, meetings with doctors at hospitals, meetings with customers' family members at homes.
- Other office duties, e.g. updating care and service plans.
- Work shift and customer allocation planning.
- Transporting supplies when necessary.
- Some morning shift workers take care of sauna and bathing assisting of own teams customers at day centers, usually from morning to afternoon.
- Afternoon home visits. Giving medication, assisting in dining, bathroom assisting. Partly handled by morning shift workers and partly evening shift workers.

Night shift, other home care

- Evening home visits. Only most important chores such as assisting in dining, bathroom assisting, changing diapers, assisting customers to bed.
- Late night home visits contain the same chores and possible late night medication.
- During night shift workers operate in pairs. Most customers who need help during night time are visited 1–4 times between 7:00–21:00.

Day shift, home health care

- Home health care operates from Monday to Friday in morning shift (office hours).
- Morning meeting with other home care and home health care staff.
- Preparing for home visits, e.g. supplies and laboratory sample paperwork.
- Home visits. E.g taking samples, details vary depending of the type of the sample, some require also fast delivery to laboratory by home health care staff.
- Wound care, administration of medication at homes and other medical care tasks.
- Transportation of health care supplies.
- Office work and lunch before time reserved for phone calls.
- Time reserved for phone calls and emailing. Checking and updating care plans, sending messages to doctors, making reservations for customer's visits to doctor, phone calls to customers' family members.
- Customers' paperwork during home visits.
- Additional home visits.
- Unplanned home visits, e.g. other home care workers order an immediate home healt care nurse visit.
- Meetings with doctors and customers' family members.
- Other meetings.
- The order of daily tasks varies without any specific order.

Especially morning and evening shifts contain duties that are hard to plan in advance because needs and time required are not always known in advance. This poses a significant problem to optimization.

4.4.4 Analysis of work time

The previous analyses described the home visit and other tasks during different days and times of day. In public discussion concerning home care it is often said that too small part of the working time is spent at actual care of the customers at their homes, and that the home visit durations are too short. Also one of the objectives of the target organization is to increase the time available for work at customers' homes. Therefore it is important to analyze and recognize the proportion of working time used for transportation and other tasks than actual home visits. After recognizing the most time consuming tasks it is possible to optimize the service process and utilize different kinds of technological solutions.

During the data collection week, there were total of 10 365 work hours, out of which 498 hours were outsourced. The average work shift length was 8 hours and 5 minutes, or approximately 10 hours in the night shift. Table 7 and Figure 21 represent the working hours in different task type categories. 41.7% of the working time was used at customers' homes. Making a home visit requires preparation (e.g. shift start/end tasks, picking up and returning keys), transit, and computer tasks, which were 14.8%, 13.8%, and 8.5% of the total working time. It may be possible to increase the effectiveness of the process by developing working methods or applying computer based solutions. The following chapters examine the possibility of applying route optimization to home care.

92% of home visits started as planned. The median duration of a home visit was 18 minutes. When the frequency of home visits increased, the home visit duration decreased and vice versa. This correlation is visible also in the 3 years data.

Workers were also requested to evaluate whether home visit took more or less time than planned. 91% of the home visits were classified as normal in duration (median duration 18 minutes). 19% of the home visits were classified to group of home visits that could have been moved to another time at least partially (for example some tasks), and 2% were classified as completely movable (i.e. not time-critical at all), Appendix Figure 61.

Figure 24 represents home visit median durations grouped by work shift, visit type, transportation type, building access, planning, and movability.

Laboratory visits were 0.3% of total working time. This is the time workers spent at a laboratory sample delivery point, such as a hospital's laboratory. As the target organization had ongoing plans concerning development of the laboratory sample process, this task was analyzed in detail.

In the case the customer cannot go to a hospital laboratory, blood and other samples can be taken at a customer's home by a registered nurse. The delivery of the sample is done by home care workers and the these tasks can be done only during office hours.

The driving time required for delivering the laboratory samples was calculated by a script code developed for this purpose. The laboratory visit duration is the time between the end of the previous home visit and the time of leaving the laboratory (Figure 23).

The mean time of a laboratory sample task and delivery was 18 minutes and during one week the total time of the laboratory sample deliveries was approximately 48 hours, more than the average working time per week of a home care worker (38.25 hours). The return trip from a laboratory can be estimated to be approximately the same as the trip to laboratory. In this case the whole process would require 23 minutes, or 64.4 hours per week.

Working time analysis results are represented in Appendix Figures 56–61. These are examples of different kinds of possibilities to utilize customer databases for planning and development purposes.

4.4.5 Analysis of home visit content

Tasks done during the home visits are diverse. In optimization home visits and other tasks are treated as blocks that are optimally allocated to different workers. Although the content of these blocks does not directly affect optimization, analyzing it may provide valuable insight to the home care process. Especially the reasons why some home visits take more time that was planned is important because this information could be utilized when planning the required home visit lengths. If succesful, this could help to decrease the amount of home visits that exceed the planned visiting time and break the optimized schedule.

The results are represented in Tables 7 and 8, and in Figure 26. Table 7 contains the task type classification created in cooperation with the home care staff. The most common tasks during home visits were medication and basic care related tasks. Most home visits contain more than one task type. The number of different task types during a home visit variated between 2 and 4 task, the average was 2. The most common reason for a home visit was medication related tasks (24% or home visits). This was often combined with heating and meal service related tasks (12.1% of home visits) or mental support, which was also included in many other home visits. 8% of home visits were related to the living environment of the customer and cooperation with the customer's family.

A data of home visit content was collected during the third week of May in 2013 by using paper forms (Figure 69). [Nak13]

Other prediction methods such as neural network predictions and time series forecasts are discussed in Chapter 8.

4.4.6 Home care teams and service areas

As described in the previous sections, the City of Jyväskylä is divided into 9 home care service areas and usually 33 home care teams operate in these areas. Each team is planned according to the needs of a particular area is serves as the geography and customer base[9] in each area can be different. Some teams work only in sheltered housing buildings.

The land area of the City of Jyväskylä grew approximately ten times larger in municipal merger. Also the variability of the geography of the city changed to include also sparsely inhabited country side and even dwellings in islands. In the new customer base there are also homes that differ from urban living. Some elderly customers in the sparsely populated areas may still live in homes that are heated by wood burning. This has added new tasks and challenges to the home care work.

Generally the workers of each team make home visits only to customers of their own team. In some special situations a worker from another team may make a home visit to another team's customer.

4.4.7 Distances and means of transportation

The main mode of transportation is by cars but a small number of home care workers may also walk, use bicycle or in some cases public transportation. In the optimization experiments all workers are assumed to be driving a car.

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9 The home care organization uses two different patient classification instruments to check regularly the functioning and the need of care of the customers.

4.4.8 Mobile devices in home care

During the collection of the data no mobile devices were in regular use. Piloting of mobile devices started in the end of 2011. In 2012 mobile devices were in use in some home care areas but in 2016 no mobile devices are used.

4.4.9 Queuing to computers

In 2011 the home care organization's mobile system was not fully functional and it lacked interface to patient information system. Notes taken with the mobile device based system could not be transferred to computer either wirelessly or by cable, but had to be manually inputted like before the mobile system pilot.

Generally most team headquarters have only one shared computer dedicated to aides and licensed practical nurses and it is common that workers have to wait before they can use it. Only home health care nurses may have a personal computer. A small data set was collected in 2006 to model the waiting time distribution. The effect of adding more computers to the queueing time can be studied by utilizing queueing models. [GH74, SWG+15] As there were no plans to acquire more computers, no further calculations were done. The data collection and analysis still revealed other useful information about the queuing times.

Queueing to computers data was collected during one work week in June 2009 during the morning shift. Workers who did not have a personal computer participated to the data collection. The data collection period was during summer vacation season so a part of the staff was on vacation. 127 individual workers, 89% of all teams (25/28) and 87% of the monitored team headquarters (20/23) returned data collection paper forms. Total working time of the workers who returned data collection forms was 2717 hours and 41 minutes. The number of work shifts was 351.

During the data collection week, by average 6 workers worked in the morning shift in each team headquarters and 119 workers in total in all areas. If all workers would have returned the data collection forms, their total working time would have been approximately 271 320 minutes. The total working time in the data was 163 061 minutes, thus the data collection covers approximately 60% of the working time. The coverage of the data collection was good concerning different geographical areas. Because of the holiday season the data does not represent typical operational situation very well.

The workers needed to use the computer approximately 1.5 times per each work shift. In 72.8% of cases the worker could access the computer without queueing. In 22.8% of the cases the worker had to queue, and in 4.3% of the cases the worker could not use the computer at all. The average queueing time in the full data was 28 minutes. The queueing time variated between days and team headquarters, the average queueing time ranging from 3 minutes to 195 minutes in different team headquarters during different days. The shortest average queueing time in an individual team headquarters in the full data was 10 minutes and the longest average time was 105 minutes. The longest queuing times were in Mondays (38 minutes) and Wednesdays (40 minutes).

The average time a worker used the team headquarters computer was 17 minutes if the worker had to queue. When the computer could be accessed without queuing, it was used by average 25 minutes. By average every worker worker with a computer 34 minutes per work shift, about 7.3% of their daily working time. 8.5% of working time was used for computer tasks in 2012 working time analysis data (Table 7). 2.1% (57 hours) of the working hours in the one week data was used in queueing to computers.[10] Although it was possible to do some other tasks while waiting, the queuing is inefficient.

10 The Centre for Social and Health Services, The City of Jyväskylä (2009). Pentti Nakari (2009).

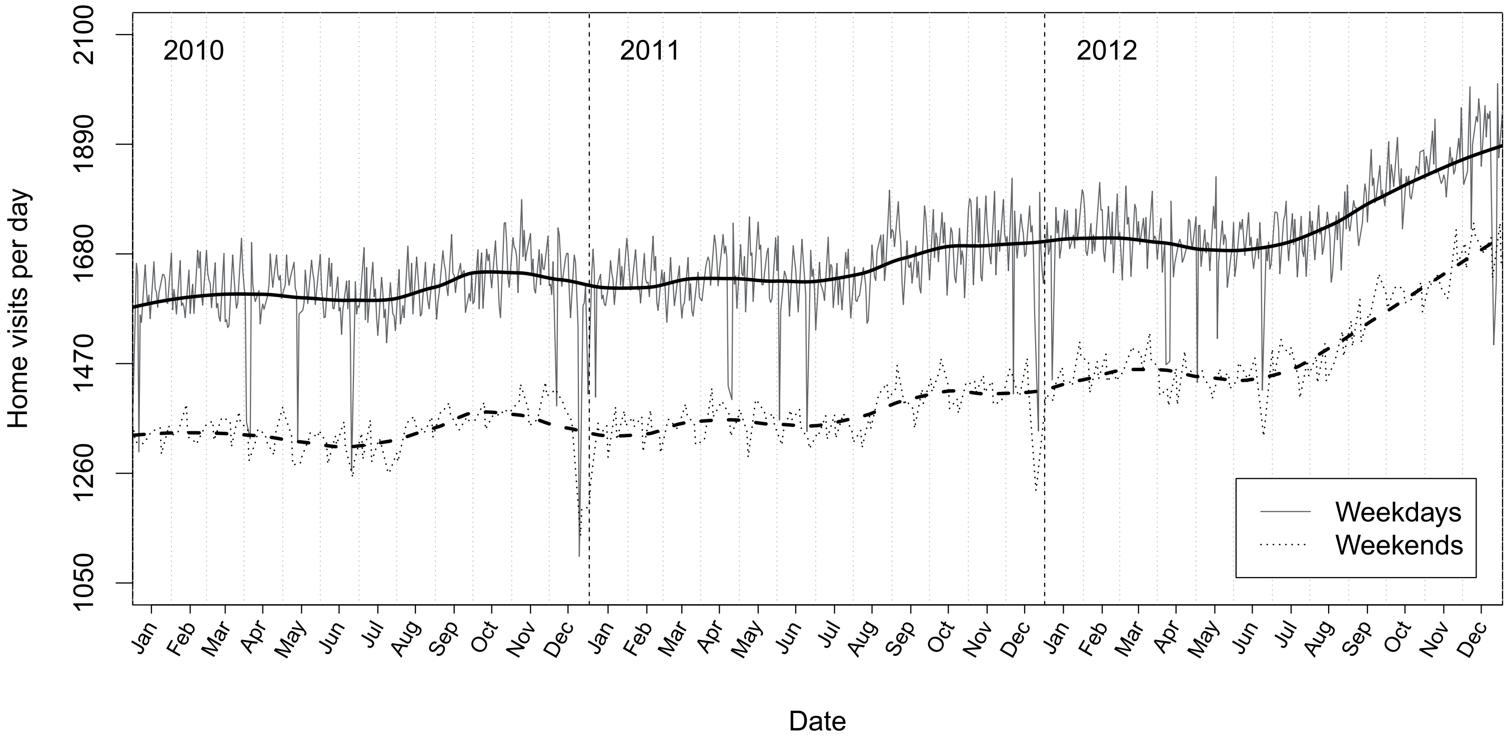

FIGURE 14 Daily number of home visits (both health care and other home care) in the City of Jyväskylä in 2010–2012.

TABLE 5 Staff size in 2011 Jyväskylä data.

Title	**N**	**English title**	**Required education**	**Rights**	**Shifts**	**Total**	**Percent**
Erityisavustaja	2	Personal assistant	Not specified. Usually folk high school courses, $\leq$ 1 year or vocational training, 1 year	None[a]	1–3 (24h)	55	18.15%
Hoitaja	7	Aide					
Kodinhoitaja	44	Home aide					
Kotiavustaja	2	Home assistant					
Lähihoitaja	198	Licensed practical nurse	Vocational degree, 3 years	Limited[b]	1–3 (24h)	203	67%
Perushoitaja	5	Licensed practical nurse					
Sairaanhoitaja	27	Registered nurse	Polytechnic B.Sc. degree, 3.5 years	Full[c]	1 (Day)	45	14.85%
Terveydenhoitaja	18	Public health nurse	Polytechnic B.Sc. degree, 4 years				
Total	303[d]					303	100%

[a] Home service workers with no nursing rights. Will be eventually phased out and replaced with licensed practical nurses.
[b] Home service and home health care workers. Both Finnish titles (the first being the newer title) refer to same regulated vocational degree. Limited nursing rights under the supervision of registered and publich health nurses.
[c] Home health care workers operating during office hours. Full registered nurses' medication administration and IV rights.
[d] 96% of the full field staff. Full staff on payroll during the data collection period was 315 field workers and 17 workers in administration, managerial and office positions, a total of 332 workers.

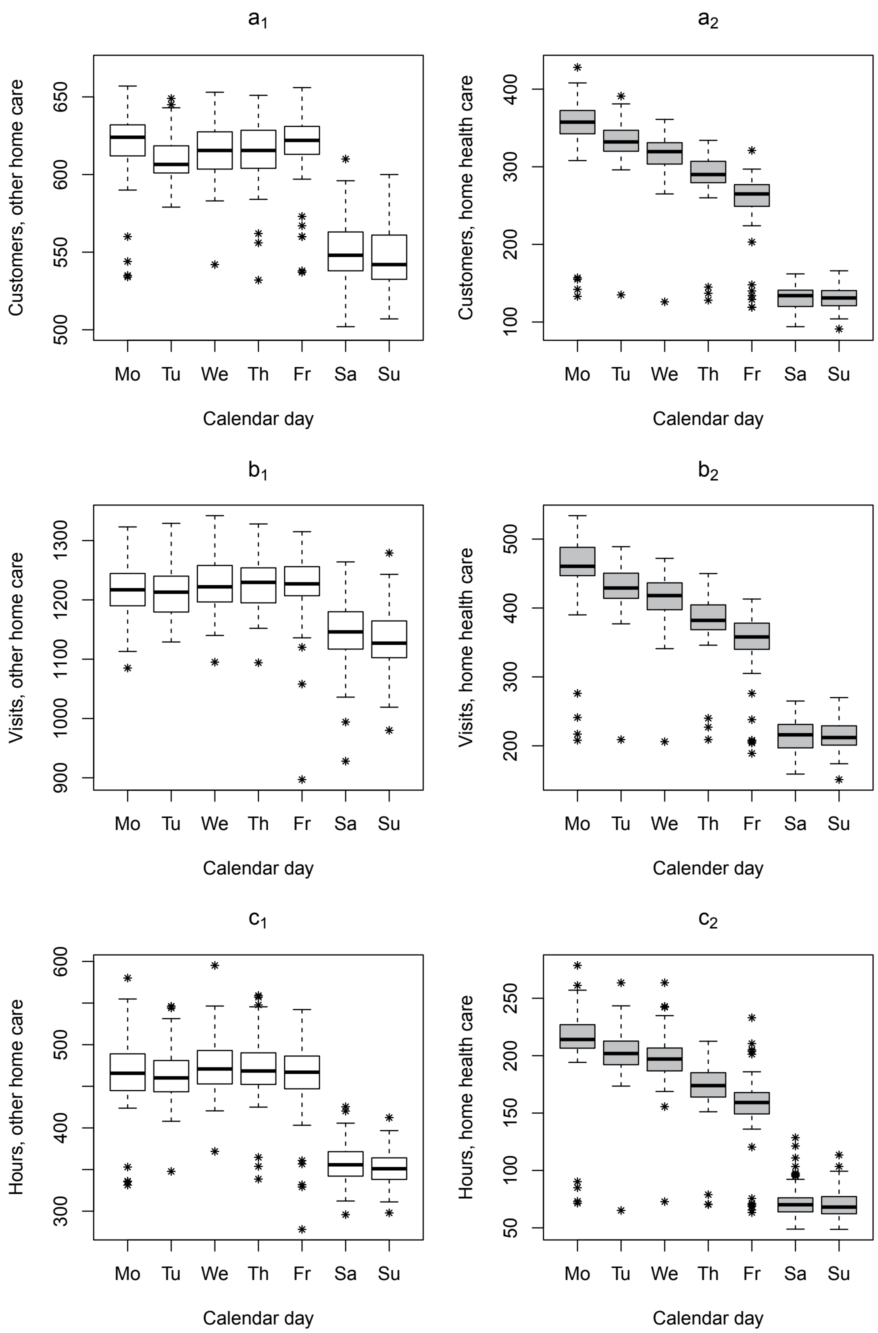

FIGURE 15 Daily number of customers (a), home visits (b) and home visit duration hours (c) in 2010–2012 grouped by calendar day. Other home care visits in white (1) and home health care visits in grey (2). Outliers caused by holidays. Kruskal-Wallis test results for year 2012 are represented in Table 6.

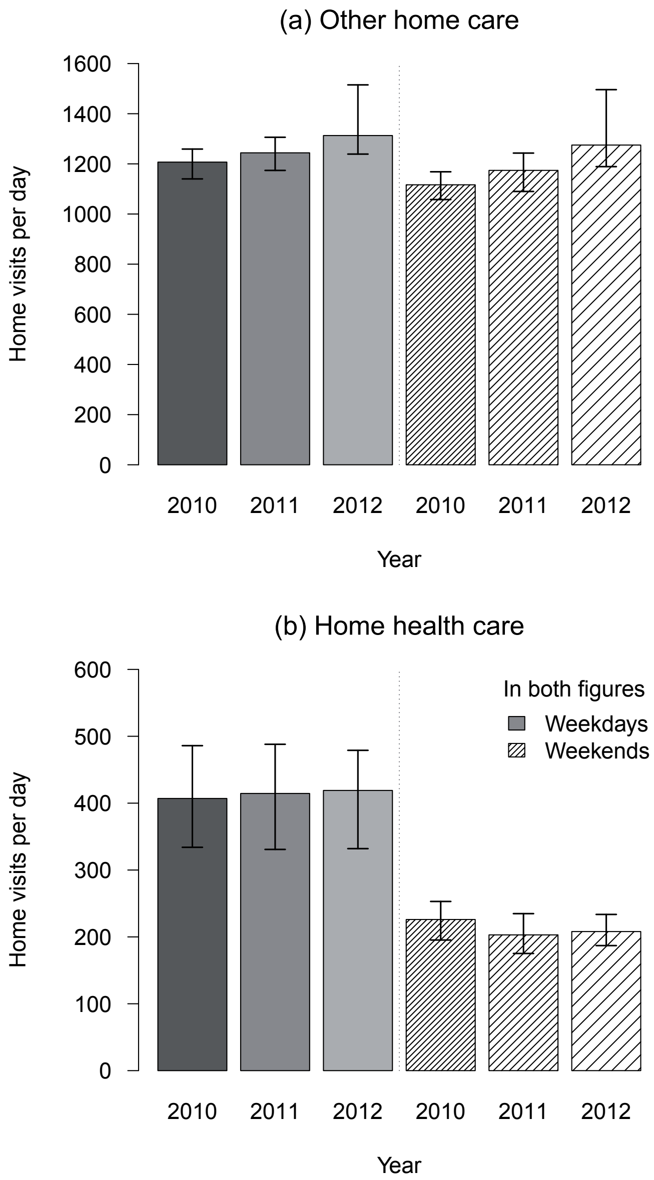

FIGURE 16 Daily home visit frequencies by year in 2010–2012. Bar represents median (weekdays and weekends separated), error bars show 90% range. Increase in both number of home visits and variation visible in Subfigure (a). Weekday visits in Subfigure (b) are actual home health care visits, weekend visits are made by licensed practical nurses but are logged as home health care visits (see Table 5). More detailed distributions are represented in Figure 48.

TABLE 6 Kruskal-Wallis rank sum test results for weekdays (Mon–Fri) in 2012 home care data (last year of data represented in Figure 15).

Daily number of	**In Figure 15**	χ^2	**DF**	***P***
Other home care customers	a_1	8.2489	4	0.08287
Other home care visits	b_1	5.5268	4	0.2374
Other home care hours	c_1	28.7528	4	< 0.0001 ***
Home health care customers	a_2	167.2769	4	< 0.0001 ***
Home health care visits	b_2	164.5942	4	< 0.0001 ***
Home health care hours	c_2	163.2247	4	< 0.0001 ***

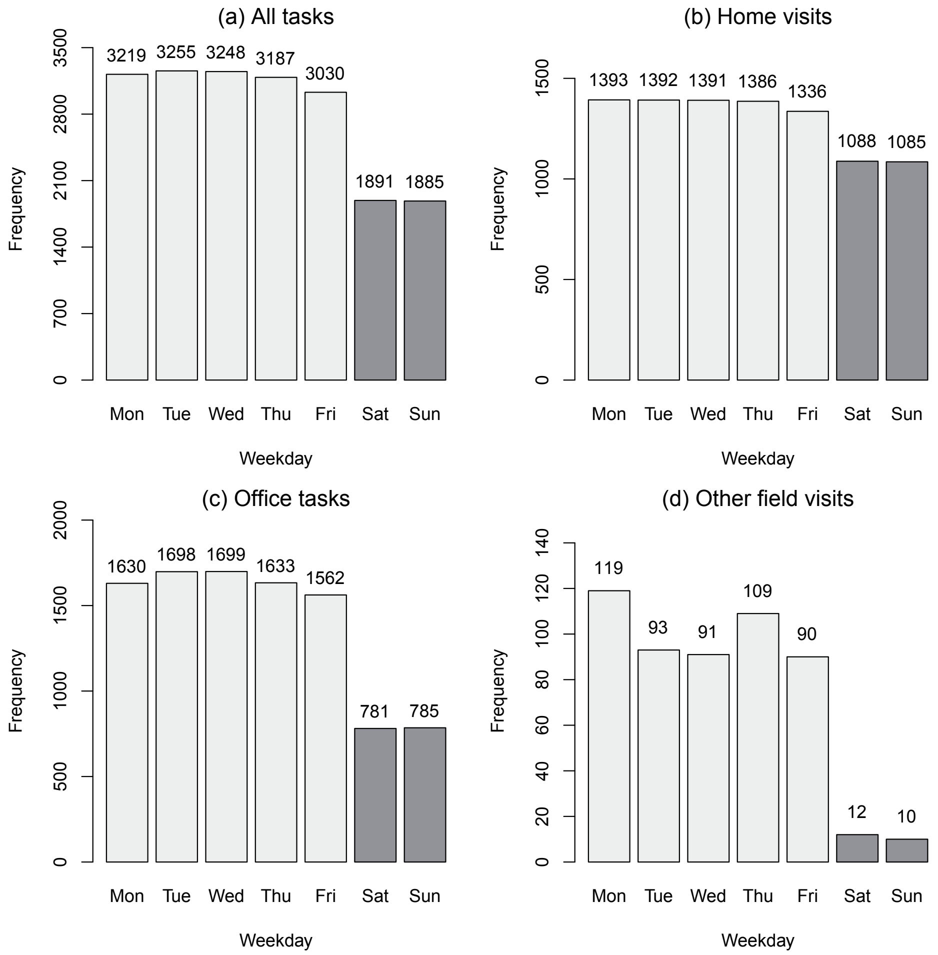

FIGURE 17 Frequencies of (a) all tasks, (b) home visits, (c) office tasks and (d) other field tasks in November 2011 one week data. Four teams working locally at service apartment buildings excluded. These teams work only in morning and evening shifts. Average daily frequency of home visits during weekdays was 190 in morning shift and 113 in evening shift, and during weekends 120 in morning shift and 124 in evening shift.

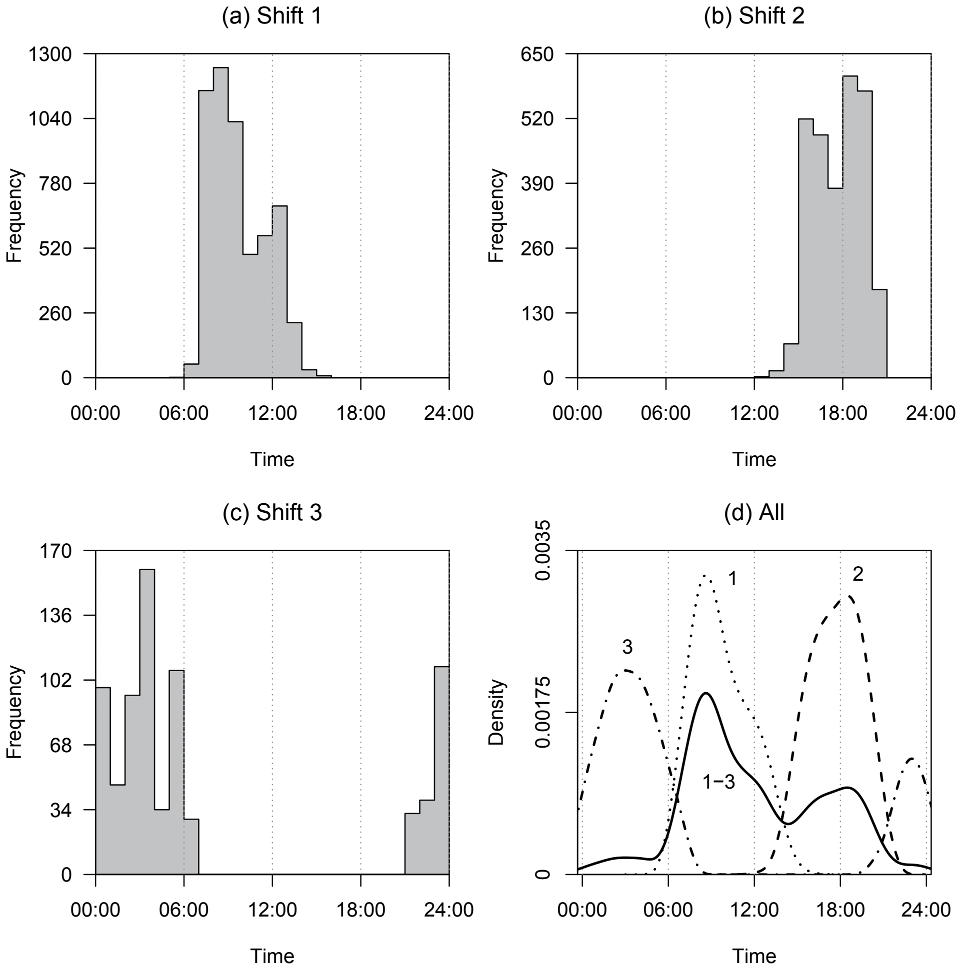

FIGURE 18 Home visit start times in one week data of November 2011. Morning shift (a), evening shift (b) and night shift (c). Approximate shift switching times–around 7:00, 14:00 and 21:00–visible in density plot (d). Includes all field workers and task types.

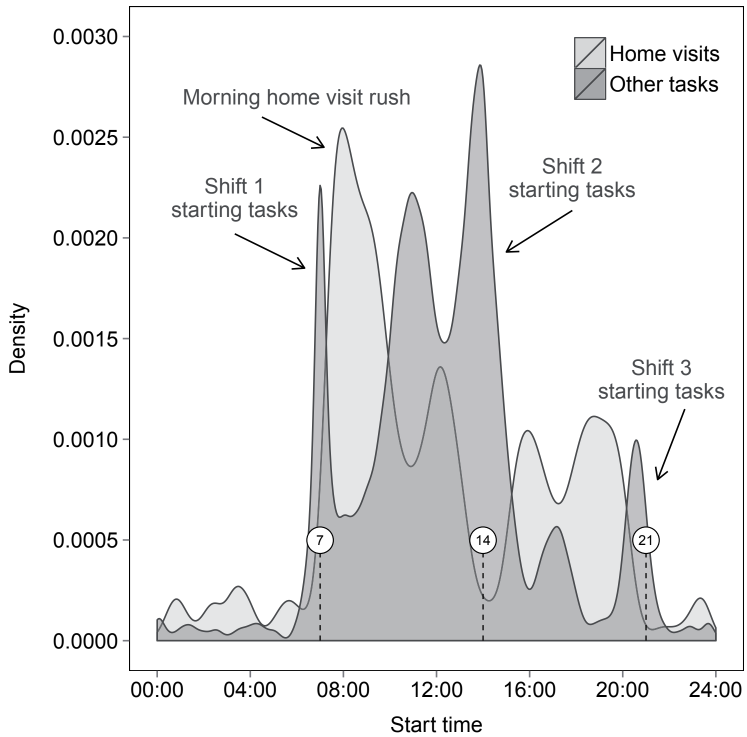

FIGURE 19 Time distribution between task types in higher detail in November 2011 one week data. Start time and task duration concentrations are represented for home visits in Figure 58, for other field tasks in Figure 59 and for office tasks in figure 60.

TABLE 7 Task types used in November 2011 one week data. See also Figures 20 and 21.

#	Task	Description	%
1	Shift start/end tasks	Picking up or returning keys etc.	14.8
2	Medication tasks	Making medication orders etc.	2.6
3	Customer meetings	Meetings with customer's family, doctors etc. at a hospital or home.	0.6
4	Computer tasks	Writing reports, emails etc. Since the beginning of 2011 a part of reporting can be done using mobile devices.	8.5
5	Laboratory visits	Transporting blood etc. samples to laboratory. Often contains waiting period in the laboratory.	0.3
6	Laundry	Laundry tasks taking place elsewhere than at customer's home, e.g. shared laundry room in an apartment building.	0.1
7	Shopping	Shopping for customers, e.g. visits to pharmacy. Groceries are usually handled as a separate support service.	0.7
8	Phone calls at office	Phone calls related to daily work.	1.4
9	Student supervision	Work related examinations by e.g. practical nurse students supervised by home care.	0.4
10	Bathing and sauna	Bathing and sauna tasks taking place in day centers, not at customer's home.	0.5
11	Workplace meetings	Mostly team meetings at the office.	2.2
12	Staff trainings	Usually taking place out of office, sometimes full day.	0.6
13	Breaks	Breaks required by law. Should take place at the office, in practice often elsewhere.	5.6
14	*Home visits*	*Home visits, both home health care and other home care.*	*41.7*
15	Other tasks	Miscellaneous tasks not in any other category.	5.9
16	Catering	Catering tasks, mostly at group homes or service homes.	0.1
17	Phone calls during transit	A task type added afterwards. Unplanned long phone calls made during transit, often requiring the worker to stop.	0.2
T	*Transit*	*Moving between addresses.*	*13.8*
	Total		100.0

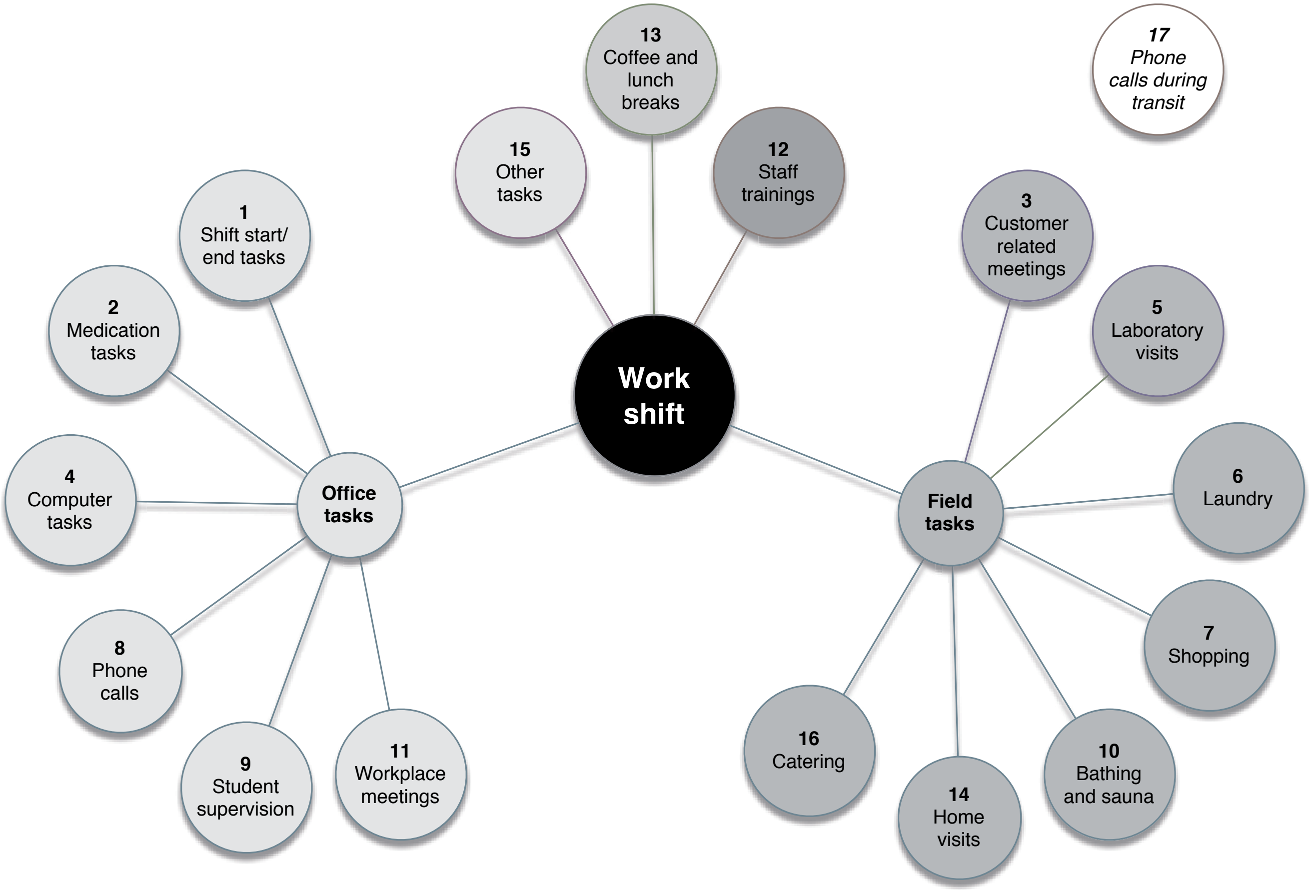

FIGURE 20 Task typed and categories used in November 2011 one week data. Many of the tasks can be roughly categorized to office and fields tasks.

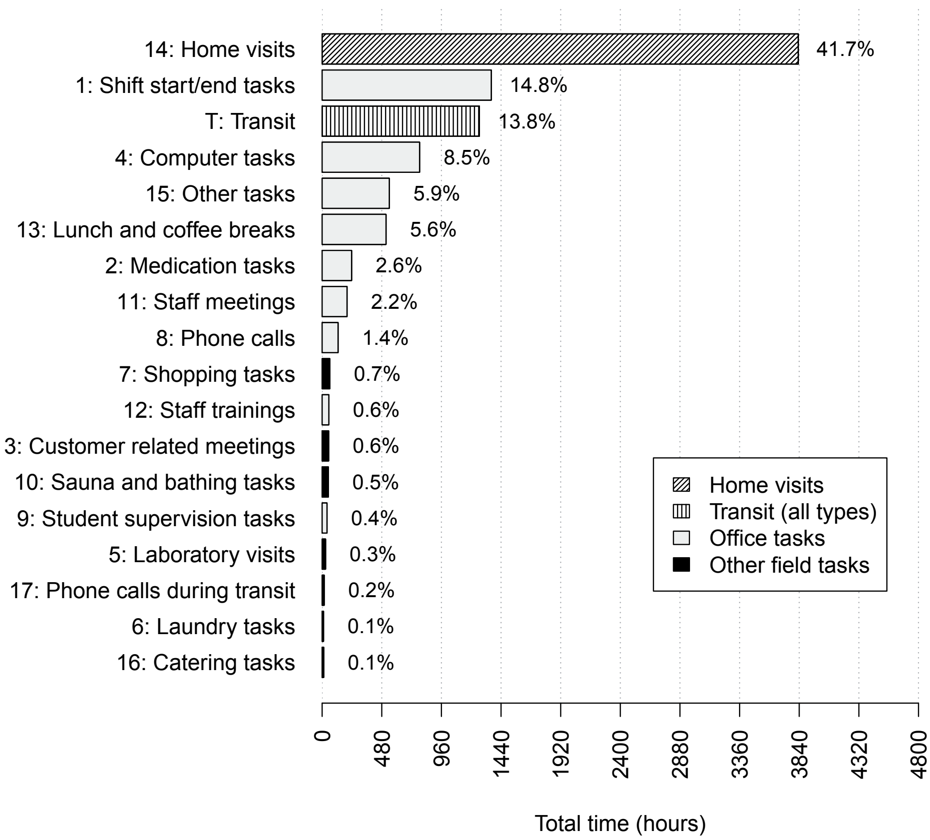

FIGURE 21 Time distribution between task types in November 2011 one week data. Task contents are described in Table 7.

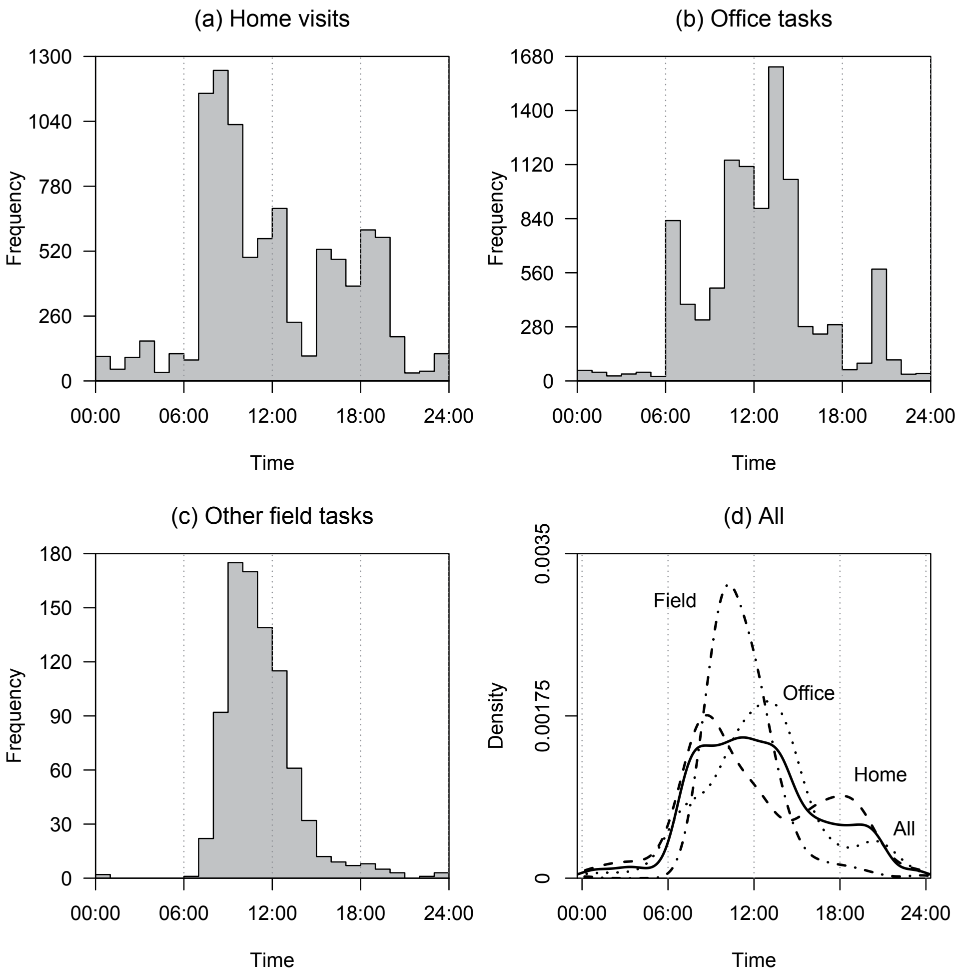

FIGURE 22 Task group start times in one week data of November 2011. Four teams working locally at service apartment buildings excluded.

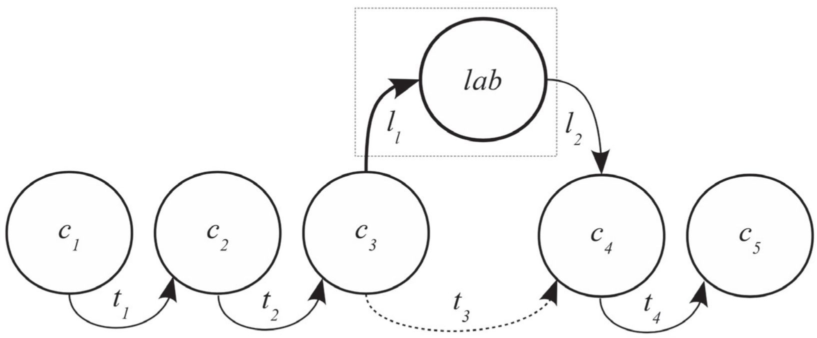

FIGURE 23 Laboratory visits between home visits.

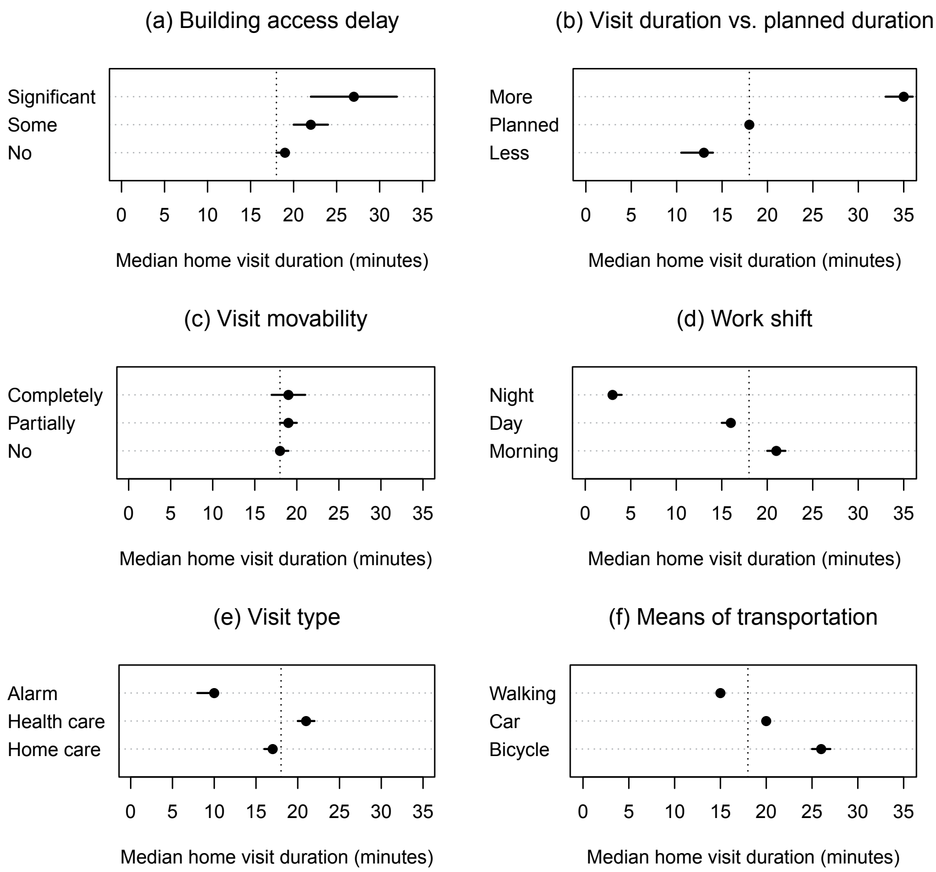

FIGURE 24 Median durations of home visits by category and 95% bootstrap confidence intervals.

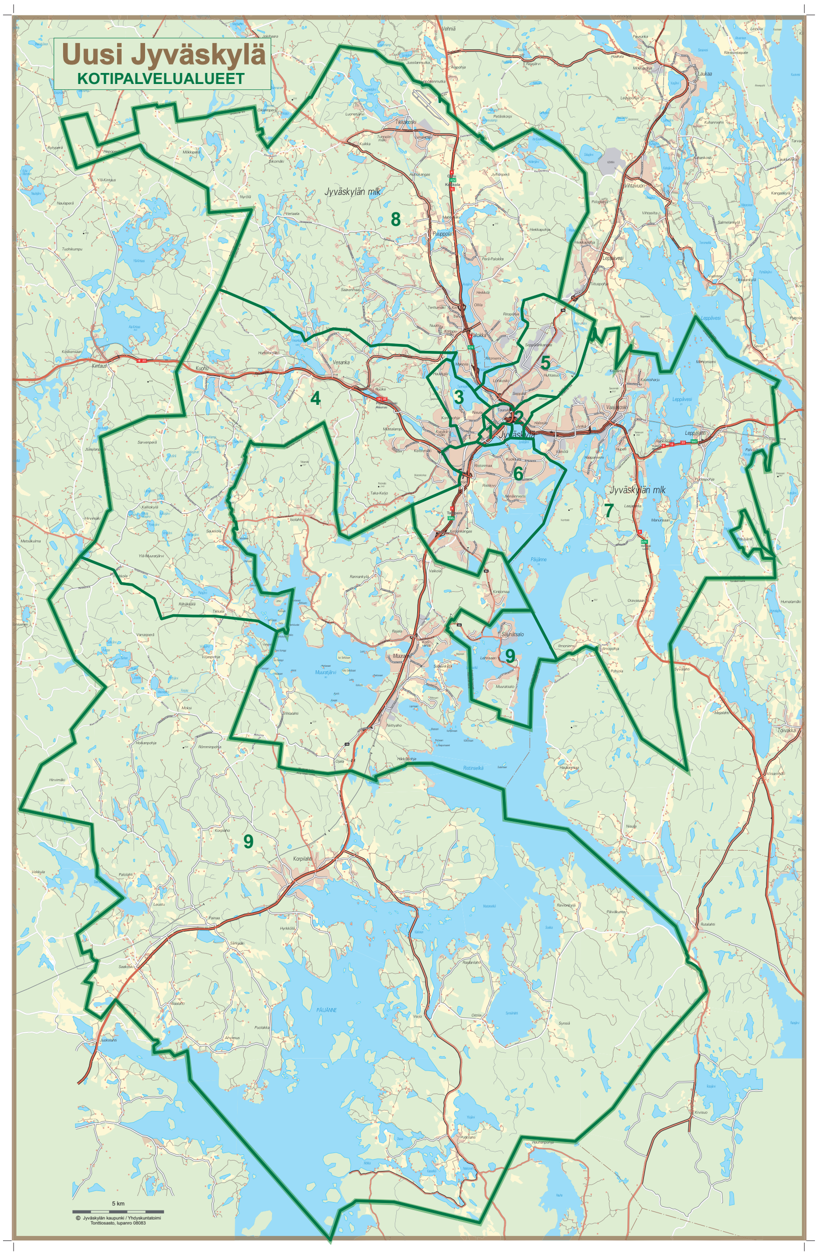

FIGURE 25 Home care service areas in Jyväskylä. Image used with permission from the Department of Social and Health Services of the City of Jyväskylä.

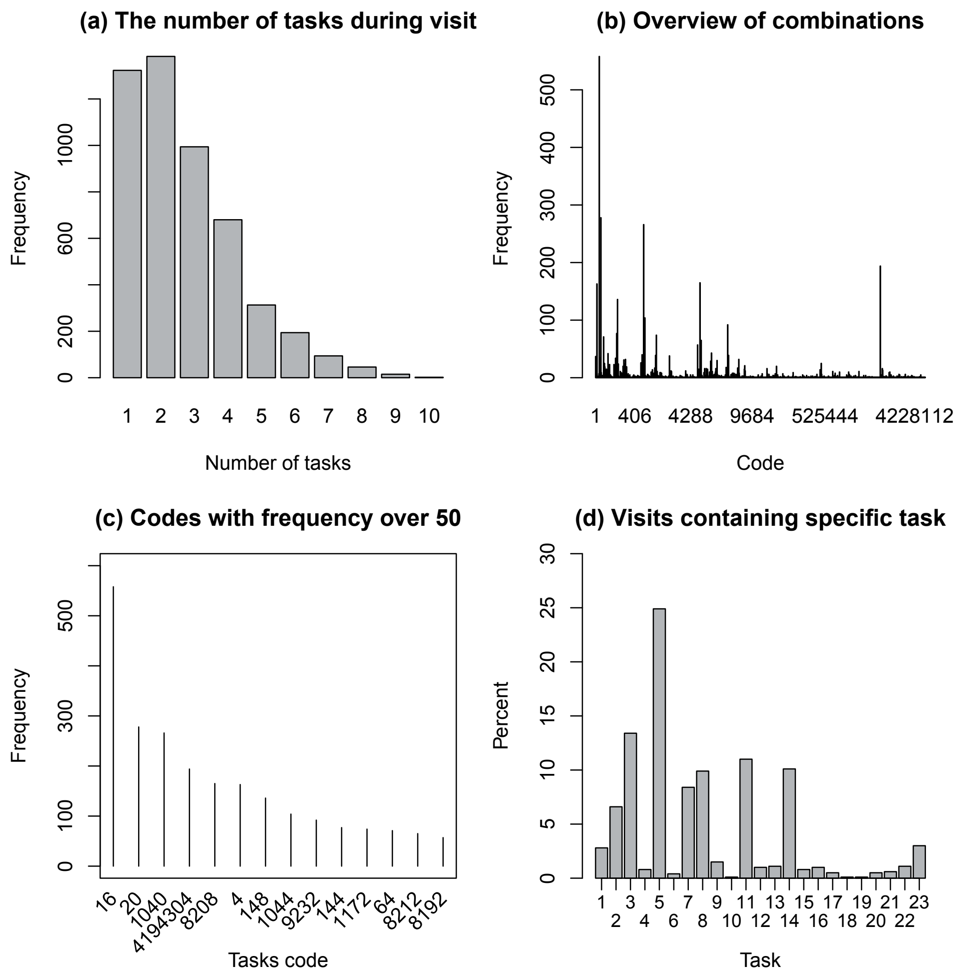

FIGURE 26 Breakdown of different tasks during home visits. See also Table 8 for single task codes (d) and Table 9 for combination codes (b & c).

TABLE 8 Task types during home visits (5044 visits). See also Figure 26 and Table 9.

Code	Description	Frequency	%
1	Lifting or moving a patient	387	2.8
2	Assisting in dressing	904	6.6
3	Heating and serving meals	1839	13.4
4	Assisting in eating, feeding	116	0.8
5	Giving medication and related tasks	3412	24.9
6	IV and fluid drips	56	0.4
7	Hygieny, bathing, WC assisting	1157	8.4
8	Cleaning of home	1359	9.9
9	Laundry and clothes	211	1.5
10	Heating, carrying firewood	7	0.1
11	Mental support	1512	11
12	Taking customer out, escorting to doctor etc.	140	1.0
13	Phone calls	147	1.1
14	Basic health care, lotions, blood pressure	1388	1.01
15	Taking laboratory samples	112	0.8
16	Wound care	142	1.0
17	Other nursing, e.g. removing stiches	66	0.5
18	Care plan (HOPASU) related tasks	17	0.1
19	RAI (patient care demand level) evaluation tasks	17	0.1
20	Filling forms and applications	71	0.5
21	Safety alarm check visit	82	0.6
22	Student guidance	148	1.1
23	Other, e.g. cooperation with family, safety etc.	411	3.0
	Total	13 701	100.0

TABLE 9 The most common task combinations during home visits (5044 visits in total of which the following comprise 42.6%). See also Figure 26 and Table 8 for task codes and descriptions.

Combination	Included tasks	Different tasks	Frequency	%
16	5	1	558	24.3
20	3, 5	2	278	12.1
1040	5, 11	2	266	11.6
4194304	23	1	194	8.4
8208	5, 14	2	165	7.2
4	3	1	163	7.1
148	3, 5, 8	3	136	5.9
1044	3, 5, 11	3	104	4.5
9232	5, 11, 14	3	92	4.0
144	5, 8	2	77	3.3
1172	3, 5, 8, 11	4	74	3.2
64	7	1	71	3.1
8212	3, 5, 14	3	65	2.8
8192	14	1	57	2.5
	Total	Avg. 2	2300	100.0

TABLE 10 Driven kilometers per day and shift in November 2011 one week data.

	Shift			
	1	2	3	Total
Monday	1 855	458	76	2 389
Tuesday	2 024	542	131	2 697
Wednesday	1 957	477	112	2 546
Thursday	1 900	456	115	2 471
Friday	1 691	563	107	2 361
Saturday	709	449	123	1 281
Sunday	717	468	115	1 300
Total	10 853	3 413	779	15 045

5 OPTIMIZATION EXPERIMENTS

The following optimization experiments demonstrate the approximate maximum travel time and distance saving achievable by VRP optimization in the case of the City of Jyväskylä's home care data.

5.1 Problem definition

The only task types of the 17 types in the data (Table 7) route and work-shift optimization can affect is transit and planning of work. The content of other task types is actual daily work that is unaffected by optimization.[1] If the transit and planning times, 13% and 18% respectively, could be eliminated completely a total of 31% of working time could be saved. This hard limit cannot be reached in reality as the transit time can never be eliminated completely. A big part of the planning time could be eliminated by using automated optimization system for creating worker rosters instead of the current manual planning. Some time would still be required for miscellaneous work planning tasks, meetings concerning home care clients' current situations and other tasks that required human workers.

5.2 Jyväskylä region street network

The home care in Jyväskylä operates in a mixed environment ranging from the city centre and suburbs to rural areas of the two former municipalities now incorporated to Jyväskylä.

The speed limits of the local street network (Figure 27) were used as precisely as possible. The map data used in optimization contains nine different road types ranging from small unpaved local roads to major freeways. In some

[1] It may be possible to improve some of these other tasks by other means irrelevant to route and work-shift optimization.

cases these do not match the road types in actual speed limit map. In a small number of roads exact matching of speed limits was not possible. This should not have any significant effect to the results.

Morning and afternoon rush hours were configured to 7:30–8:30 and 15:30–16:30 in order to reduce the driving speed during these times.

Because the data was collected during fall time, seasonal driving condition based adjustments were not needed. In operational optimization the maximum driving speeds may have to be reduced further during snowy and dark winter time.

5.3 Analysis of transit delays between parking lots and customers

Route optimization softwares generally calculate driving times based on street addresses. In practice home care workers utilizing cars have to find a suitable parking lot—which may be located at some distance from the target address—park the car, pick up required supplies and walk to the customer's home. In the case of apartment buildings the worker may have to wait for an elevator or take time climbing stairs. If the customer is able to move, even slowly, the worker also has to wait for the customer to open the door. Generally the home care has a key to a customer's home only if the customer is bedbound.

Current route optimization softwares usually cannot discern different building types from map data but different approximate delays can be inserted when a new customer is added to an optimization system. Although separate delays for different addresses could not be used in the optimization experiments at this time, a small data was collected for estimating the transit delay between parking lots and customer addresses.

A total of 104 home care customer addresses were selected by random sampling. Home care workers visiting these addresses measured the walking time to a customer and back in seconds. The time measured does not include possible waiting time at the customer's door or time required for picking up supplies. Buildings were classified into three categories: single family houses (Type I), row houses and balcony access blocks (Type II), and (high-rise) apartment and condominium blocks[2] (Type III).

5.3.1 Access delays by building type

Walking time distributions between building types are statistically different.[3] Type I buildings, usually with their own parking space which eliminates the need of walking, differ from both Type II and Type III buildings.[4] The difference between

[2] Usually 6–10 floors, or in some parts of the city 12–15 floors high.

[3] Kruskal-Wallis rank sum test, H = 51.9453, df = 2, $p < 0.001$.

[4] Kruskal-Wallis pairwise comparison, H = 34.55729, df = 1, $p < 0.001$ (Type I vs. Type II) and H = 49.38021, df = 1, $p < 0.001$ (Type I vs. Type III).

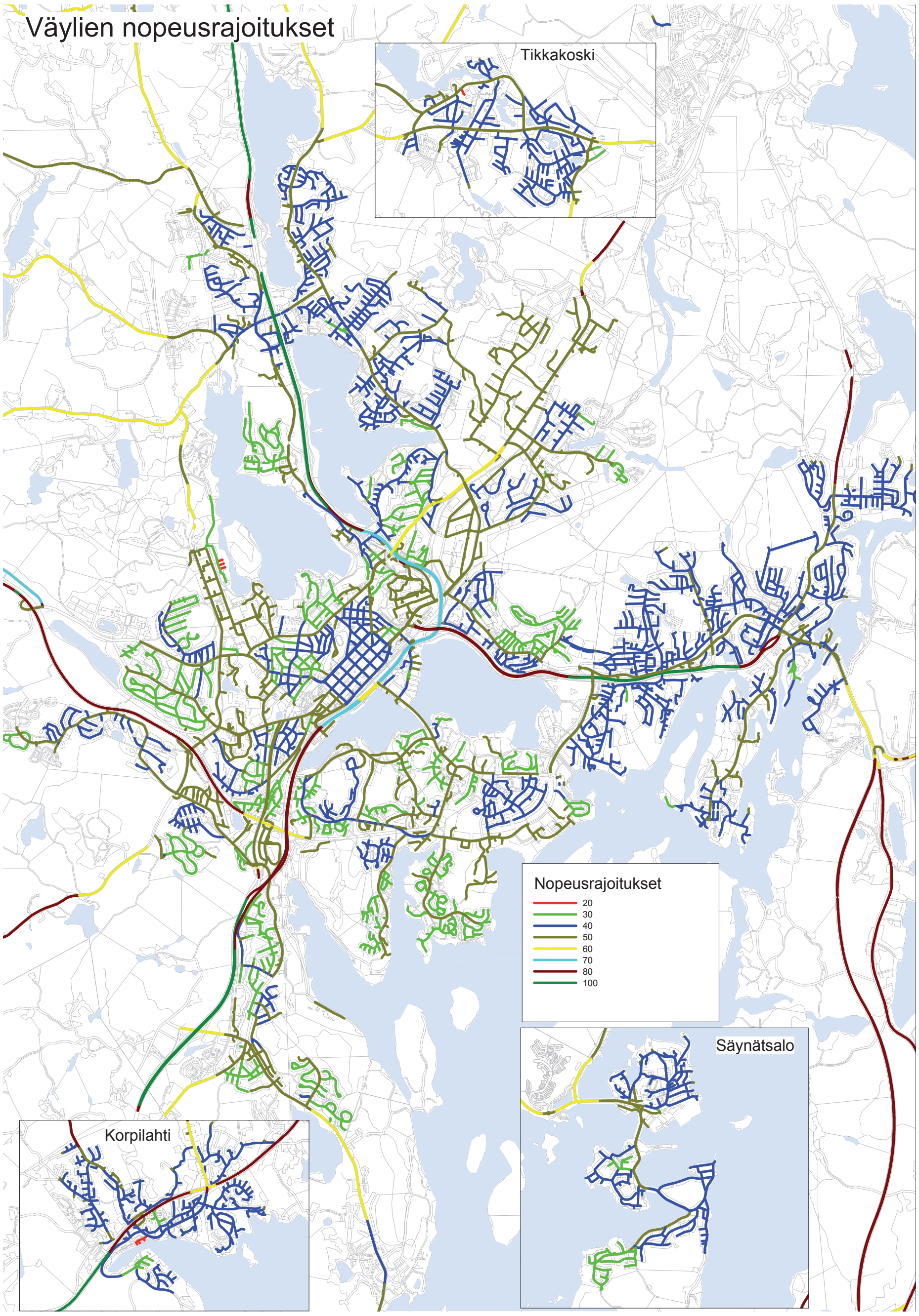

FIGURE 27 Speed limits in Jyväskylä (kilometers per hour). Image used with permission from the Department of Urban Design and Town Planning of the City of Jyväskylä (Jyväskylän kaupunki / Tonttituotanto, lupa nro. 12022).

TABLE 11 Access delays (two-way) in seconds by building type. 95% confidence intervals are based on Bias-corrected and accelerated bootstrap resampling (BCa, 10 000 replicates). See also Figure 54.

	Building type				
Statistic	All types	Type I	Type II	Type III	Type II+III
N	104	32	24	48	72
%	100	30.8	23	46.2	69.2
Q_2	96.5	40.5	102.5	138.5	131.5
$\bar{x}$	109	44.2	112.8	150.3	137.8
SD	72.9	18.3	64.2	69.3	69.5
SEM	7.15	3.24	13.11	10	8.19
Shapiro-Wilk P	< 0.001	0.087	0.72	< 0.001	0.024
Anderson-Darling P	< 0.001	0.16	0.83	< 0.014	0.143
$\bar{x}$ 95% CI	96–124	39–51	88–139	133–172	123–155
Q_2 95% CI	74–118	34–48	74–144	120–159	113–152

Type II and Type III buildings was not statistically significant, thus they can be treated as one group.[5] The median delay was 40.5 seconds for Type I buildings and 131.5 seconds for Type II and III buildings. The data and results are summarised in Table 11 and visualized in Figure 54.

5.3.2 Total time needed for walking

In November 2011 49.1% of visits to customers were made by car, 39.5% by feet, 7.3% by bicycle and 4.1% were left without answer (Figure 55(a)). Assuming that approximately 50% of home visits are made by car and 30% of the visiting addresses belong to Type I category and 70% to Type II+III category (Table 11), the walking time between parking lots and customers' homes can be estimated to be approximately 21 hours, or nearly three 7.5 hour shifts per day. During weekends the daily walking time is approximately 15 hours or two shifts per day. During one week approximately 18 shifts (936 shifts per year) worth of working time is used for walking between parking lots and customer addresses.[6]

More accurate estimate can be calculated using bootstrap resampling methods. A 95% confidence interval using non-parametric bootstrap (250 000 replicates) is 902–1000 shifts (6777–7504 hours) per year. Parametric bootstrap[7] (250 000 replicates and three building types) gives confidence interval of 950–1027 shifts (7115–7701 hours) per year.

These estimates do not include possible waiting time at customer's door

5 Kruskal-Wallis pairwise comparison, $H = 14.82292$, $df = 1$, $p = 0.148$.

6 In the November 2011 one week data this time is included in the transit time.

7 Although visually nearly normal, some subsets of the data are not stricly normally distributed according to Shapiro-Wilk and Anderson-Darling tests for normality (Table 11).

or time needed for picking up or packing supplies. Similar walking delays are also expected during other fields visits which were not included in the previous estimates or delay data. It should also be noted that the data was collected in summertime (June 2012). The walking time is expected to be higher during winter months due to snow and ice.

5.4 Planning of optimization scenarios

The following optimization scenarios are based on shifts 1 and 2 (which cover 95% of the tasks) of the November 2011 one week data. The aim of the optimization experiments was to find out the maximum possible saving in terms of travel time and distance achievable by a high-quality VRP solver when many real life constraints of home care are relaxed. In reality operational optimization of home care requires more constraints and the results should be considered as the upper limit that can be reached by optimization.

Planning of optimization scenarios and constraints can be a very complicated task. All optimization scenarios in the following result tables and visualizations contain many compromises in time window and work shift related parameters.[8] Time window settings and other parameters settings are based on discussions with the home care services of the City of Jyväskylä and attempt to be as realistic as was possible to define in the optimization software used so that decrease in transit kilometers could be achieved.

The optimization scenarios and results do not attempt to represent operational level realistic optimization configurations but are at best compromises for demonstrating the difficulties in building plausible optimization configurations for home care work. Despite the many compromises in the optimization scenarios, the results roughly demonstrate the improvement that is in principle available by optimization, and also the the difficulty of balancing the parameters so that the optimization leads to a reasonable solution in terms of both in route lenghts as well as required number of work shifts. It should also be noted that the used optimization software is not primarily intended for home care type of activities and thus the scenarios cannot include all the details needed for home care.

5.4.1 Optimization constraints

Each home care customer has a small group of personal home care workers. In practice this is implemented by dividing the home care service areas further to smaller home care teams. Each team takes care of its own customers which ensures that each customer gets help from familiar workers. In the following optimization experiments this is the main constraint. In reality a home visit is either home health care (requiring registered nurse or public health nurse) or other

[8] Here the term *work shift* refers to the number of workers in duty.

home care (requiring licensed practical nurse or aide). Because a large number of possible work shifts starting and ending at a slightly different times was configured to the optimization software, using two worker categories did not affect the results.

Time windows for different task types was varied in different optimization scenarios and the proportion of fixed time critical and more freely movable tasks was varied as described in result tables and Table 12.

5.5 Optimization results

Optimization scenarios are described in Table 12 and optimization results for each scenario are represented in Tables 14–31. The Table 13 contains real data values. Visualizations of the results are represented in Figures 28–39.

In most cases the number of work shifts (workers on duty) required is larger than the number of work shifts that were present in the actual data. In order to configure the optimization runs to yield significant savings in kilometers driven it was necessarily to weight the cost of driven kilometers, time used for transit, and the number of work shifts so that a slight increase in the number of work

TABLE 12 Optimization scenarios, time windows and margins. Work shift related configurations are described in corresponding result tables.

	Time window or margin in scenarios		
Task	A/B/D	F	E/G
1 – Day start/end tasks	+/- 20 min	+/- 10 min	+/- 20 min
2 – Medic. distribution	+/- 6 h	+/- 4 h	+/- 6 h
3 – Customer meetings	+/- 10 m	+/- 5 m	+/- 10 min
4 – Computer tasks	+/- 6 h	+/- 4 h	+/- 6 h
5 – Laboratory visits	+/- 1 h	+/- 10 min	+/- 1 h
6 – Laundry	+/- 6 h	+/- 4 h	+/- 6 h
7 – Shopping	+/- 6 h	8:00–16:00	07:00–19:00
8 – Phone calls	+/- 6 h	+/- 4 h	+/- 6 h
9 – Student supervision	+/- 6 h	8:00–15:00	07:00–15:00
10 – Bathing	+/- 6 h	8:00–13:00	08:00-14:00
11 – Work meetings	+/- 20 min	+/- 10 m	+/- 20 min
12 – Staff trainings	+/- 20 min	+/- 10 m	+/- 20 min
13 – Breaks	+/- 2 h	+/- 1 h	+/- 2 h
14 – Home visits *	+/- 6 h	+/- 4 h	+/- 6 h
15 – Miscellaneous	+/- 6 h	+/- 4 h	+/- 6 h
16 – Catering	+/- 4 h	7:00–21:00	07:00–21:00
** Critical home visits (of 14)*	*+/- 20 min*	*+/- 10 min*	*+/- 10 min*

shifts was allowed. This demonstrates the difficulty of balancing the optimization constraints. In real life it is questionable if the decreased number of kilometers driven and time spend in transit would compensate the required additional work shifts. To get balanced results that contain approximately the correct number of work shifts but also significant savings in transit would probably require more home care optimization specific fine tuning in the optimization algorithms used.

The results are intentionally reported only as distance and time savings. Actual economical savings are not calculated because the optimization experiments are not directly applicable to real-life operational use. Also the results of the survey (Chapter 6) sent to home organizations support the conclusion that many of the route optimization solutions currently available for home care use may not be mature enough to produce significant savings in practice.

5.5.1 Time and driving distance savings

In all scenarios the route optimization was able to produce solutions that offer significant driving time and distance savings. The minimum and maximum values are represented in Figure 40. In most cases the number of required work shifts (workers) was increased as well. In practice the total expenses might not be lower that in unoptimized operations due to increased worker expenses. As the software used for the optimization experiments is not intended for home care, it lacks the necessary constraint and adjustment possibilities needed for operational home care optimization.

5.5.2 Limitations of software

The software used for the optimization experiments is intended for delivery logistics optimization and did not contain precise constraint possibilities that are needed for home care operations. Only constraints such as basic time windows and worker teams could be used. This may have caused the results (driving time and kilometers) to be more optimistic than what could be achieved if all realistic constraints are included in an operational home care optimization system. On the other hand the increase in work shifts could have been lower which home care specific functionality as well.

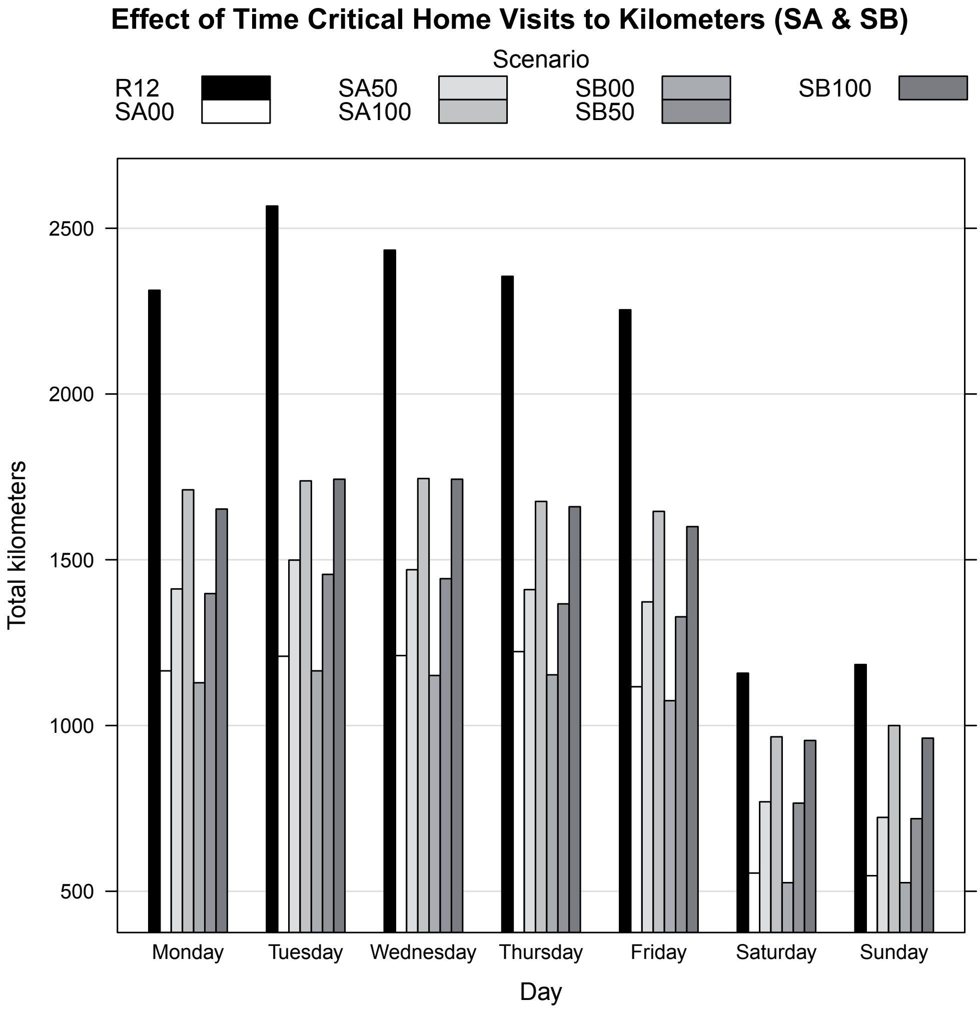

FIGURE 28 Optimization results, kilometers in scenarios SA & SB (number refers to the percentage of fixed home visits, 0%, 50% or 100%). R12 is the original data.

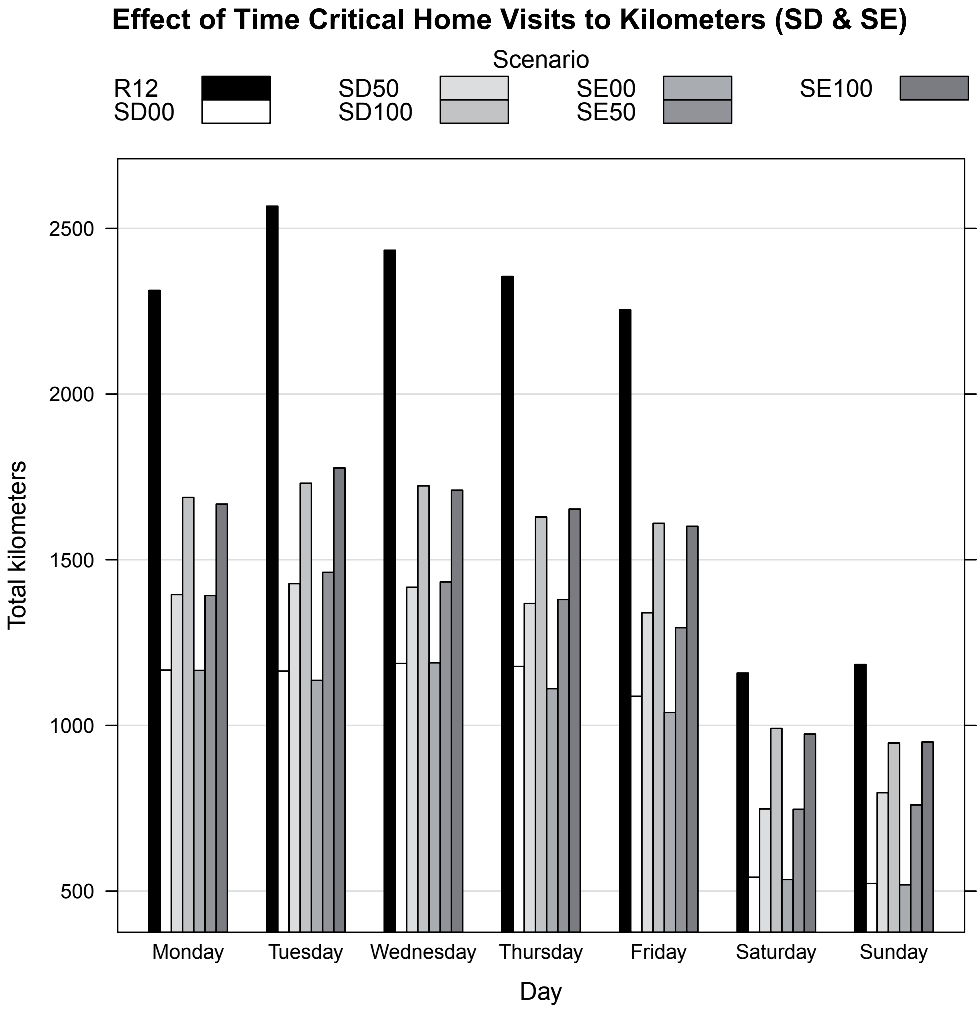

FIGURE 29 Optimization results, kilometers in scenarios SD & SE (number refers to the percentage of fixed home visits, 0%, 50% or 100%). R12 is the original data.

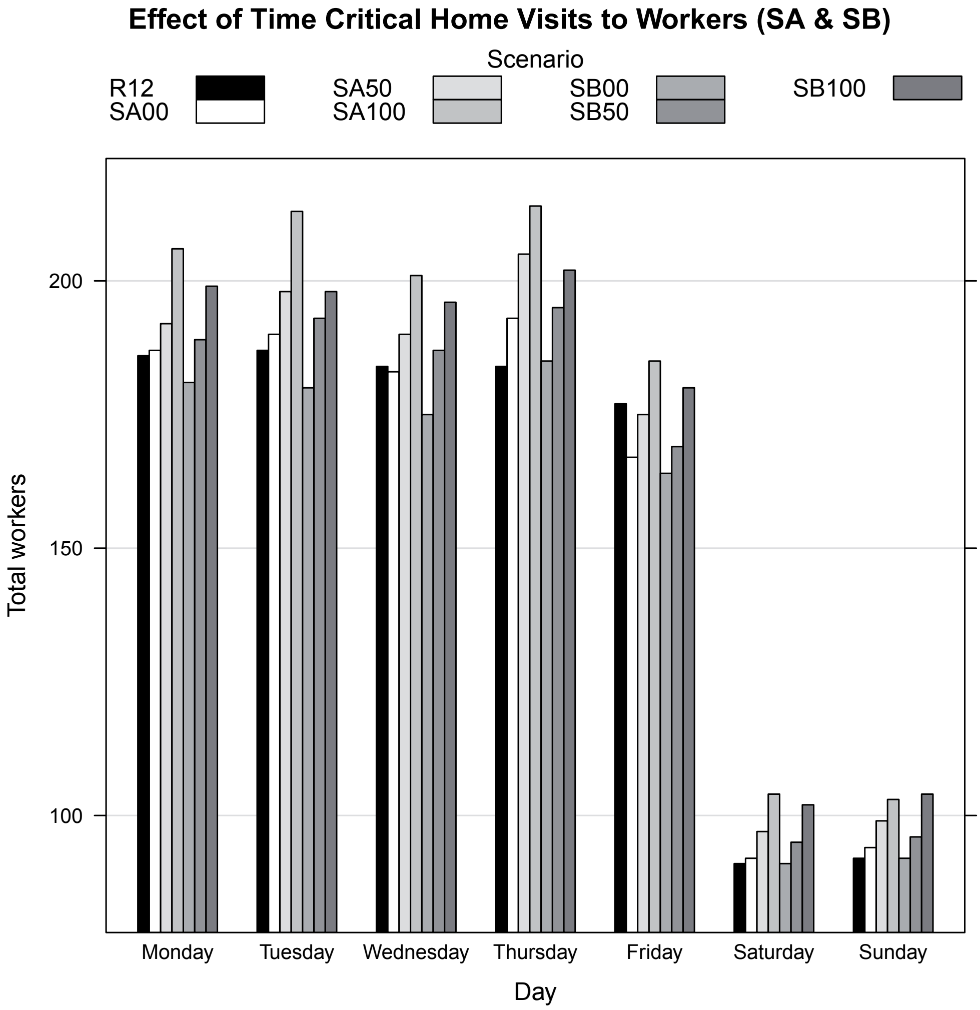

FIGURE 30 Optimization results, workers in scenarios SA & SB (number refers to the percentage of fixed home visits, 0%, 50% or 100%). R12 is the original data.

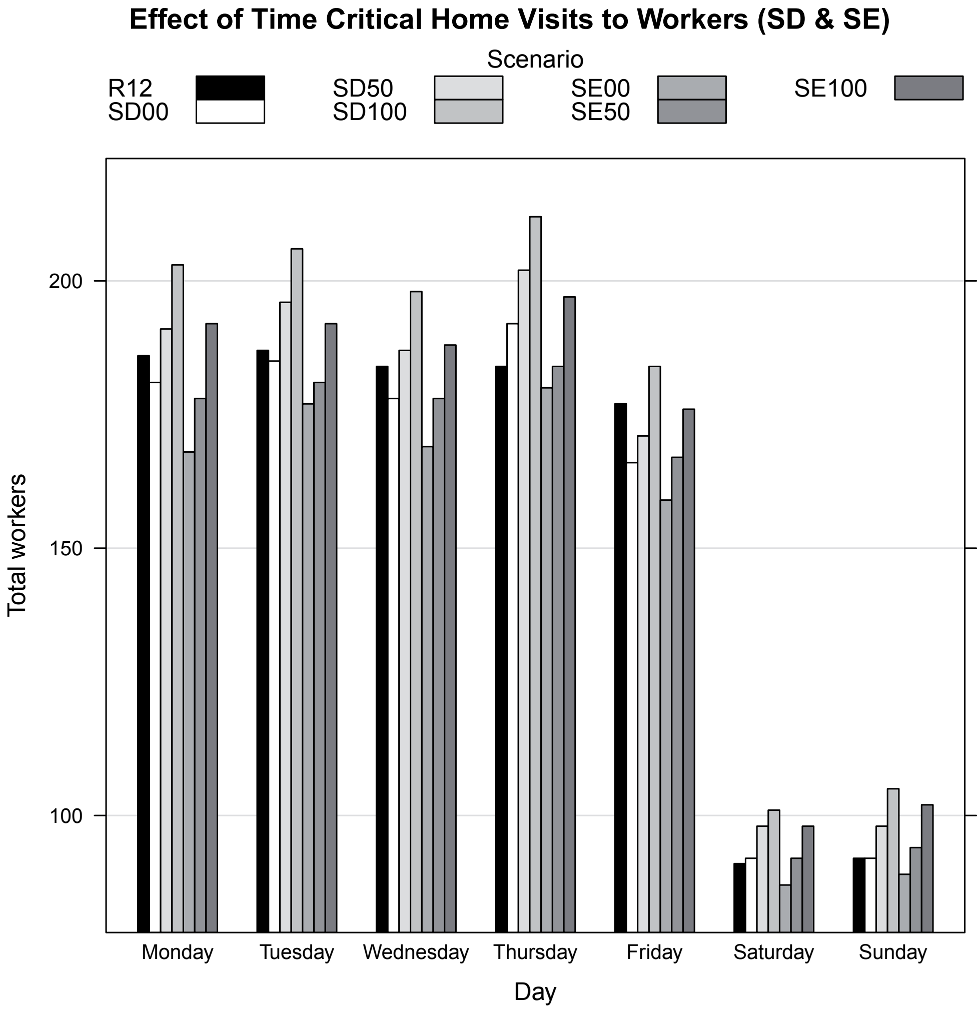

FIGURE 31 Optimization results, workers in scenarios SD & SE (number refers to the percentage of fixed home visits, 0%, 50% or 100%). R12 is the original data.

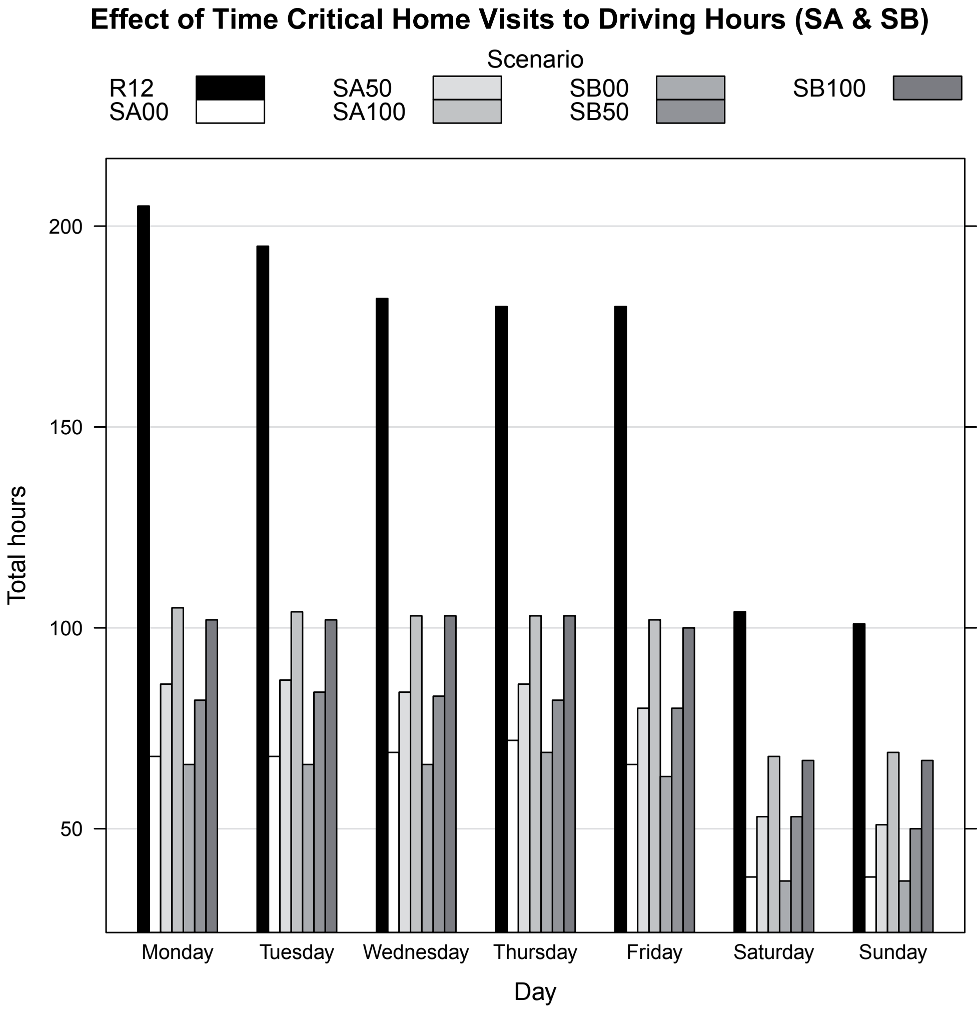

FIGURE 32 Optimization results, driving hours in scenarios SA & SB (number refers to the percentage of fixed home visits, 0%, 50% or 100%). R12 is the original data.

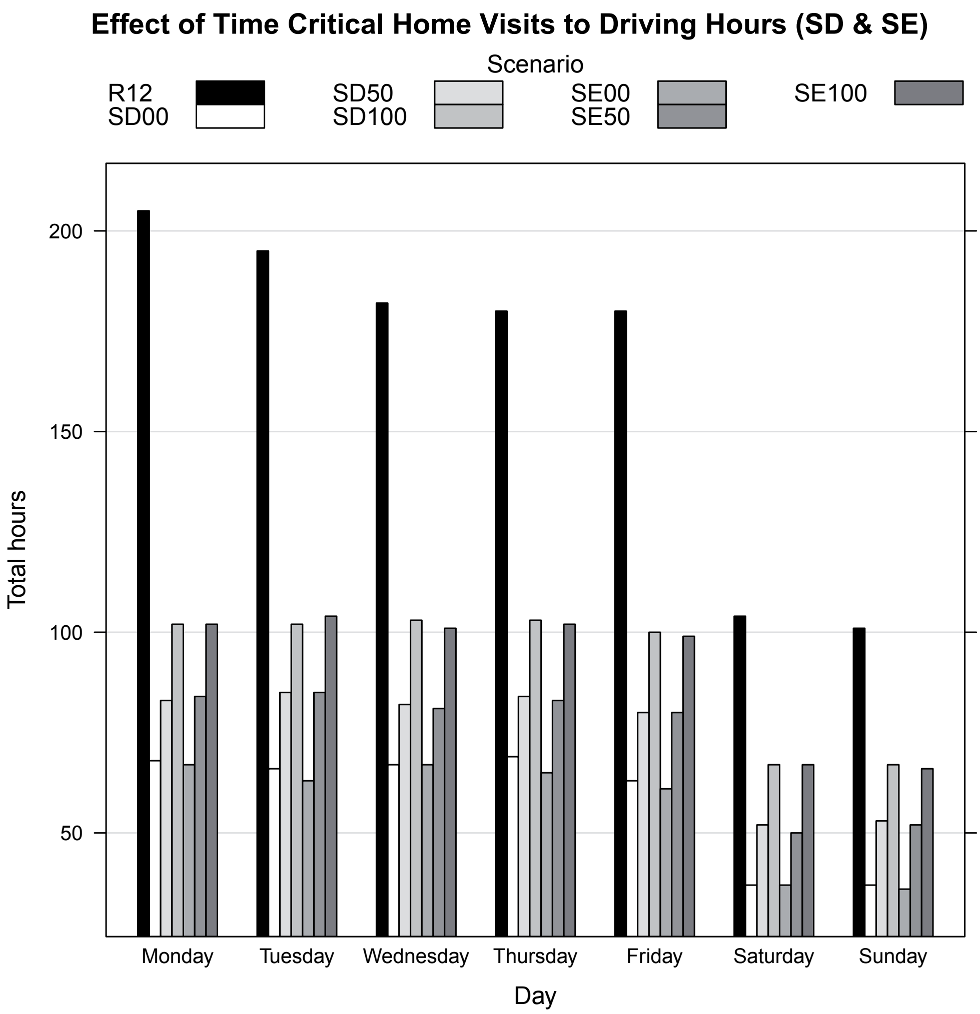

FIGURE 33 Optimization results, driving hours in scenarios SD & SE (number refers to the percentage of fixed home visits, 0%, 50% or 100%). R12 is the original data.

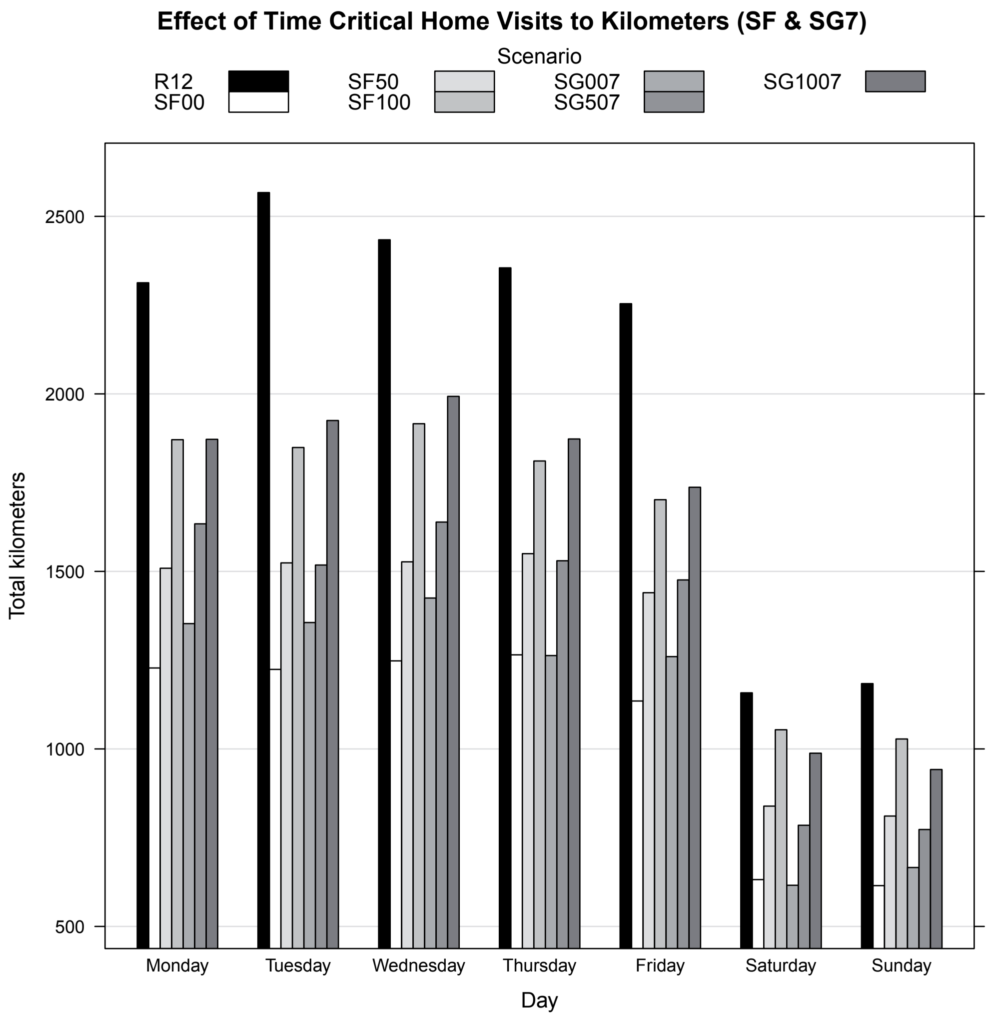

FIGURE 34 Optimization results, kilometers in scenarios SF & SG7 (first number refers to the percentage of fixed home visits, 0%, 50% or 100%, second number to the length of work shifts, 7–9h). R12 is the original data.

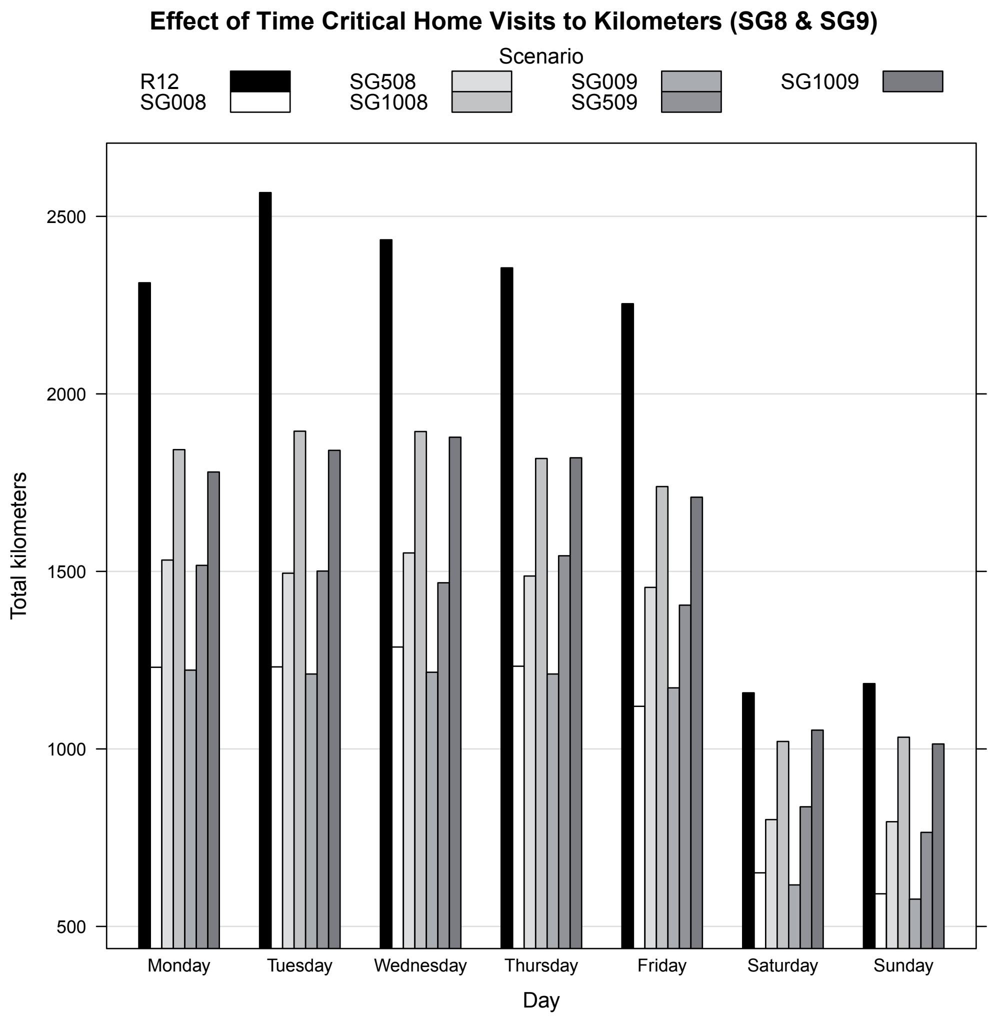

FIGURE 35 Optimization results, kilometers in scenarios SG8 & SG9 (first number refers to the percentage of fixed home visits, 0%, 50% or 100%, second number to the length of work shifts, 7–9h). R12 is the original data.

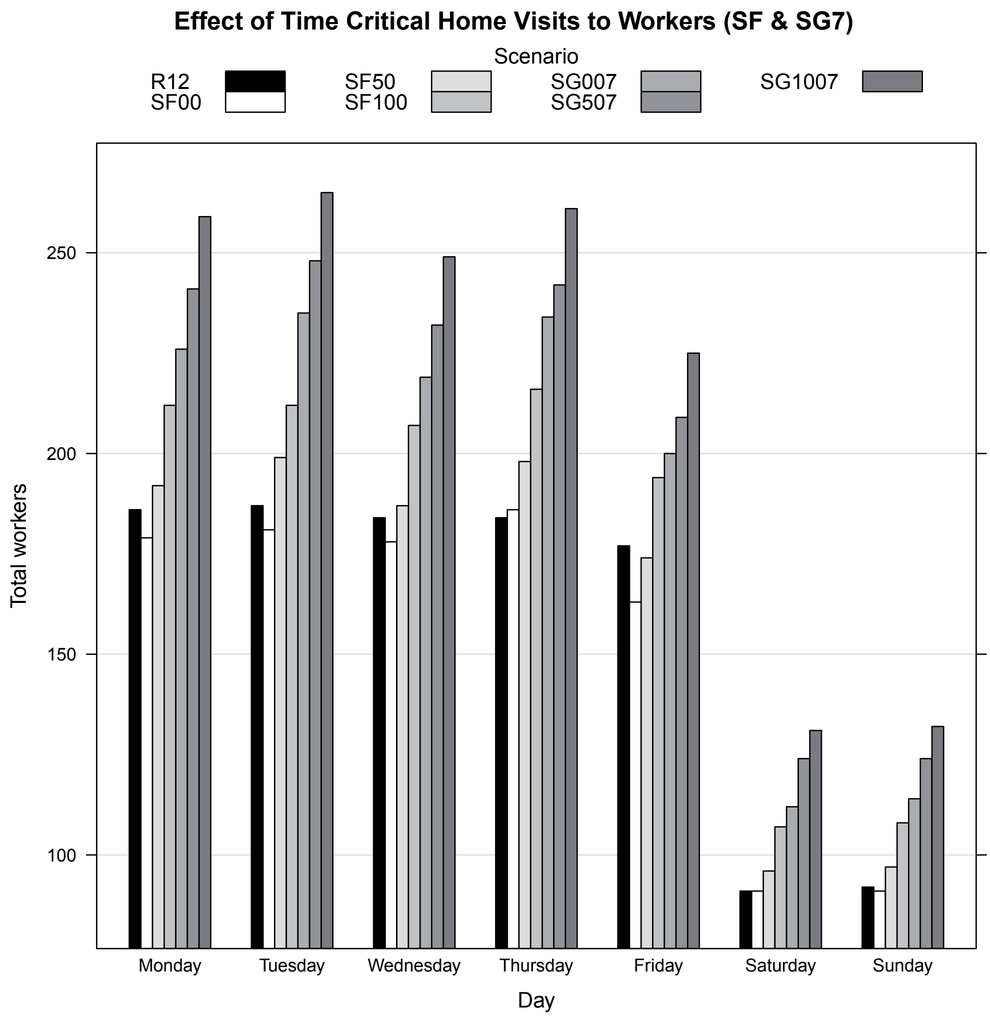

FIGURE 36 Optimization results, workers in scenarios SF & SG7 (first number refers to the percentage of fixed home visits, 0%, 50% or 100%, second number to the length of work shifts, 7–9h). R12 is the original data.

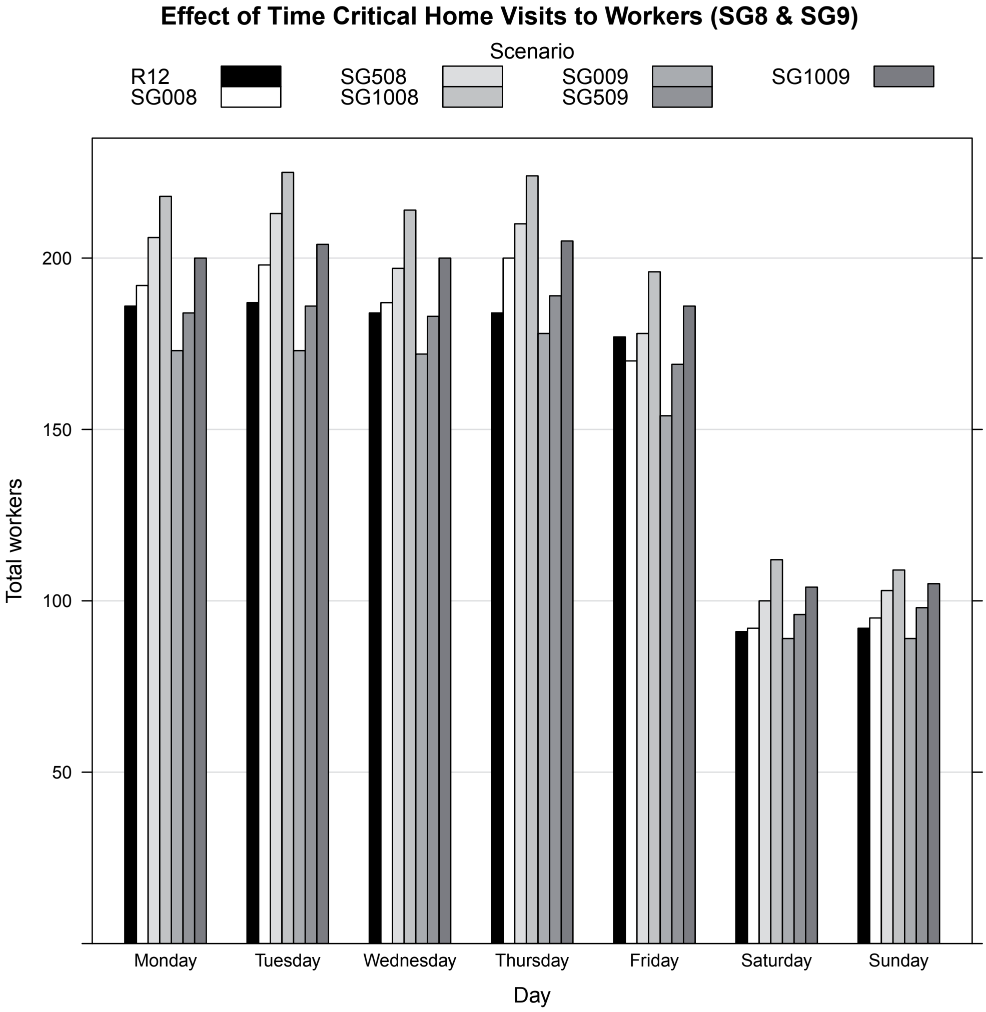

FIGURE 37 Optimization results, workers in scenarios SG8 & SG9 (first number refers to the percentage of fixed home visits, 0%, 50% or 100%, second number to the length of work shifts, 7–9h). R12 is the original data.

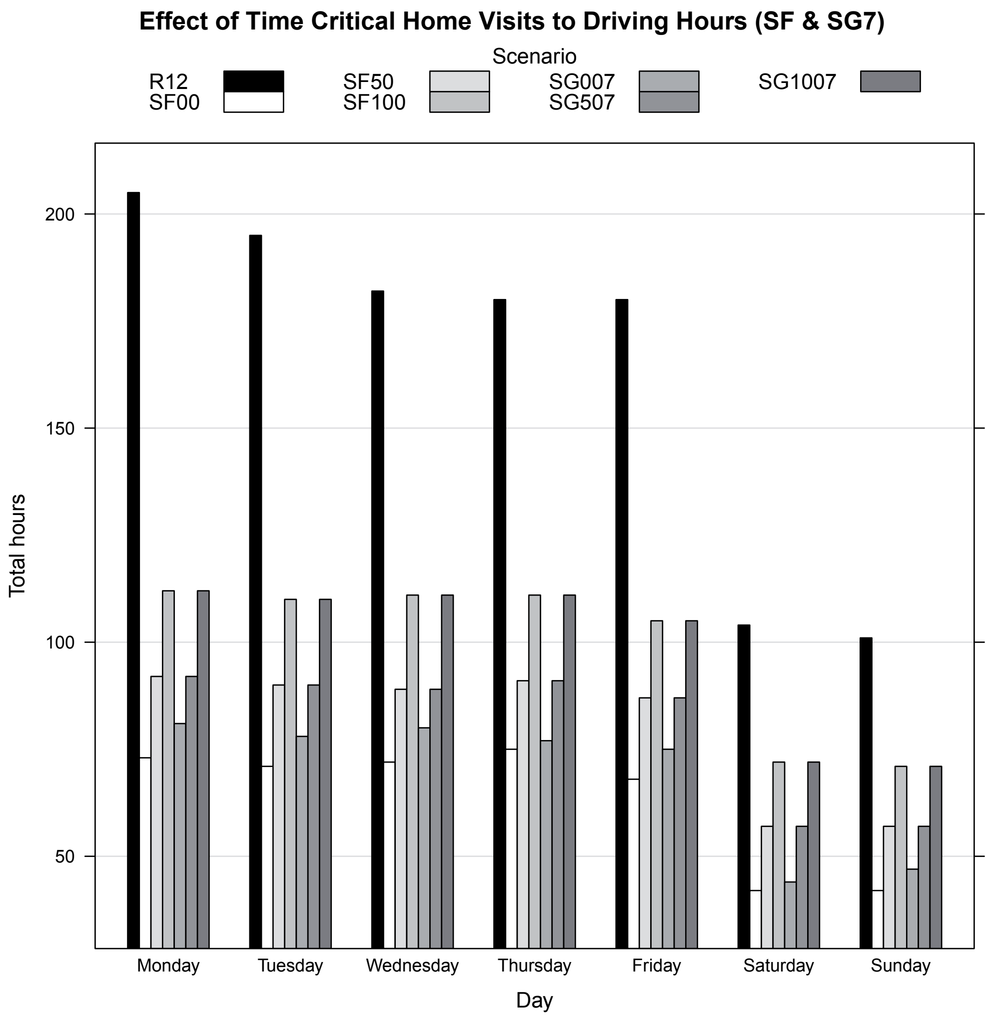

FIGURE 38 Optimization results, workers in scenarios SF & SG7 (first number refers to the percentage of fixed home visits, 0%, 50% or 100%, second number to the length of work shifts, 7–9h). R12 is the original data.

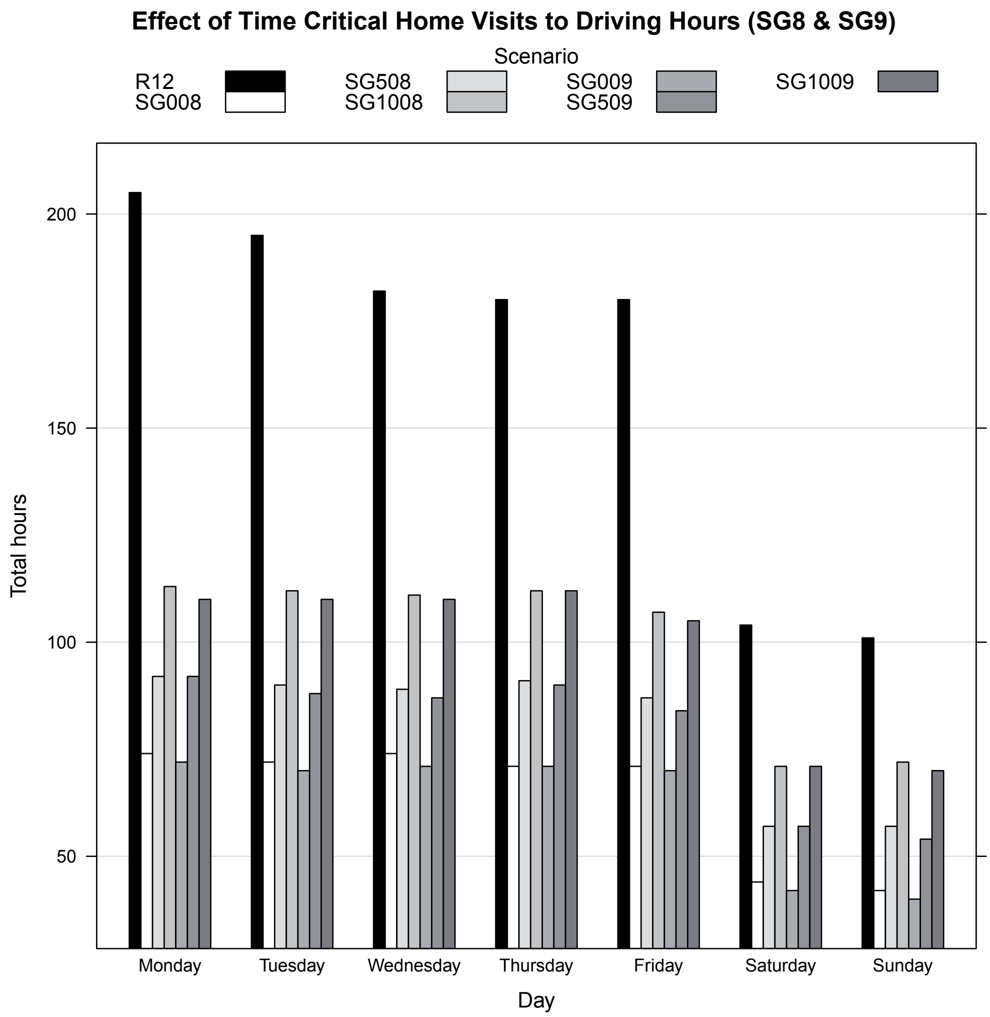

FIGURE 39 Optimization results, workers in scenarios SG8 & SG9 (first number refers to the percentage of fixed home visits, 0%, 50% or 100%, second number to the length of work shifts, 7–9h). R12 is the original data.

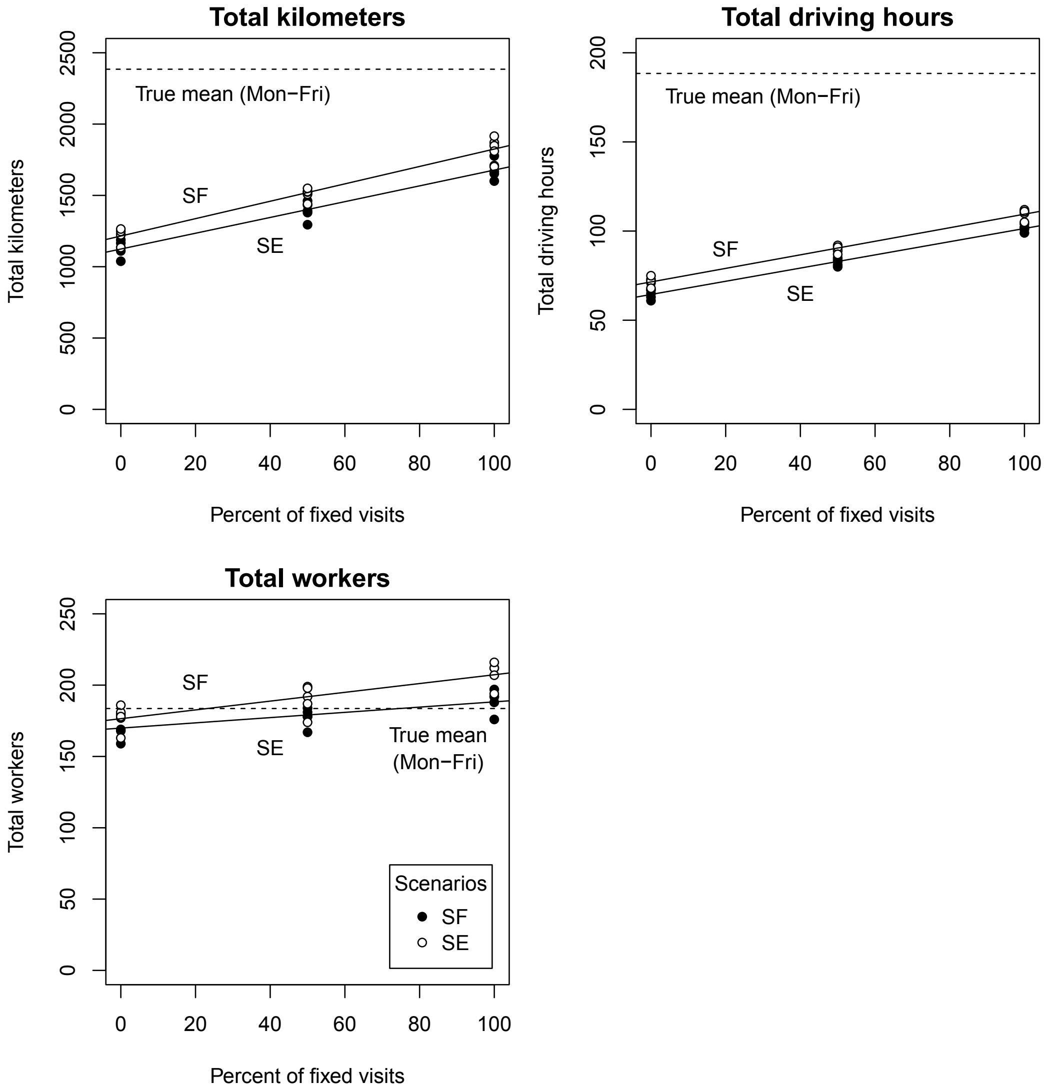

FIGURE 40 Regressions for scenarios with minimum (scenario SF) and maximum (scenario SE) savings–the effect of the proportion of fixed time home visits in contrast to home visits with more time margin allowed. The rest of the scenarios are omitted for clarity as they lie in between the two scenarios depicted in the figures and have very little variation.

TABLE 13 Real data values.

Scenario	Real values from November 2011 one week data for shifts 1 and 2. Km column includes only kilometers driven by car. Transit time includes all means of transportation (car, bicycle, walking, bus). Drive time (in hours) includes only driving time by car (slight inaccuracies due to missing values possible).						
Day	**Addresses**	**Workers**	**Km**	**Transit time**	**Drive time**	**Home Visit time**	**Total Time**
Monday	3055	186	2313	205	106	607	1244
Tuesday	3037	187	2567	195	109	578	1262
Wednesday	3031	184	2434	182	103	588	1214
Thursday	2970	184	2355	180	98	567	1263
Friday	2828	177	2254	180	101	543	1118
Saturday	1716	91	1158	104	58	337	582
Sunday	1719	92	1184	101	58	341	587
Total	18356	1101	14265	1147	633	3561	7293

TABLE 14 Scenario SA00.

Scenario *SA00*	0% of home visits with +/- 10 min time window. All transportation types included, without service apartments teams, without catering, no worker title separation, team constraints were in use.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	181	1205.7	70:49	1243:57	50.37%	100.54%	33.17%
Tuesday	3037	183	1262.8	69:32	1262:23	47.10%	101.60%	34.87%
Wednesday	3031	176	1225.2	69:53	1214:00	49.75%	99.46%	37.91%
Thursday	2970	188	1199.7	70:35	1263:28	51.93%	104.89%	40.00%
Friday	2828	164	1114.7	65:05	1117:58	49.56%	94.35%	36.67%
Saturday	1716	91	542.5	38:27	581:36	47.93%	101.10%	36.54%
Sunday	1719	91	527.5	37:18	587:05	46.20%	102.17%	37.62%
Total	18351	1074	7078.1	421:0	7270:0	$\bar{x} = 49.26\%$	$\bar{x} = 100.0\%$	$\bar{x} = 36.53\%$

TABLE 15 Scenario SA50.

Scenario *SA50*	50% of home visits with +/- 10 min time window. All transportation types included, without service apartments teams, without catering, no worker title separation, team constraints were in use.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	192	1412.1	85:35	1243:57	61.05%	103.23%	41.95%
Tuesday	3037	198	1494.8	86:58	1262:23	58.40%	105.88%	44.62%
Wednesday	3031	190	1469.7	84:02	1214:00	60.39%	103.26%	46.15%
Thursday	2970	205	1410.2	86:13	1263:28	59.87%	111.41%	47.78%
Friday	2828	175	1373.7	80:23	1117:58	60.91%	98.87%	44.44%
Saturday	1716	97	770.0	52:45	581:36	66.49%	106.59%	50.96%
Sunday	1719	99	722.6	50:30	587:05	6106.20%	107.61%	50.50%
Total	18351	1156	8653.1	527:0	7270:0	$\bar{x} = 60.69\%$	$\bar{x} = 105.0\%$	$\bar{x} = 45.95\%$

TABLE 16 Scenario SA100.

Scenario *SA100*	100% of home visits with +/- 10 min time window. All transportation types included, without service apartments teams, without catering, no worker title separation, team constraints were in use.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	206	1710.9	104:51	1243:57	73.97%	110.75%	51.22%
Tuesday	3037	213	1738.3	103:55	1262:23	67.71%	113.90%	53.33%
Wednesday	3031	201	1745.3	103:17	1214:00	71.69%	109.24%	56.59%
Thursday	2970	214	1676.3	103:11	1263:28	71.17%	116.30%	57.22%
Friday	2828	185	1646.3	102:24	1117:58	73.03%	104.52%	56.67%
Saturday	1716	104	966.4	67:46	581:36	83.42%	114.29%	65.38%
Sunday	1719	103	999.5	68:47	587:05	84.46%	111.96%	68.32%
Total	18351	1226	10483.0	654:0	7270:0	$\bar{x} = 73.48\%$	$\bar{x} = 111.4\%$	$\bar{x} = 57.02\%$

TABLE 17 Scenario SB00.

Scenario *SB00*	0% of home visits with +/- 10 min time window. All transportation types included, without service apartments teams, without catering, no worker title separation, team constraints were in use. 8 and 9 hour work shifts (9 hour more expensive).							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	181	1128.5	66:29	1243:57	48.81%	97.31%	32.20%
Tuesday	3037	180	1165.1	65:39	1262:23	45.38%	96.26%	33.85%
Wednesday	3031	175	1151.0	65:48	1214:00	47.29%	95.11%	36.26%
Thursday	2970	185	1153.2	68:44	1263:28	48.96%	100.54%	38.33%
Friday	2828	164	1074.9	62:36	1117:58	47.69%	92.66%	35.00%
Saturday	1716	91	525.9	36:31	581:36	45.42%	100.00%	35.58%
Sunday	1719	92	525.5	36:45	587:05	44.43%	100.00%	36.63.00%
Total	18351	1068	6724.1	0	7270:0	$\bar{x} = 47.14\%$	$\bar{x} = 97.0\%$	$\bar{x} = 35.22\%$

TABLE 18 Scenario SB50.

Scenario *SB50*	50% of home visits with +/- 10 min time window. All transportation types included, without service apartments teams, without catering, no worker title separation, team constraints were in use. 8 and 9 hour work shifts (9 hour more expensive).							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	189	1397.8	81:34	1243:57	60.44%	101.61%	40.00%
Tuesday	3037	193	1455.7	83:34	1262:23	56.72%	103.21%	43.08%
Wednesday	3031	187	1443.1	83:22	1214:00	59.29%	101.63%	45.60%
Thursday	2970	195	1367	82:02	1263:28	58.05%	105.98%	45.56%
Friday	2828	169	1327.5	80:15	1117:58	58.92%	95.48%	44.44%
Saturday	1716	95	765.9	52:35	581:36	66.15%	104.40%	50.96%
Sunday	1719	96	718.6	50:23	587:05	60.73%	104.35%	49.50%
Total	18351	1124	8475.6	513:45	7270:27	$\bar{x} = 59.43\%$	$\bar{x} = 102.09\%$	$\bar{x} = 44.81\%$

TABLE 19 Scenario SB100.

Scenario *SB100*	100% of home visits with +/- 10 min time window. All transportation types included, without service apartments teams, withour catering, no worker title separation, team constraints were in use. 8 and 9 hour work shifts (9 hour more expensive).							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	189	1397.8	81:34	1243:57	71.47%	106.99%	49.76%
Tuesday	3037	193	1455.7	83:34	1262:23	67.90%	105.88%	52.31%
Wednesday	3031	187	1443.1	83:22	1214:00	71.61%	106.52%	56.59%
Thursday	2970	195	1367.0	82:02	1263:28	70.49%	109.78%	57.22%
Friday	2828	169	1327.5	80:15	1117:58	70.98%	101.69%	55.56%
Saturday	1716	95	765.9	52:35	581:36	82.47%	112.09%	64.42%
Sunday	1719	96	718.6	50:23	587:05	81.25%	113.04%	66.34%
Total	18351	1123	8475.6	514	7270:27	$\bar{x} = 72.32\%$	$\bar{x} = 107.27\%$	$\bar{x} = 56.15\%$

TABLE 20 Scenario SD00.

Scenario *SD00*	0% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	181	1166.5	68:11	1243:57	50.45%	97.31%	33.17%
Tuesday	3037	185	1164.2	65:46	1262:23	45.34%	98.93%	33.85%
Wednesday	3031	178	1187.2	67:10	1214:00	48.77%	96.74%	36.81%
Thursday	2970	192	1177.7	68:48	1263:28	50.02%	104.35%	38.33%
Friday	2828	166	1088.2	62:53	1117:58	48.27%	93.79%	35.00%
Saturday	1716	92	542.0	37:28	581:36	46.80%	101.10%	35.58%
Sunday	1719	92	523.3	36:30	587:05	44.17%	100.00%	36.63%
Total	18351	1086	6848.1	407:00	7270:27	$\bar{x} = 48.01\%$	$\bar{x} = 98.64\%$	$\bar{x} = 35.48\%$

TABLE 21 Scenario SD50.

Scenario *SD50*	50% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	191	1394.7	83:32	1243:57	60.31%	102.69%	40.49%
Tuesday	3037	196	1428.3	84:34	1262:23	55.63%	104.81%	43.59%
Wednesday	3031	187	1416.9	81:44	1214:00	58.22%	101.63%	45.05%
Thursday	2970	202	1367.8	84:12	1263:28	58.09%	109.78%	46.67%
Friday	2828	171	1339.9	80:24	1117:58	59.45%	96.61%	44.44%
Saturday	1716	98	747.4	51:57	581:36	64.59%	107.69%	50.00%
Sunday	1719	98	796.6	52:47	587:05	67.31%	106.52%	52.48%
Total	18351	1143	8491.6	520:00	7270:27	$\bar{x} = 59.54\%$	$\bar{x} = 103.81\%$	$\bar{x} = 45.25\%$

TABLE 22 Scenario SD100.

Scenario *SD100* 100% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use.

Day	Addresses	Workers	Km	Drive time	Visit time	Of real km	Of real workers	Of real time
Monday	3050	203	1688.3	103:49	1243:57	72.98%	109.14%	49.76%
Tuesday	3037	206	1731.3	102.38	1262:23	67.43%	110.16%	52.31%
Wednesday	3031	198	1722.5	101:51	1214:00	70.79%	107.61%	56.59%
Thursday	2970	212	1628.5	100:48	1263:28	69.17%	115.22%	57.22%
Friday	2828	184	1610.1	99:12	1117:58	71.43%	103.95%	55.56%
Saturday	1716	101	990.5	68:24	581:36	85.58%	110.99%	64.42%
Sunday	1719	105	947.2	66:52	587:05	79.98%	114.13%	66.34%
Total	18351	1209	10318.4	644:00	7270:27	$\bar{x} = 72.34\%$	$\bar{x} = 109.81\%$	$\bar{x} = 56.15\%$

TABLE 23 Scenario SE00.

Scenario *SE00*	0% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 8, 8.5 and 9 hour work shifts (longer more expensive).							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	168	1166.1	67:06	1243:57	50.41%	90.32%	32.68%
Tuesday	3037	177	1136.1	63:01	1262:23	44.25%	94.65%	32.31%
Wednesday	3031	169	1188.9	67:01	1214:00	48.85%	91.85%	36.81%
Thursday	2970	180	1111.0	65:32	1263:28	47.18%	97.83%	36.11%
Friday	2828	159	1039.0	61:12	1117:58	46.10%	89.83%	33.89%
Saturday	1716	87	534.9	36:41	581:36	46.20%	95.60%	35.58%
Sunday	1719	89	519.3	35:50	587:05	43.83%	96.74%	35.64%
Total	18351	1029	6704.3	397:0	7270:27	$\bar{x} = 46.93\%$	$\bar{x} = 93.46.0\%$	$\bar{x} = 34.52\%$

TABLE 24 Scenario SE50.

Scenario *SE50*	50% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 8, 8.5 and 9 hour work shifts (longer more expensive).							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	178	1392.1	83:34	1243:57	60.18%	95.70%	40.98%
Tuesday	3037	181	1462.3	85:09	1262:23	56.95%	96.79%	43.59%
Wednesday	3031	178	1432.7	81:18	1214:00	58.87%	96.74%	44.51%
Thursday	2970	184	1380.2	82:30	1263:28	58.60%	100.00%	46.11%
Friday	2828	167	1294.7	79:40	1117:58	57.45%	94.35%	44.44%
Saturday	1716	92	746.6	50:22	581:36	64.51%	101.10%	48.08%
Sunday	1719	94	760.3	52:04	587:05	64.19%	102.17%	51.49%
Total	18351	1074	8468.9	515:00	7270:27	$\bar{x} = 59.37\%$	$\bar{x} = 97.55\%$	$\bar{x} = 44.90\%$

TABLE 25 Scenario SE100.

Scenario *SE100*	100% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 8, 8.5 and 9 hour work shifts (longer more expensive).							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	192	1668.0	83:34	1243:57	72.11%	103.27%	49.76%
Tuesday	3037	192	1776.9	85:09	1262:23	69.22%	102.67%	53.33%
Wednesday	3031	186	1709.8	81:18	1214:00	70.25%	102.17%	55.49%
Thursday	2970	197	1653.2	82:30	1263:28	70.19%	107.07%	56.67%
Friday	2828	176	1601.3	79:40	1117:58	71.03%	99.44%	55.00%
Saturday	1716	98	974.4	50:22	581:36	84.11%	107.69%	64.42%
Sunday	1719	102	950.2	52:04	587:05	80.24%	110.87%	65.53%
Total	18351	1143	10332.9	515:00	7270:27	$\bar{x} = 72.44\%$	$\bar{x} = 104.01\%$	$\bar{x} = 55.88\%$

TABLE 26 Scenario SF00.

Scenario *SF00* 0% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 8, 8.5 and 9 hour work shifts (longer more expensive). Different time windows than in SE.

Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	179	1228.4	73:24	1243:57	53.09%	96.24%	35.61%
Tuesday	3037	181	1223.5	71:03	1262:23	47.68%	96.79%	36.41%
Wednesday	3031	178	1248.3	71:50	1214:00	51.27%	96.74%	39.56%
Thursday	2970	186	1265.1	74:37	1263:28	53.72%	101.09%	41.67%
Friday	2828	163	1134.7	68.04	1117:58	50.35%	92.09%	37.78%
Saturday	1716	91	632.1	42:24	581:36	54.58%	100.00%	40.38%
Sunday	1719	91	614.7	42:05	587:05	51.94%	98.91%	41.58%
Total	18351	1069	7346.8	443:00	7270:27	$\bar{x} = 51.50\%$	$\bar{x} = 97.09\%$	$\bar{x} = 38.62\%$

TABLE 27 Scenario SF50.

Scenario *SF50*	50% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 8, 8.5 and 9 hour work shifts (longer more expensive). Different time windows than in SE.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	192	1509.1	91:32	1243:57	65.24%	103.23%	44.88%
Tuesday	3037	199	1523.7	90:02	1262:23	59.37%	106.42%	46.15%
Wednesday	3031	187	1527.1	89:17	1214:00	62.74%	101.63%	48.90%
Thursday	2970	198	1549.6	90:51	1263:28	65.82%	107.61%	50.56%
Friday	2828	174	1439.7	87:14	1117:58	63.89%	98.31%	48.33%
Saturday	1716	96	838.7	56:40	581:36	72.45%	105.49%	54.81%
Sunday	1719	97	811.1	56:53	587:05	68.50%	105.43%	56.44%
Total	18351	1143	9199.0	563:00	7270:27	$\bar{x} = 64.50\%$	$\bar{x} = 103.81\%$	$\bar{x} = 49.08\%$

TABLE 28 Scenario SF100.

Scenario *SF100*	0% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 8, 8.5 and 9 hour work shifts (longer more expensive). Different time windows than in SE.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	212	1871.1	112:27	1243:57	80.89%	113.98%	54.63%
Tuesday	3037	212	1848.7	109:30	1262:23	72.03%	113.37%	56.41%
Wednesday	3031	207	1916.2	111:05	1214:00	78.72%	112.50%	60.99%
Thursday	2970	216	1810.5	110:40	1263:28	76.90%	117.39%	61.67%
Friday	2828	194	1702.8	105:07	1117:58	75.51%	109.60%	58.33%
Saturday	1716	107	1054.2	71:30	581:36	91.02%	117.58%	69.23%
Sunday	1719	108	1027.9	70:42	587:05	86.82%	117.39%	70.30%
Total	18351	1256	11231.4	692:00	7270:27	$\bar{x} = 78.73\%$	$\bar{x} = 114.08\%$	$\bar{x} = 60.33\%$

TABLE 29 Scenario SG00.

Scenario *SG00*	0% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 7, 8 and 9 hour work shifts (longer more expensive). Different time windows than in SE.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	192	1229.5	74:13	1243:57	53.18%	103.23%	36.10%
Tuesday	3037	198	1231.4	71:41	1262:23	47.95%	105.88%	36.92%
Wednesday	3031	187	1287.0	74:16	1214:00	52.88%	101.63%	40.66%
Thursday	2970	200	1232.5	74:27	1263:28	52.36%	108.70%	39.44%
Friday	2828	170	1199.8	71:03	1117:58	49.69%	96.05%	39.44%
Saturday	1716	92	650.9	44:16	581:36	56.22%	101.10%	42.31%
Sunday	1719	95	591.5	42:10	587:05	50.00%	103.26%	41.58%
Total	18351	1256	7422.6	451:00	7270:27	$\bar{x} = 51.42\%$	$\bar{x} = 103.98\%$	$\bar{x} = 39.06\%$

TABLE 30 Scenario SG00.

Scenario *SG00*	50% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 7, 8 and 9 hour work shifts (longer more expensive). Different time windows than in SE.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	206	1531.7	91:55	1243:57	66.23%	110.75%	44.88%
Tuesday	3037	213	1494.7	88:09	1262:23	58.24%	113.90%	46.15%
Wednesday	3031	197	1552.2	89:30	1214:00	63.76%	107.07%	48.90%
Thursday	2970	210	1487.4	90:41	1263:28	63.14%	114.13%	50.56%
Friday	2828	178	1454.5	87:37	1117:58	64.55%	100.56%	48.33%
Saturday	1716	100	800.9	55:48	581:36	69.17%	109.89%	54.81%
Sunday	1719	103	795.3	54:58	587:05	67.15%	111.96%	56.44%
Total	18351	1256	9116.7	555:00	7270:27	$\bar{x} = 63.91\%$	$\bar{x} = 109.63\%$	$\bar{x} = 49.08\%$

TABLE 31 Scenario SG100.

Scenario *SG100*	100% of home visits with +/- 10 min time window. All transportation types and catering included, without service apartments teams, no worker title separation, team constraints were in use. Mixed 7, 8 and 9 hour work shifts (longer more expensive). Different time windows than in SE.							
Day	**Addresses**	**Workers**	**Km**	**Drive time**	**Visit time**	**Of real km**	**Of real workers**	**Of real time**
Monday	3050	218	1842.9	112:39	1243:57	79.68%	117.20%	55.12%
Tuesday	3037	225	1895.1	112.08	1262:23	73.82%	120.32%	57.44%
Wednesday	3031	214	1894.4	111:09	1214:00	77.81%	116.30%	60.99%
Thursday	2970	224	1817.8	111:36	1263:28	77.20%	121.74%	62.22%
Friday	2828	196	1738.6	107:28	1117:58	77.15%	110.73%	59.44%
Saturday	1716	112	1020.6	70:47	581:36	88.17%	123.08%	68.27%
Sunday	1719	109	1032.7	71:50	587:05	87.25%	118.48%	71.29%
Total	18351	1256	11242.3	698:00	7270:27	$\bar{x} = 78.81\%$	$\bar{x} = 117.89\%$	$\bar{x} = 60.85\%$

6 CHALLENGES IN HOME CARE OPTIMIZATION

In order to allocate a home visit or any other task its duration must be known and input to an optimization software. In Jyväskylä's home care each home visit is planned individually by workers at the beginning of each work shift. A rough time estimate is determined based on written care plan and the time is adjusted (usually only increased if necessary) based on other relevant information such as the customer's current condition, worker's experience and other details. These may change constantly. If an optimization software is used, each home visit duration should be decided beforehand which is hard to do in practice. If the home visit time is too short, the worker will risk missing the next customer's time window. On the other hand if the visit durations are unnecessarily long, time will be wasted. Also worker area and personal nurse constraints should be maintained in home care, which makes utilizing workers from other home care areas in rush situations undesirable. In March 2016 the Social and Health Minister of Finland paid attention to the fact that within one month one home care customer may be visited by several dozens of different workers. [Il16] This will break the continuity of care and thus is not acceptable.

Home visits taking more time that was planned are common. Figures 66 and 67 show the percentage and distribution of planned home visit duration vs. actual home visit duration in data from VASKE project in Eastern Finland. The data was originally intended to be used in neural network experiments in order to predict customer visits that may take more time that was expected. However, the actual home visit durations are too inaccurate. The Figure 67(b) includes also home visits that took less time than planned. Under normal circumstances a home visit should never be significantly shorter than the planned duration. Also in this case the shorten than planned visit durations are caused by inaccuracies in the data and errors during data collection. Thus also the longer than planned home visit durations may contain errors and should be treated as a rough estimate only.

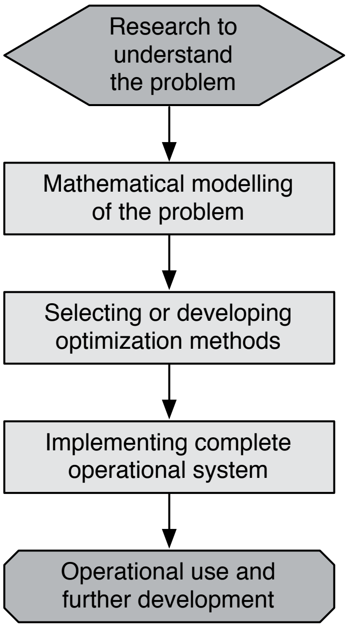

FIGURE 41 Phases of optimization.

6.1 What is missing from commercial optimization solutions for home care?

Two surveys were send to Finnish home care organizations, smaller one in 2009 and more extensive one in 2013. The following sections represent the results and the home care experts' views and experiences concerning optimization and its suitability for home care operations.

6.2 2009 survey to Finnish home care organizations

A small questionnaire of five questions was sent to 100 largest Finnish home care organizations in 2009. A total of 27 (27%) organizations of varying sizes from large to small answered.

The questions asked were:

- Q1: Is route optimization used in the organization.
- Q2: Is route optimization methodology familiar in the organization.
- Q3: What are the reasons if route optimization is not used in the organization.
- Q4: Experiences of route optimization if it has been used in the organization.

– Q5: Plans and needs concerning route optimization in the organization.

Only six (22%) of the organizations answered yes to the first question (Q1). In practice none of the organizations had an actual operational route optimization software but two had plans to start route optimization within a year or two. The other four organizations either had some automatization in planning home care but no actual route optimization, or had a partner organizations taking care of some home care operations. These partner organizations were mentioned to be using optimization softwares that were not specified in detail. In addition one organization that did not answer the question was known to be one of the first organizations using an optimization software developed specifically for home care operations.

11 organizations (41%) had very little or no knowledge of route optimization possibilities (Q2). The rest of the organizations (59%) had some knowledge about route optimization and many of them had received visits from companies producing optimization software.

The reasons why route optimization was not used varied (Q3). Most common reasons were technical difficulties in connecting route optimization softwares to organization's information systems, lack of knowledge, small resources, expenses, and suspicions that route optimization might not increase efficiency and decrease costs.

Only two organization had experience of the actual use or pilot study of a route optimization software (Q4). In the pilot study the route optimization did not contain necessary constraint possibilities to be useful in operational use. The only organization that had an operational and home care specific route optimization software was satisfied to its performance after difficulties in the beginning, but the size of the home care organization was very small (approximately 150 customers).

18 of the organizations (67 %) had varying plans concerning route optimization in the future (Q5). A few organizations were already in the process of acquiring a route optimization sofware in the near future and the rest had varying level interest towards optimization possibilities but no immediate plans to start using optimization.

6.3 2013 survey to Finnish home care organizations

A more detailed 8 page and 31 questions long structured survey was sent to all Finnish home care organizations serving at least 10 000 people area in 2013–2014. The knowledge about home care optimization possibilities was significantly better than four years earlier and the many organizations responded without a delay. A few organizations had to be reminded about their legal duty to provide information about public services. The final response percent was 100%. 29 (26.9%) of the home organizations in the survey are joint municipal organizations and 69 (70.4%) home care organizations operated by single city or municipality.

The organizations were selected by sorting all municipalities in Finland to descending order by the population size in the end of the year 2012 and selecting all municipalities in mainland Finland that had the population size of 10 000 or above. Some organizations selected this way were jointly operated by several smaller municipalities, or smaller municipalities and a bigger city. Thus the survey covers a total of 178 municipalities and even excluding the city of Helsinki the total population of these municipalities was 4 195 493, or 87.5% of the population of Finland (excluding Helsinki and Åland islands).

The survey was send by email to the directors of each organization's home care or social and health care department depending on the organizational structure. There were three alternative ways to respond; on the web, by sending the filled form by email as a PDF file, or by sending the filled form by regular post. Most organizations chose the web form or PDF emailing alternative. Additional background information concerning the municipalities were collected from official public statistics by Statistics Finland[1] and The Association of Finnish Local and Regional Authorities.[2]

The results of the survey are represented in the following chapters.

TABLE 32 2013 Survey question 1.

1. Organization's knowledge level concerning route optimization possibilities. n = 93 (94.9 %)			
	Freq.	All %	Ans. %
0 – N/A	*5*	*5.1*	—
1 – No knowledge	3	3.1	3.2
2 – Very little knowledge	27	27.6	29.0
3 – Basic knowledge	40	40.8	43.0
4 – Good knowledge	14	14.3	15.1
5 – Excellent knowledge and expertise available through cooperation	9	9.2	9.7
	98	100.1	100.0

1 `http://www.tilastokeskus.fi`
2 `http://www.kunnat.net` and `http://www.sotka.net/`

TABLE 33 2013 Survey question 2.

2. Using optimization solutions in organization. n = 98 (100 %)			
	Freq.	All %	Ans. %
0 – N/A	*0*	—	—
1 – Not used	71	72.4	72.4
2 – Only work shift optimization	19	19.4	19.4
3 – Only route optimization	3	3.1	3.1
4 – Both work shift and route optimization	5	5.1	5.1
	98	100.0	100.0

TABLE 34 2013 Survey question 3.

3. Optimization software demonstrated by a manufacturer. n = 93 (94.9 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*5*	*5.1*	—
1 – No	20	20.4	21.5
2 – Only work shift optimization software	7	7.1	7.5
3 – Only route optimization software	10	10.2	10.8
4 – Both work shift and route optimization software	56	57.1	60.2
	98	99.9	100.0

TABLE 35 2013 Survey question 4.

4. Getting familiar with an optimization used by another organization. n = 91 (92.9 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*7*	*7.1*	—
1 – No	50	51.0	54.9
2 – Yes	41	41.8	45.1
	98	99.9	100.0

TABLE 36 2013 Survey question 5.

5. Route optimization software piloted. n = 96 (98.0 %)			
	Freq.	All %	Ans. %
0 – *N/A*	2	*2.0*	—
1 – No	79	80.6	82.3
2 – Only work shift optimization software	4	4.1	4.2
3 – Only route optimization software	6	6.1	6.2
4 – Both work shift and route optimization software	7	7.1	7.3
	98	99.9	100.0

TABLE 37 2013 Survey question 6.

6. Future plans concerning route optimization. n = 88 (89.8 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*10*	*10.2*	—
1 – Not discussed	19	19.4	21.6
2 – Discussed and made a decision not to utilize route optimization	7	7.1	8.0
3 – Discussed and under consideration to pilot a route optimization software	30	30.6	34.1
4 – Discussed and decided to pilot a route optimization software	5	5.1	5.7
5 – Discussed and under consideration to acquire a route optimization software	17	17.3	19.3
6 – Discussed and decided to acquire a route optimization software	10	10.2	11.4
	98	99.9	100.1

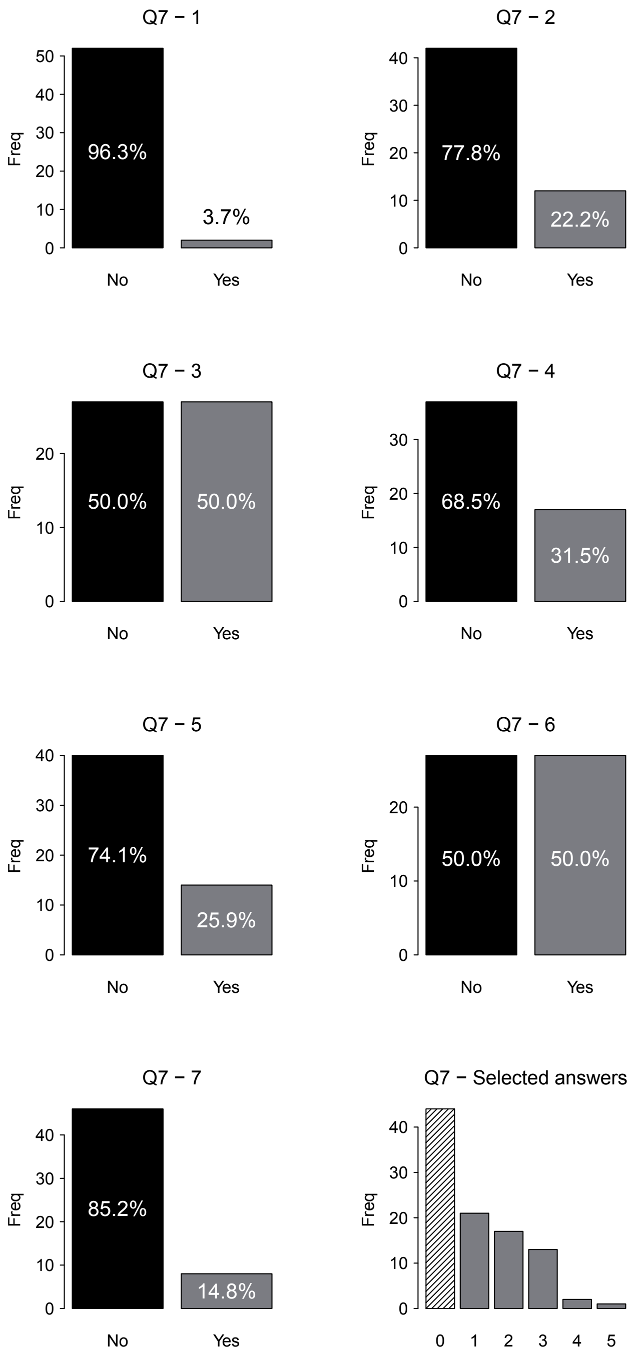

FIGURE 42 Future plans concerning route optimization. See also Table 38.

TABLE 38 2013 Survey question 7. See also Figure 42.

7. Main reasons why acquiring or piloting a route optimization software is not considered. n = 54 (55.1 %)	
	Freq.
0 – *N/A*	*44*
1 – Doubts if route optimization methods can be applied to home care	2
2 – Doubts if route optimization methods can be applied to answerer's own organization even though they may work in another organization with different kind of operational environment or model	12
3 – Purchase and maintenance costs	27
4 – Lack of knowledge	17
5 – Organizational reasons, route optimization is not current matter	14
6 – Technical challenges, difficulties in connection optimization software to existing information systems	27
7 – Other unspecified reasons	8
Marked reasons average/organization	2

TABLE 39 2013 Survey question 8.

8. Mobile system utilization in home care. n = 96 (98.0 %)			
	Freq.	All %	Ans. %
0 – *N/A*	2	*2.0*	—
1 – Not used	70	71.4	72.9
2 – Yes, without optimization	14	14.3	14.6
3 – Yes, with route optimization	1	1.0	1.0
4 – Yes, with work shift optimization	6	6.1	6.2
5 – Yes, with both route and work shift optimization	5	5.1	5.2
	98	99.9	99.9

TABLE 40 2013 Survey question 10.

10. Is/was the used or piloted system flexible enough for operational use. n = 15 (15.3 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*83*	*84.7*	—
1 – No	10	10.2	66.7
2 – Yes	5	5.1	33.3
	98	100.0	100.0

TABLE 41 2013 Survey question 12. See also Figure 43.

12. Route optimization software is/was able to function independently enough in everyday operational use. n = 13 (13.3 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*85*	*86.7*	—
1 – Disagree fully	2	2.0	15.4
2 – Disagree somewhat	5	5.1	38.5
3 – Neutral	2	2.0	15.4
4 – Agree somewhat	4	4.1	30.8
5 – Agree fully	0	0	0
	98	99.9	100.1

TABLE 42 2013 Survey question 13. See also Figure 43.

13. Used or piloted route operating system is/was clearly beneficial. n = 13 (13.3 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*85*	*86.7*	—
1 – Disagree fully	1	1.0	7.7
2 – Disagree somewhat	1	1.0	7.7
3 – Neutral	1	1.0	7.7
4 – Agree somewhat	6	6.1	46.2
5 – Agree fully	4	4.1	30.8
	98	99.9	100.1

TABLE 43 2013 Survey question 14. See also Figure 43.

14. Optimization software providers have enough expertise in the field of home care. n = 15 (15.3 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*83*	*84.7*	—
1 – Disagree fully	2	2.0	13.3
2 – Disagree somewhat	4	4.1	26.7
3 – Neutral	3	3.1	20.0
4 – Agree somewhat	5	5.1	33.3
5 – Agree fully	1	1.0	6.7
	98	100	100

TABLE 44 2013 Survey question 15. See also Figure 43.

15. Research and development of home care optimization systems is worthwhile. n = 93 (94.9 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*5*	*5.1*	—
1 – Disagree fully	4	4.1	4.3
2 – Disagree somewhat	0	0.0	0.0
3 – Neutral	1	1.0	1.1
4 – Agree somewhat	36	36.7	38.7
5 – Agree fully	52	53.1	55.9
	98	100	100

TABLE 45 2013 Survey question 16. See also Figure 44.

16. Credibility of marketing claims concerning optimization softwares. n = 93 (94.9 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*83*	*84.7*	—
1 – Increase in service quality	2	2	
2 – Decrease of work load	3	3	
3 – Positive environmental impact	10	10	
4 – Direct economic savings	35	35	
5 – Easier planning of work	45	45	
	98	100	100

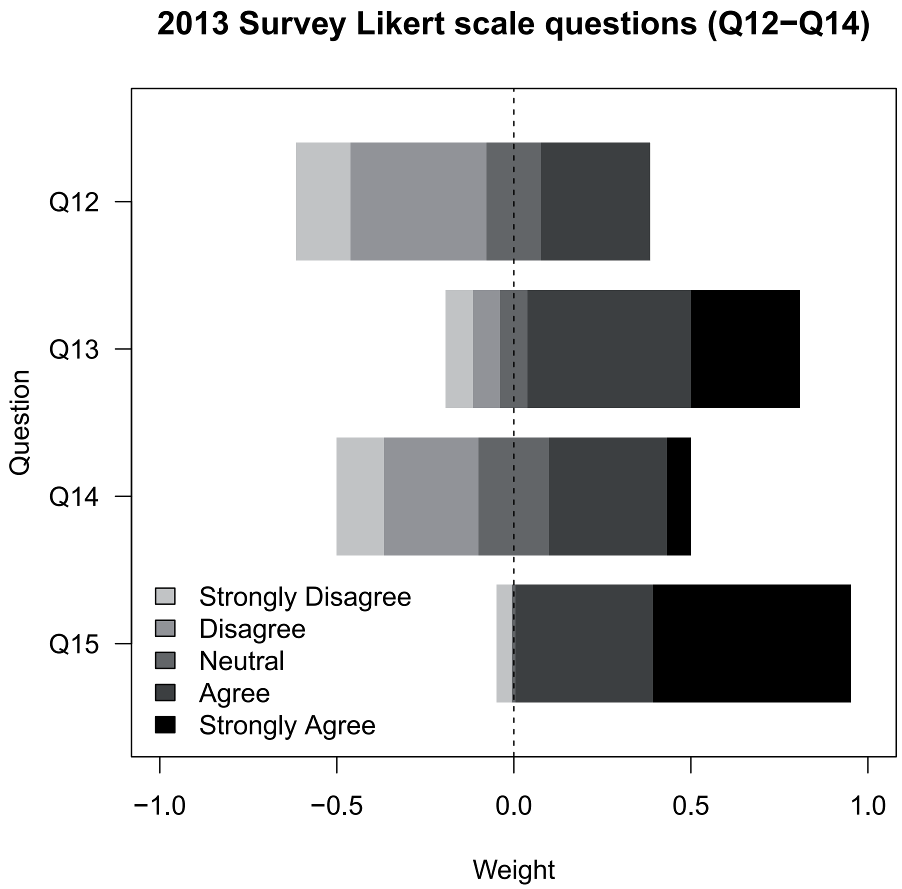

FIGURE 43 2013 Survey Likert scale questions (Q12–Q15). See also Tables 41–44.

TABLE 46 2013 Survey question 17.

17. Do you find the claims of significant economic savings by route optimization credible.
n = 94 (95.9 %)

	Freq.	All %	Ans. %
0 – *N/A*	*4*	*4.1*	—
1 – No	16	16.3	17.0
2 – Yes	78	79.6	83.0
	98	100.0	100.0

TABLE 47 2013 Survey question 18.

18. Have your organization applied simulation methods to improving processes. n = 95 (96.9 %)			
	Freq.	All %	Ans. %
0 – *N/A*	*3*	*3.1*	—
1 – Not familiar with the concept of simulation	40	40.8	42.1
2 – No, but the concept of simulation is familiar	28	28.6	29.5
3 – Processes have been described as flow-charts or verbally but not simulated or modelled mathematically	24	24.5	25.3
4 – Processes have been modelled mathematically and simulated	3	3.1	3.2
	98	100.1	100.1

6.4 Free comments

Some questions were free comment boxes. 56 organizations included their own comments. These answers are classified into main groups in Table 48 and Figure 45. The most common free comment was that the organization is in the process of acquiring a route optimization system (9 organizations) in the near future. The second most common comment type was that the organization is currently considering acquiring a route optimization system (8). The third most common comment class includes serious suspicions about the suitability of route optimization in home care (7). These organizations had either piloted a home care route optimization system, or had otherwise experimented with optimization systems. According to them route optimization was not suitable for home care because it was seen as too rough, too superficial, and too inflexible for actual home care operations. Many of the comments in this class were highly critical and were provided by larger organizations with first hand experience with optimization in home care. The fourth most common comment contained descriptions of technical problems preventing adding a mobile or optimization system on top of the current information systems as an interface was not available or was too expensive.

6.4.1 Examples of the free comments

A few most relevant comments (freely translated and partially shortened) about why the organization has or has not considered route optimization.[3]

> "Route planning is based on many things such as urgency (insulin injections, customer's hospital visit in the morning, taking blood samples etc.). Routes cannot be optimized based on addresses alone, the route planning must be done according to the contents of the home visit." *(Small-size organization)*

> "ERP and other information systems should be able to access other systems on a national level. Corresponding ministries and the Association of Finnish Local and Regional Authorities have been too lax in pressurizing the parliament to create a law that requires that all information systems can communicate with each others." *(Medium-size organization)*

> "At the moment it seems that work shift optimization provides more benefits that route optimization so we chose to pilot a work shift optimization system first. Connecting different systems to each others is a challenge and most system are not very user friendly. When developing new systems, the needs and requirements of both user organizations as well as individual workers should be taken into account." *(Large-size organization)*

> "Building an interface between patient information system and mobile system was way too expensive." *(Large-size organization)*

> "The questions in the survey were surprisingly accurate. As my answers show, optimization is currently under development in our organization. At this moment route optimization is too inflexible and cannot operate 'independently' enough." *(Large-size organization)*

> "Route optimization is done manually at the moment. Other reasons why we have not considered route optimization is because we have listened the opinions on the workers." *(Small-size organization)*

> "Software manufacturers have demonstrated optimization in our organization – but the actual maturity of these systems?" *(Small-size organization)*

> "We would need more actual research based information about optimization. Also there are technical interface difficulties. . . . In pilot the software did not handle all constraints that would be needed, sudden changes in plans were a problem to the system, efficiency did not get any better in the pilot. . . . Important research topic! Electronic keys, automated medication packaging, and an efficient ERP system is the most important combination in increasing efficiency in home care." *(Large-size organization)*

> "Acquisition decision was made but the matter was taken to the market court. Now we are thinking about how to proceed, a new competitive bidding is required." *(Medium-size organization)*

> "Route optimization is not important in home care. The important thing is optimal resource planning and management. It is important to get the right worker to the right place in the right time. . . . Operations planning must be based on the needs of the customer, route and workshift optimization does not quarantee improvements in home care. Mobile systems are welcome if they can increase the time the workers can use at customers' homes. . . . ERP can help to allocate the workers to the customers." *(Large-size organization)*

[3] Organizations with less than approximately 100 workers are classified as small-size, organizations with approximately 100–150 workers as medium-sized, and organizations with larger staff sizes are classified as large-size.

"According to our experience, route optimization is not the most relevant question in home care. Work shift optimization and resource allocation is more important. ... I would criticize if the research is based in the assumption that route optimization if the most relevant thing in home care. ... Additionally simulation should definitely be utilized in the social and health care sector. Not only in home care but the whole process chain including home care, first aid, special care, hospital periods etc. This would improve the development of health care on larger scale and the political decision making." *(Large-size organization)*

"Technical difficulties and the lack of interfaces is the biggest reason why we have not using optimization fully yet. We are expecting good results from optimization. Even during the 'primitive' piloting the staff has been satisfied. Allocating workers to customers is more fair now and the work load is levelled more evenly. Also sudden changes can be handled through the mobile system. ... We are interested to see the results of the thesis." *(Large-size organization)*

TABLE 48 Free comments in 2013–2014 Survey. See also Figure 45.

Code	Free comment class description	Frequency	%
1	Mobile system without optimization coming	9	16.1
2	Considering route optimization system	8	14.3
3	Pilot or demonstration did not convince that route optimization is suitable for home care	7	12.5
4	No interface available or other technical difficulties	5	9
5	Route optimization system coming	4	7.1
6	Only demonstration	4	7.1
7	Mobile system without route optimization coming but process slowed down by interface difficulties	4	7.1
8	No need for route optimization	3	5.3
9	Only work shift optimization considered	2	3.6
10	Costs and interface difficulties	1	1.8
11	Costs	1	1.8
12	No route optimization because of opinions of workers	1	1.8
13	Simulation important, not route optimization	1	1.8
14	Resource planning system (ERP) is important, not route optimization	1	1.8
15	Legal difficulties	1	1.8
16	New route optimization system coming to replace older one and mobile system coming, interface difficulties	1	1.8
17	Using route optimization	1	1.8
18	Mobile coming, route optimization too expensive	1	1.8
19	Using mobile system without route optimization	1	1.8
	Total	56	100.1

6.5 Survey results compared to optimization experiments

Many of the organizations currently operating route optimization systems or that have at least piloted them expressed their concerns about the suitability of route optimization in home care. The most common optimization related problem was the inflexibility of the software used as well as the lack of all the necessary constraint setting possibilities. While different kinds of constraints can be included in optimization systems, the inflexibility stemming from the customer oriented and volatile nature of home care work can be harder to solve. Even if a route optimization software can create an efficient routing, allocate the right worker to the right customer, and include all the necessary constraints, the optimization result is valid only as long as the operational situation does not change. In practice sudden and unexpected changes[4] will happen in home care work and break the optimized routing and schedule. Usually this means that the optimization needs to be done again for either the whole staff and customer base, or at least a part of them. This can lead to changes that propagate further and change the routing of many other workers. In practice, the staff may have to resort to manual routing again in order to solve the situation. Similar problems affected also the optimization experiments prepresented in the previous chapters. Although significant savings in terms or driving time and kilometers was achieved, also most of the real life home contstraints necessary in home care work had to be omitted.

Especially larger organizations with optimization experience were not always convinced of the benefits of route optimization and they suggested other ways to improve home care operations, such as improving the communication between resource planning systems, customer databases, and mobile systems [Tie14]. Plain work shift optimization was sometimes seen as a better alternativeto route optimization at the moment. Simulation and improving processes was mentioned by few organizations. Also non-software based solutions such as electronic or mobile keys [Yle15] to customers' home and automated medication packaging [Apt15] was suggested. Many organizations are also concerned that the new technologies may also create new problems unless they are first evaluated carefully before deploying them into operational use. [EKS14]

6.6 The maturity of home care route optimization

The US information technology research and advisory company Gartner represents the maturity level of different kinds of new technologies by the Hype Cycle. The Hype Cycle is divided into five phases (Figure 46) starting from the Technology Trigger. At this moment route optimization in home care appears to be located in the second phase, the Peak of Inflated Expectations. New technologies

[4] Unexpected change in the customer's physical or mental condition, technical problems at home, and even missing demented customers [LV13] are often reported.

in this phase are still immature, and although a few success stories may emerge, the expectations concerning the technology is inflated and unrealistic. This is followed by the Through of Disillusionment and Slope of Enlightenment. Finally new technologies reach the Plateau of Productivity as they mature, and they can be productively applied in real life. [Gar16]

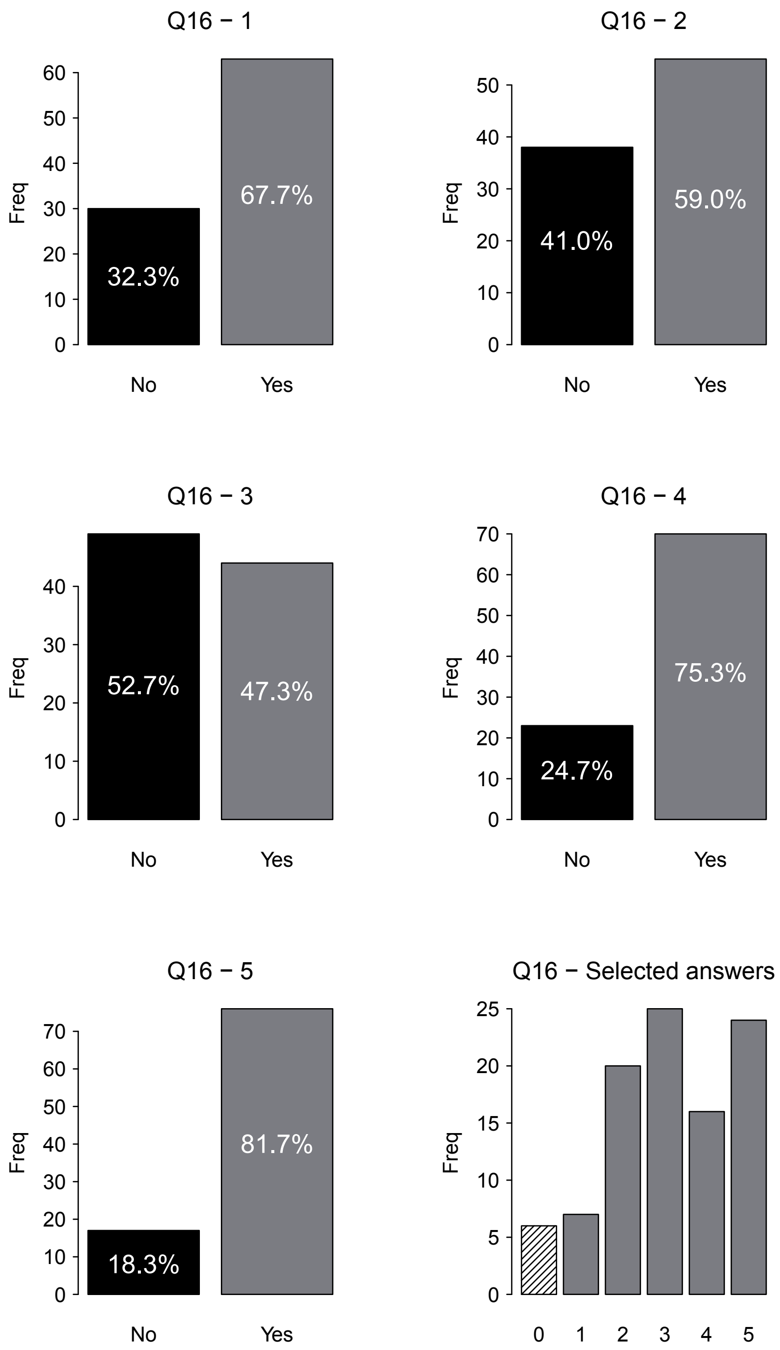

FIGURE 44 Credibility of marketing claims concerning optimization softwares. Frequencies are represented also in Table 45.

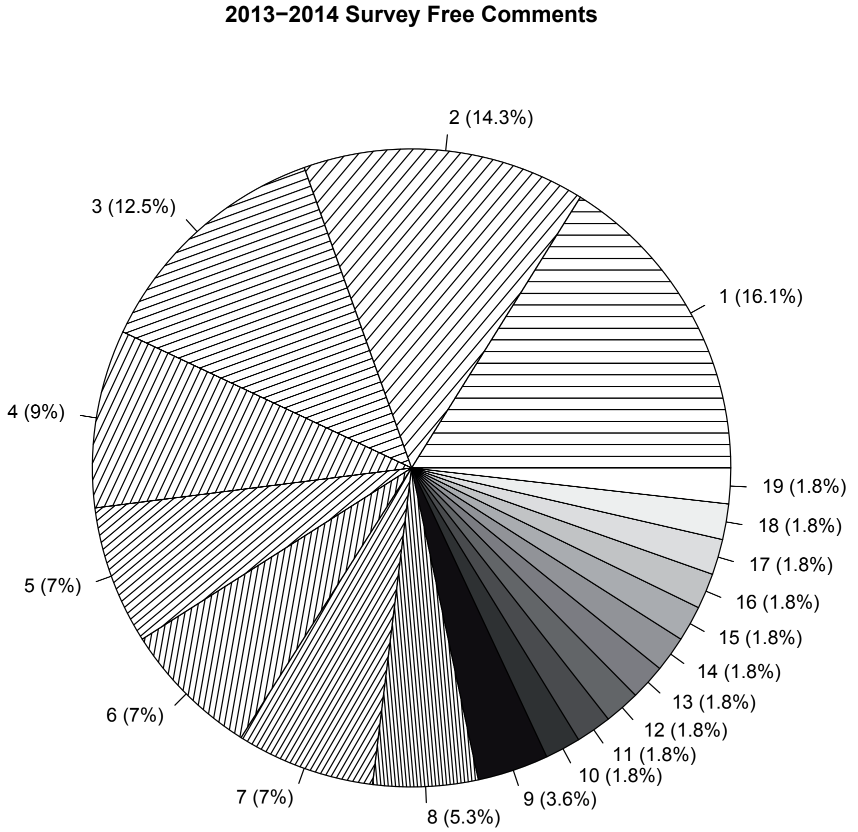

FIGURE 45 Free comments in 2013–2014 Survey chart. The numeric codes are described in detail in Table 48.

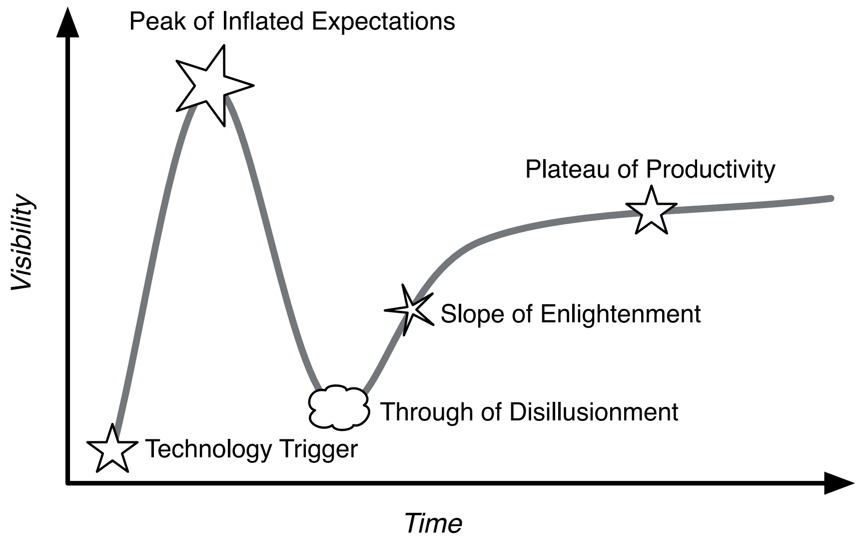

FIGURE 46 Gartner Hype Cycle. [Gar16]

7 POSSIBLE SOLUTIONS

Tackling the challenges the aging of the population poses to services requires new tools and approaches. The main objective of this study was to examine to what extent vehicle routing optimization approach is applicable to real life home care operations, and what kind of improvements can be expected in the best case if many constraints are left out. Also detailed analysis was conducted in order to understand how daily home care operations work in practice.

The results of the optimization experiments and surveys show that as such big economical savings in terms of decreased driving time and kilometers cannot be achieved by many currently available plain route optimization solutions alone. This is largely caused by the ever changing customer situations of home care work that often render the carefully optimized routes and schedules useless in practice. Route optimization can still be a part of automated work shift planning and ERP (Enterprise Resource Planning) of home care organizations. This way it may decrease working time required for initial planning of workshifts and their use in different task groups.

The study also showed that new information for decision making and development of home care processes can be found by exploratory and other data analysis methods.

Home care is not the only field where operational situations can change quickly and forecasting could be applied to optimization. Advanced forecasting and planning softwares are already used in some other fields where the environment is constantly changing and includes a large number of variables and constraints. One example is large-scale airport planning and operations where advanced data mining and forecasting techniques are used in both real-time operational planning and in long term strategic planning. In such environments sudden random delays, technical problems and weather changes are common and affect a large number of passenges, staff members and operations. [L14]

In addition to the methods proposed in previous research as represented in the review of literature, other approaches could be utilized in home care optimization and planning as well. Two possible fields are described shortly in the following two sections.

7.1 Predicting changes

Random changes can be predicted by different mathematical and statistical methodologies. One such field is Artificial Neural Networks (ANN). ANNs are inspired by biological neural networks. Typically they contain several layers of mathematical representation of neurons connected by synapses. Data to be processed by the ANN is fed to input neurons and it is passed through the whole neural network until it is finally outputted by the output neuron layer which will represent the solution.

As described in the previous chapters, a typical problem that makes home care route optimization difficult is a random delay at a customer's home. While not all such random delays can be predicted it is probable that certain customers cause random delays more than others. These customers could be configured into a route optimization system manually but in the case of a large customer base and changing situations this can be hard in practice.

Artificial Neural Networks are well suited for classification of data into groups. In the case of home care data the information about customer, visit type and content, time of the day and other parameters could be used in classifying the customers to different groups by the probablity that the home visit in the customer's home address can or cannot be completed as planned. These groups could be utilized in route optimization so that the planned home visit duration is extended in the cases where the ANN predicts delays. As ANN methods are machine learning algorithms they can learn from data and improve the accuracy of predictions as well as adjust to changes.

Classification of home visits by an ANN was tested with a real home care data from a home care organization located in Eastern Finland (visualized in Figures 66 and 67 in the Appendix). The test data was collected manually and some workers had recorded the home visit times more precisely than others. This effect caused the ANN to learn to classify the data by the home care workers and not by the customers. In practice successful classification by neural networks would require preferably automatically collected very accurate data. Further experiments with high quality data might yield better results that could be usable in home care optimization and operational planning.

Also time series analysis can be utilized in work shift planning. The error component in the time series decomposition in Figure 63 reveals error peaks (i.e. larger or smaller amount of home visits than what is typical) caused by events such as the national holidays. Also sudden rushes caused by other events can cause similar error peak that could be detected in real-time monitoring of home care data and utilized in work shift planning. Time series models can also be to predict how e.g. the number of customers or home visits develop in the near future.

7.2 Process mining

Process mining is a relatively new field of data analytics. It allows automatic transformation of large-scale log files into graphical process graphs and related numerical information. The generated process graph can be adjusted so that only the core process is visible and connections between activity nodes that are most likely random noise are removed.

While process mining does not solve daily operational optimization and routing problems, it allows monitoring any kind of processes and is particularly well suited for analyzing service processes. Process mining has been successfully utilized in optimizing health care processes by discovering bottle necks which can make them inefficient and it could be applied to home care processes as well. [LBR16, RML+15, LAD16]

One example of a process mining software is REMASTER process mining desktop by Synesa Solutions Oy, Finland. ReMaster allows quick visualization, removal of random noise, filtering and statistical analysis of event log files. A small example visualization in Figure 47 represents the relationships of the activities, the flow of the process, and the frequencies how many times each activity and transition between the activities is present in the data. Actual usage of the software allows detailed filtering and analysis of a process as well as removal of noise (i.e. those parts of the process that are likely to be caused by logging and other errors and thus are not actual features of interest).

It is also possible to compare process models numerically to detect if the planned nominal process and actual operational process differ. This kind of analysis could be automated so that operational data is used to model the operational process on regular basis to detect possible signs of the process starting to deviate from the planned process more than what is specified.

7.3 Stochastic discrete event simulation and optimization

Simulation is a separate field from optimization and can be classified to many different types. One of these types, Stochastic Discrete Event Simulation–or *system simulation*–can be utilized in studying complex systems and processes. [BCNN01] They have been widely used in health care sector as well. [Ruo07, RN13]

Although simulation can be used as a tool in developing processes it does not give optimal solutions but instead answers to "what if?" type of questions. Combinatorial optimization is needed for optimizing daily operations. Simulation experiments can still be valuable in detecting bottle necks and other performance issues in home care. New processes can be evaluated by using simulation models without making any changes to operational processes until the effects of possible changes are understood and confirmed to be practical by simulation results. When processes are stream-lined, they are also easier to optimize.

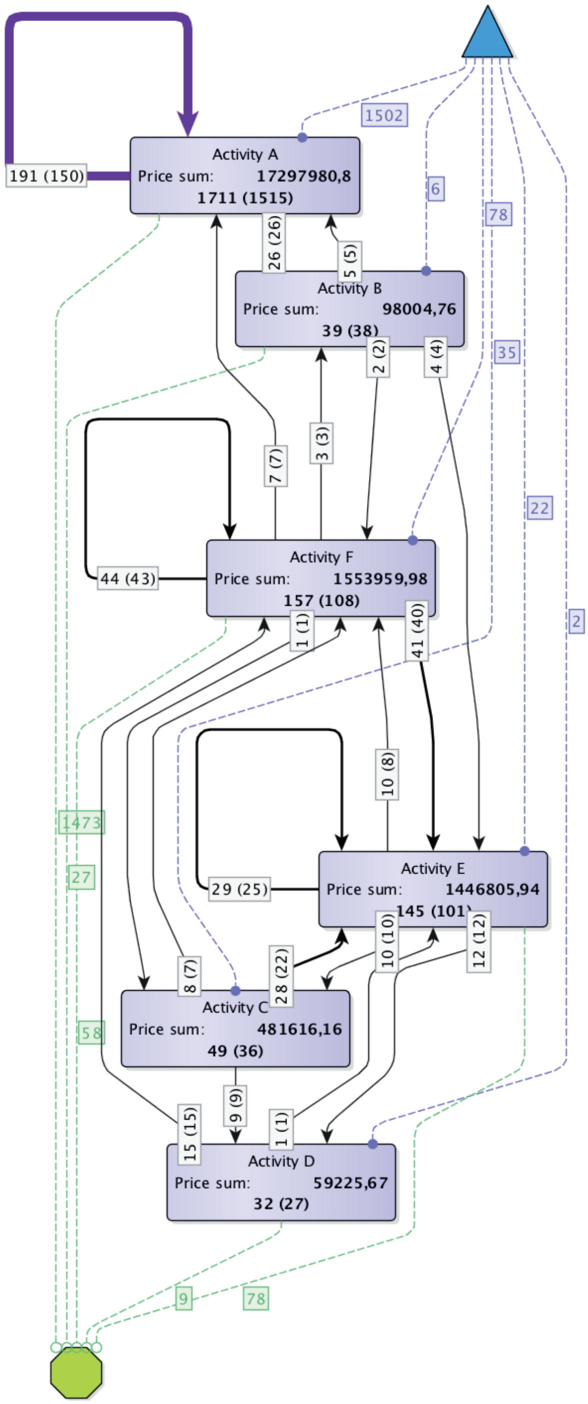

FIGURE 47 Small random event log based example process graph produced with Synesa Solutions Oy REMASTER process mining software (P. Nakari). Graph shows the relations of different consecutive tasks, frequecies of connections and cases, and the start and end point of the process.

YHTEENVETO (FINNISH SUMMARY)

Mahdollisuudet ja haasteet kotihoidon palveluprosessin optimoinnissa – reitinoptimoinnin soveltaminen

Kotihoidon tarve kasvaa väestön ikääntyessä ja myös julkisten palvelujen tehokkuusvaatimukset kasvavat. Palveluissa tarvitaan uusia, myös laskennallisiin tieteisiin pohjautuvia ratkaisuja. Tutkimuksessa paneuduttiin erityisesti reitinoptimoinnin hyödyntämiseen, mutta osoitettiin myös kuinka analysoimalla ja visualisoimalla kotihoidon toimintaan liittyvää dataa voidaan saada uutta informaatiota päätöksenteon ja kehittämisen pohjaksi.

Useat kotihoito-organisaatiot hyödyntävät erilaisia toiminnanohjausjärjestelmiä ja mobiiliteknologiaa, mutta mobiilijärjestelmiin liitetty reitinoptimointi ei ole vielä yleisesti käytössä. Kotihoitotyön luonteen vuoksi reitinoptimoinnin soveltaminen on monimutkaisempaa kuin kaupallisen ja teollisen logistiikan alueella. Nopeasti muuttuvat asiakaslähtöiset tilanteet, runsaasti erilaisia tehtäviä sisältävä kotihoitotyö ja monimutkaiset rajoitteet tekevät optimoinnin toteuttamisesta ja hyödyntämisestä haasteellista. Nämä ongelmat tulevat esiin sekä tehdyissä reitinoptimointikokeissa että monien kotihoito-organisaatioiden kyselyvastauksissa.

Vaikka kotihoidon reitinoptimointijärjestelmiä käyttävät tai koekäyttäneet organisaatiot raportoivatkin käytännön vaikeuksista ja myös asiaan liittyvän tietämyksen puutteesta, on suhtautuminen kotihoidon reitinoptimointijärjestelmien tutkimiseen ja kehittämiseen pääsääntöisesti myönteistä.

Reitinoptimointi itsessään ei välttämättä tuota kotihoidon kaltaisessa toiminnassa runsaita säästöjä samassa mielessä kuin monilla muilla toimialoilla, mutta se on käytännössä merkittävä osa automatisoitua työvuorojen ja resurssien kohdentumisen suunnittelua. Työvuorojen ja työn kohdentumisen suunnittelun tehokasta automatisointia on vaikea toteuttaa huomioimatta liikkuvien työntekijöiden kulkureittejä ja liikkumiseen kuluvaa aika. Aiemmin, ja monissa organisaatioissa vielä nykyisinkin, käsityönä tapahtuva työvuorojen ja työn suunnittelu sekä työn seuranta ja raportointi vie runsaasti aikaa. Toiminnan tehostumiseen voidaan päästä jo kulkureitit huomioivan suunnittelutyön automatisoinnin ja helpottumisen myötä. Säästyvä aika voidaan käyttää palvelujen laadun parantamiseen esimerkiksi kotikäyntien keston pidentämisen muodossa. Reitinoptimointi voisi olla myös osa toiminnanohjausjärjestelmää (ERP).

Myös muita mahdollisuuksia, kuten laskennallisia neuroverkkoja, simulointia ja prosessien louhintaa tulisi tutkia tarkemmin kotihoidon tuottavuuden, taloudellisuuden ja laadun kehittämiseksi. Näistä menetelmäalueista kahta kuvattiin tutkimuksessa lyhyesti.

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APPENDIX 1 ADDITIONAL LISTS AND FIGURES

APPENDIX 1.1 Softwares used

- Data analysis, statistical testing and visualization programming:[1]
  R programming language, version 3.0.0–3.2.3 (GPL license)
- Statistical test cross-checking: **IBM® SPSS® Statistics, versions 20–22**
- Additional calculations and visualizations: **Wolfram Mathematica®, versions 8–10**, **Maxima** (GPL license) and **Octave** (GPL license)
- Data processing and additional programming: **Ruby programming language, version 1.9.3–2.0.0** (GPL license)
- Optimization experiments: **Spider Solutions AS SPIDER Designer, version 4** and **Concorde TSP Solver**
- Document typesetting: **LaTeX** (GPL license) with **Vi 7.4** and **MacVim 8.0** text editors (GPL license)

APPENDIX 1.2 Figures

1 Mac OS X versions.

FIGURE 48 Daily frequency of home visits in 2010–2012 as a violin plot. Smaller frequencies in Subfigures (a) and (c) are weekend home visits logged as home health care (see also Figure 16).

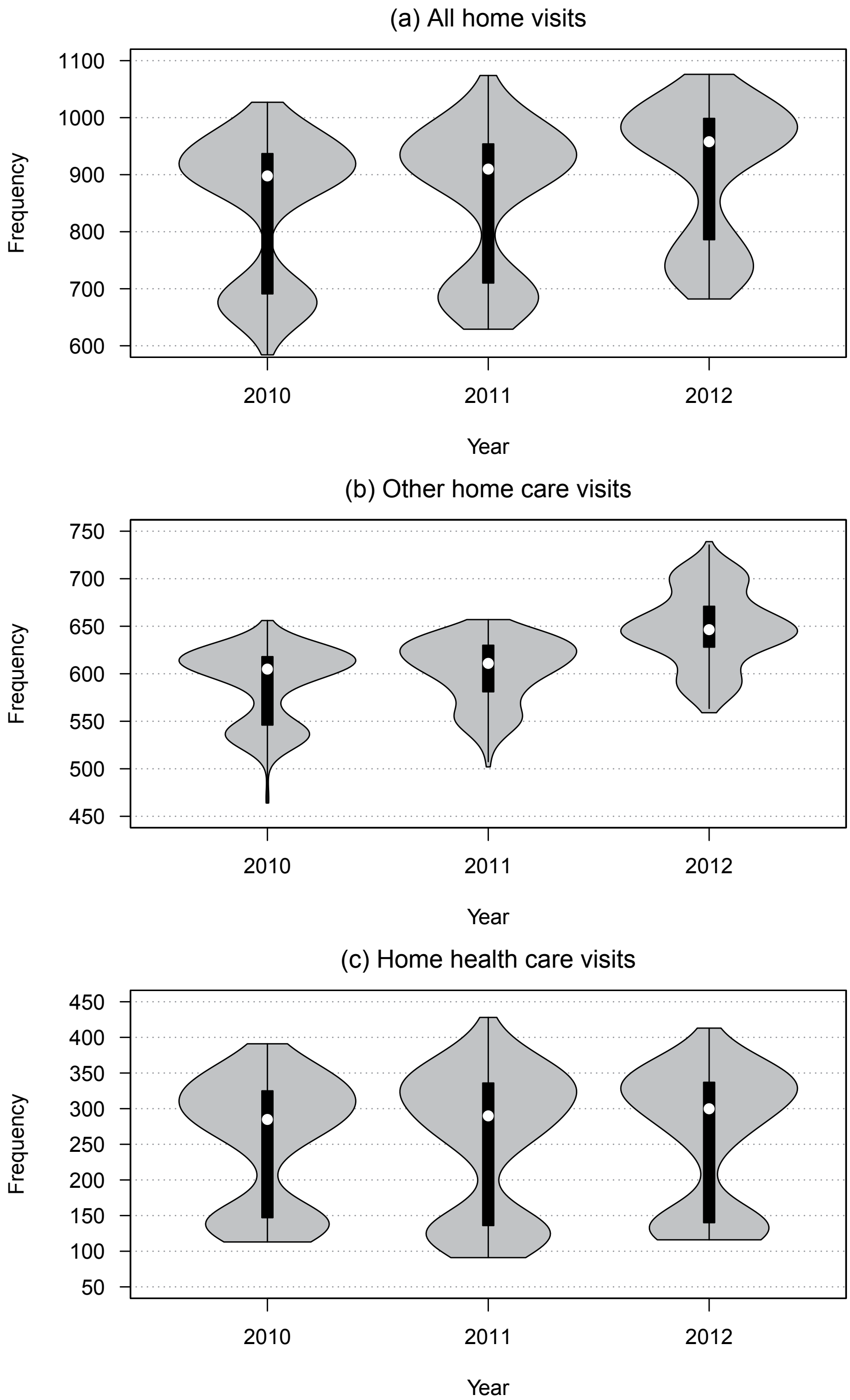

FIGURE 49 Daily frequency of separate customers served in 2010–2012 as a violin plot. Smaller frequencies in Subfigures (a) and (c) are weekend home visits logged as home health care (see also Figure 16).

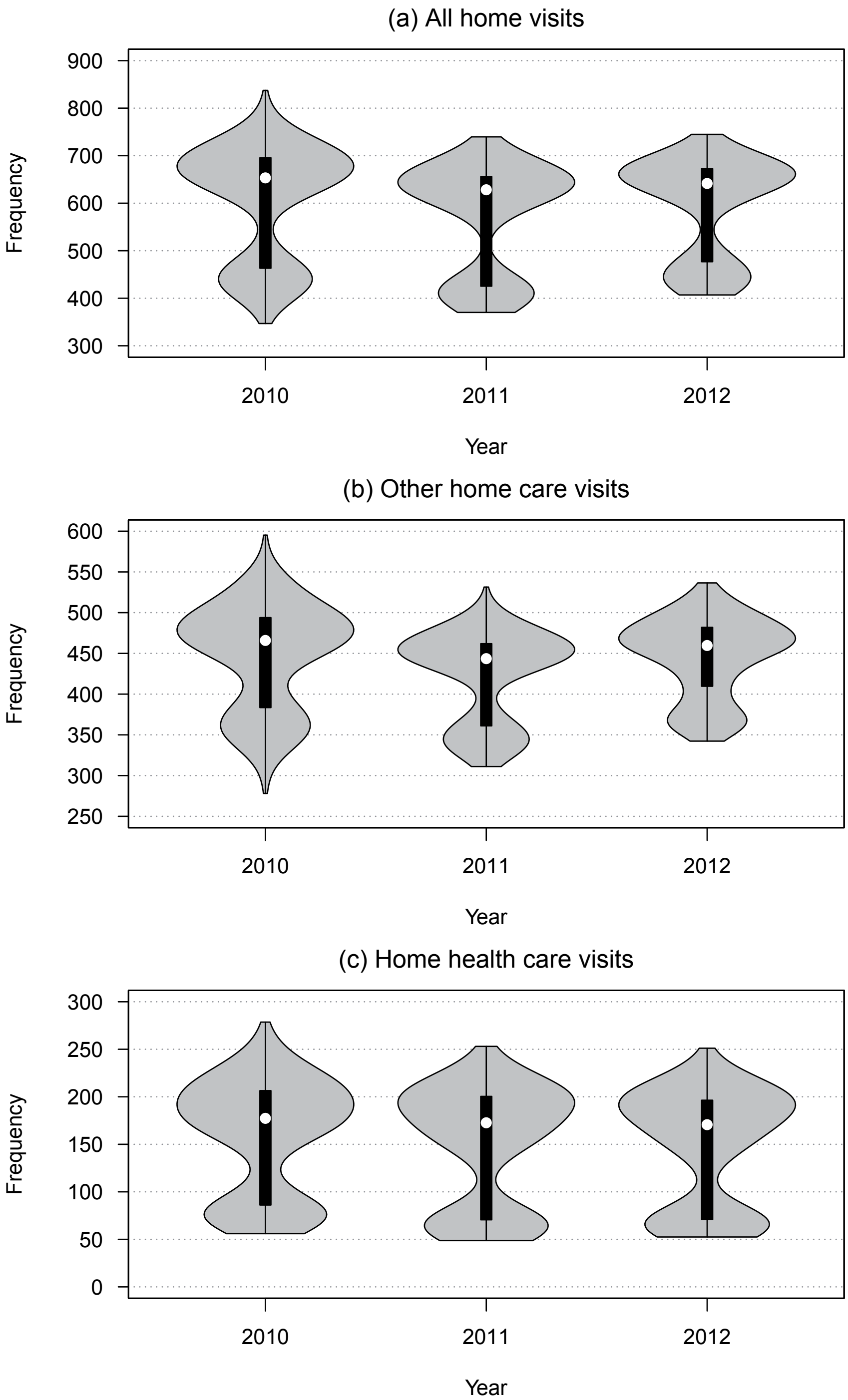

FIGURE 50 Daily home visit hours in 2010–2012 as a violin plot. Smaller frequencies in Subfigures (a) and (c) are weekend home visits logged as home health care (see also Figure 16).

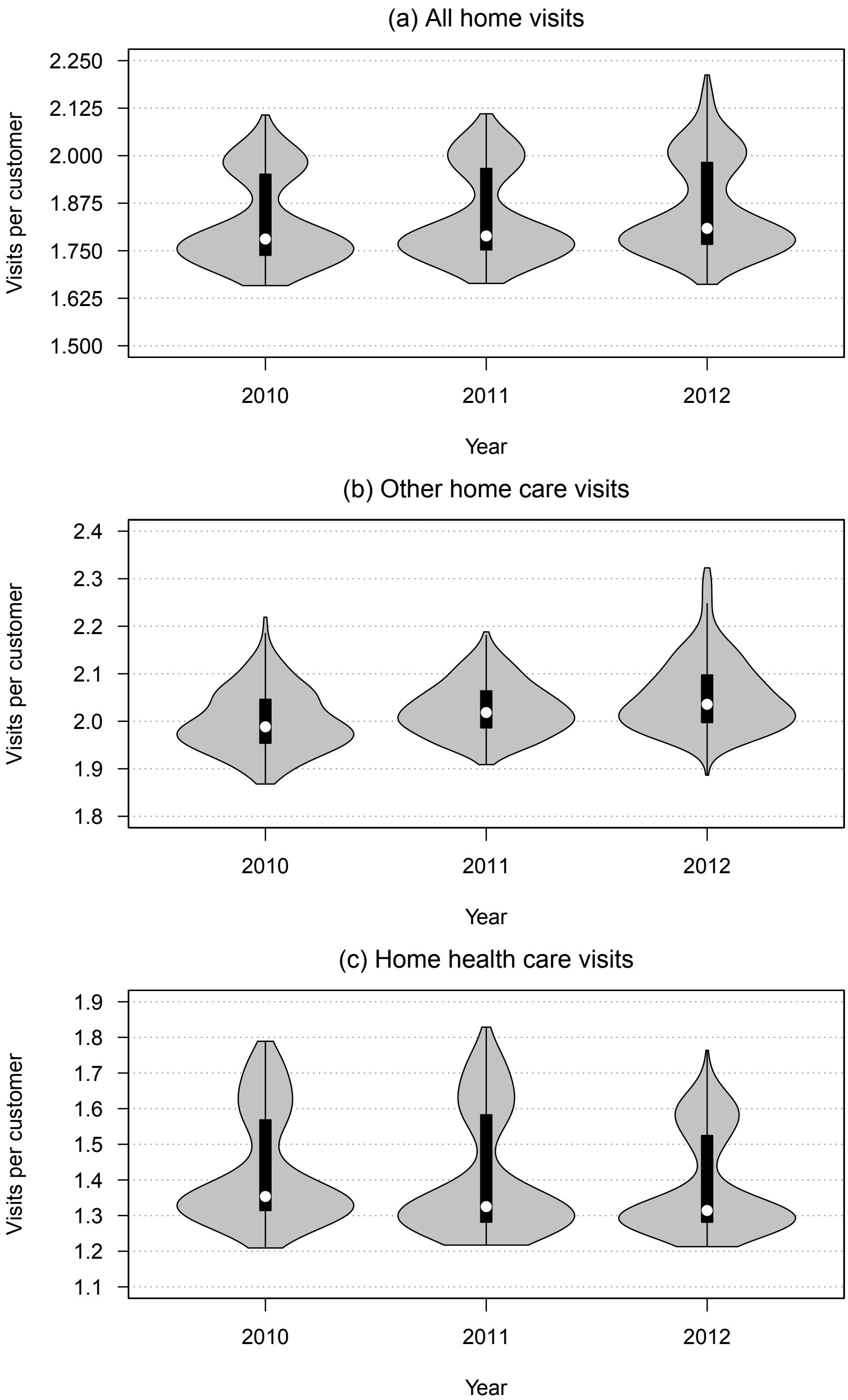

FIGURE 51 Daily home visit per customer ratio in 2010–2012 as a violin plot. Smaller frequencies in Subfigures (a) and (c) are weekend home visits logged as home health care (see also Figure 16).

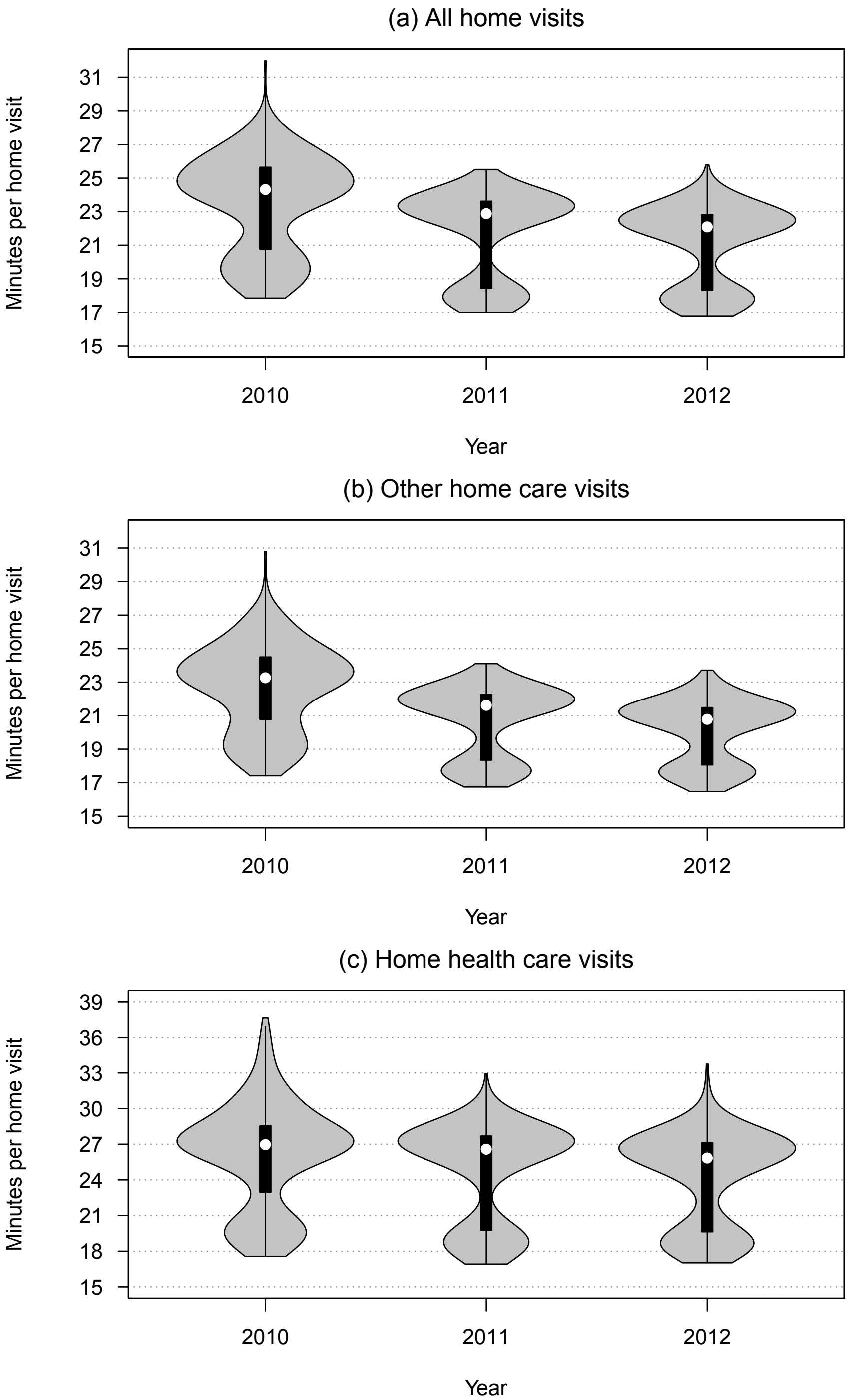

FIGURE 52 Daily home visit mean durations in 2010–2012 as a violin plot. Smaller frequencies in Subfigures (a) and (c) are weekend home visits logged as home health care (see also Figure 16).

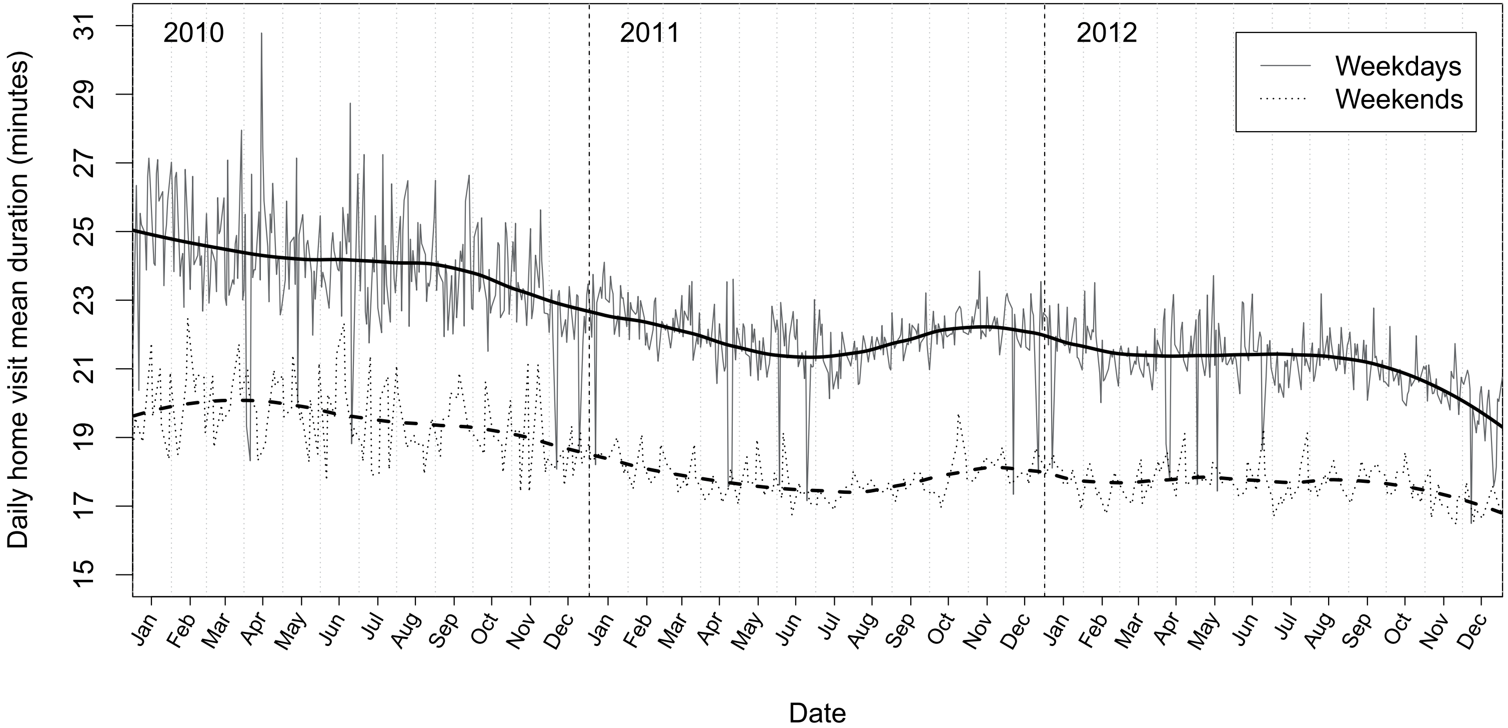

FIGURE 53 Daily mean home visit duration of other home care visits (home health care not included) in 2010–2012.

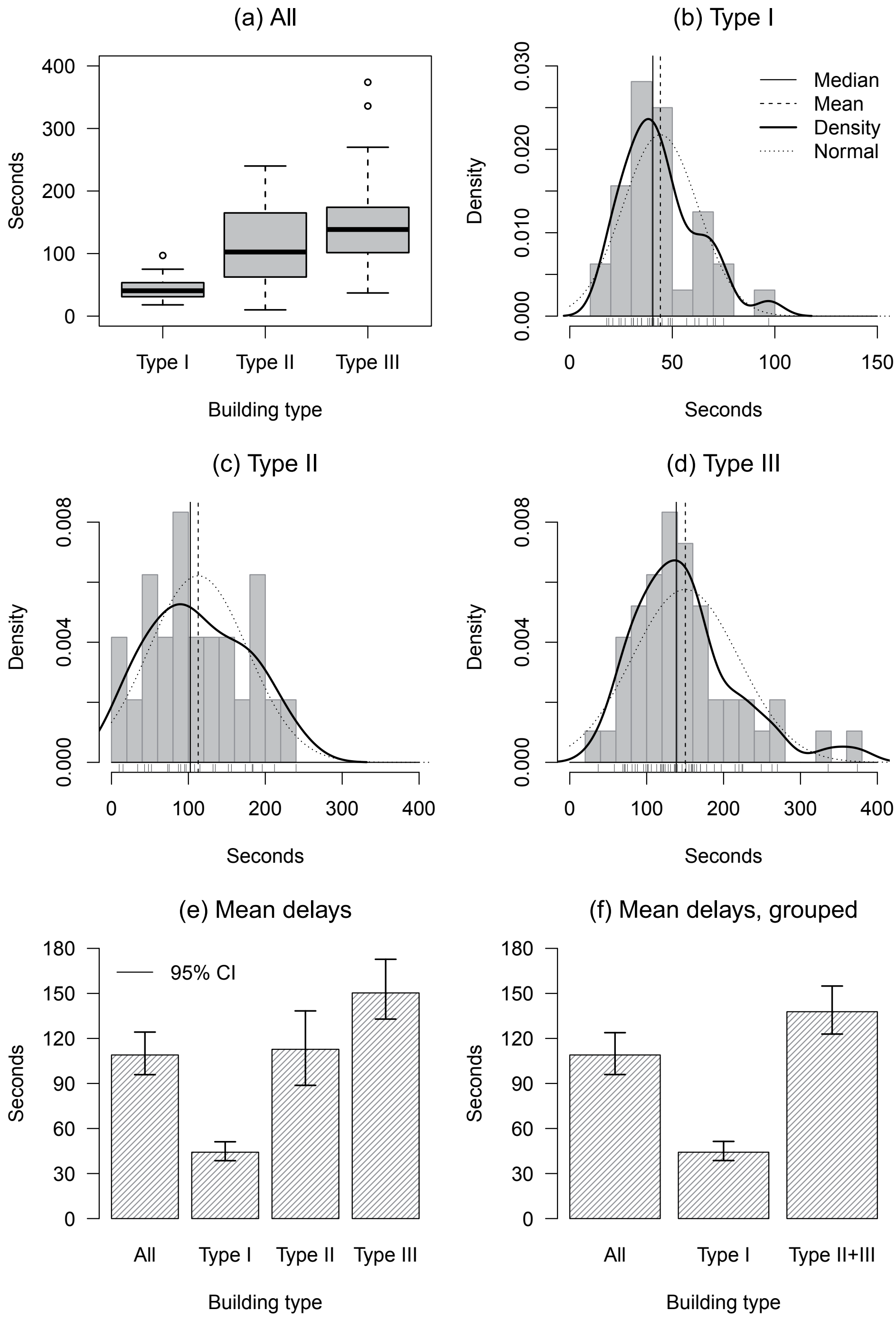

FIGURE 54 Time delays by building type. 95% confidence intervals (Bias-corrected and accelerated bootstrap) for means included in (e) and (f).

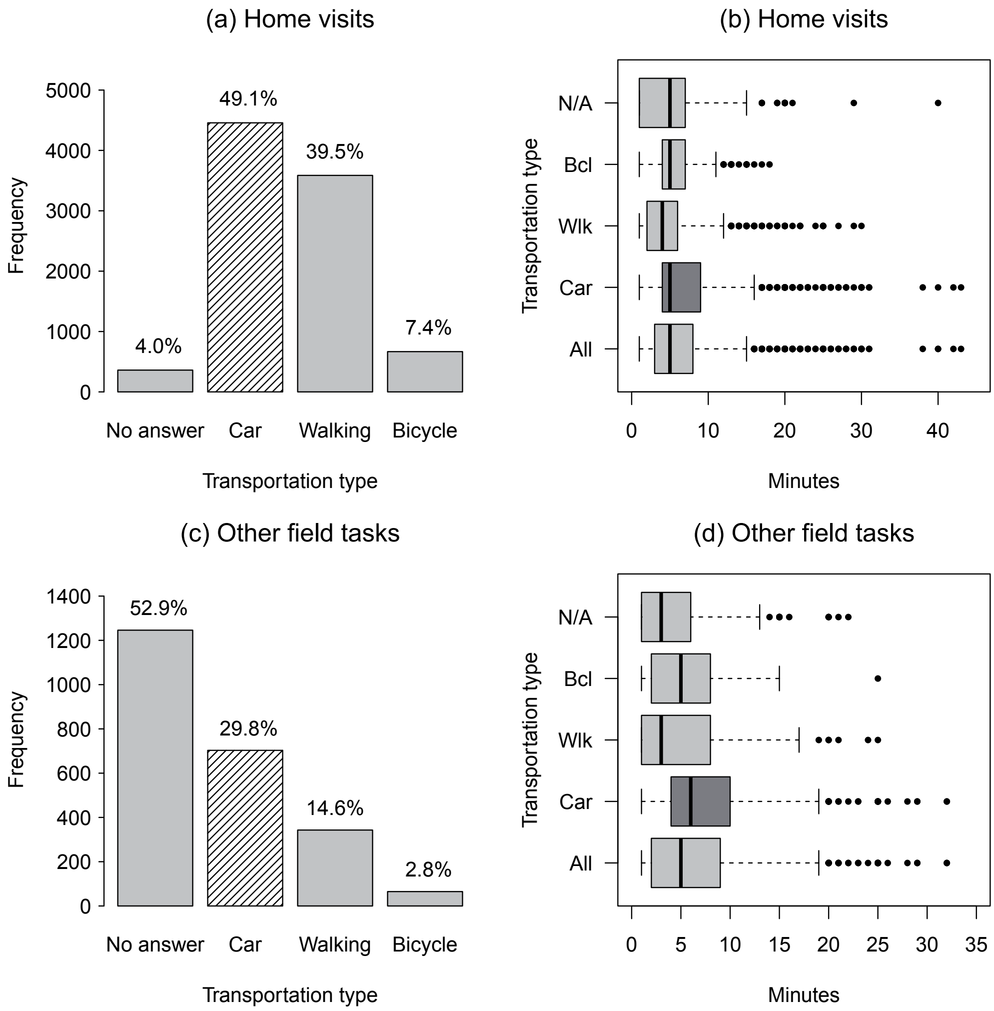

FIGURE 55 Transit times by transportation type. Home visits (a) and (b) excludes teams working at serviced apartment buildings. Distribution of transit time (some outliers excluded) by transit type is represented in (b) and (d).

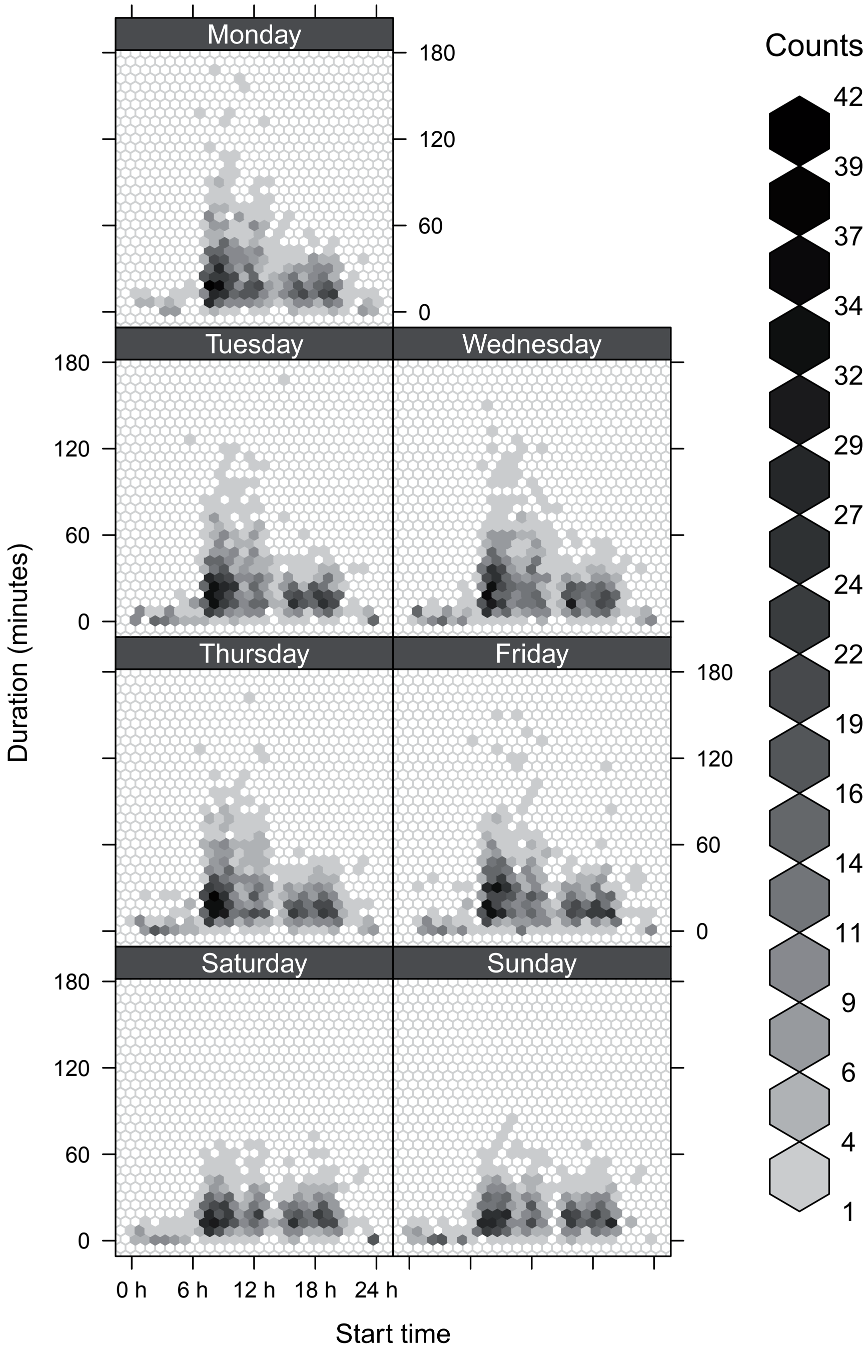

FIGURE 56 Home visit start times and durations per day in November 2011 one week data. Darker color indicates higher concentration.

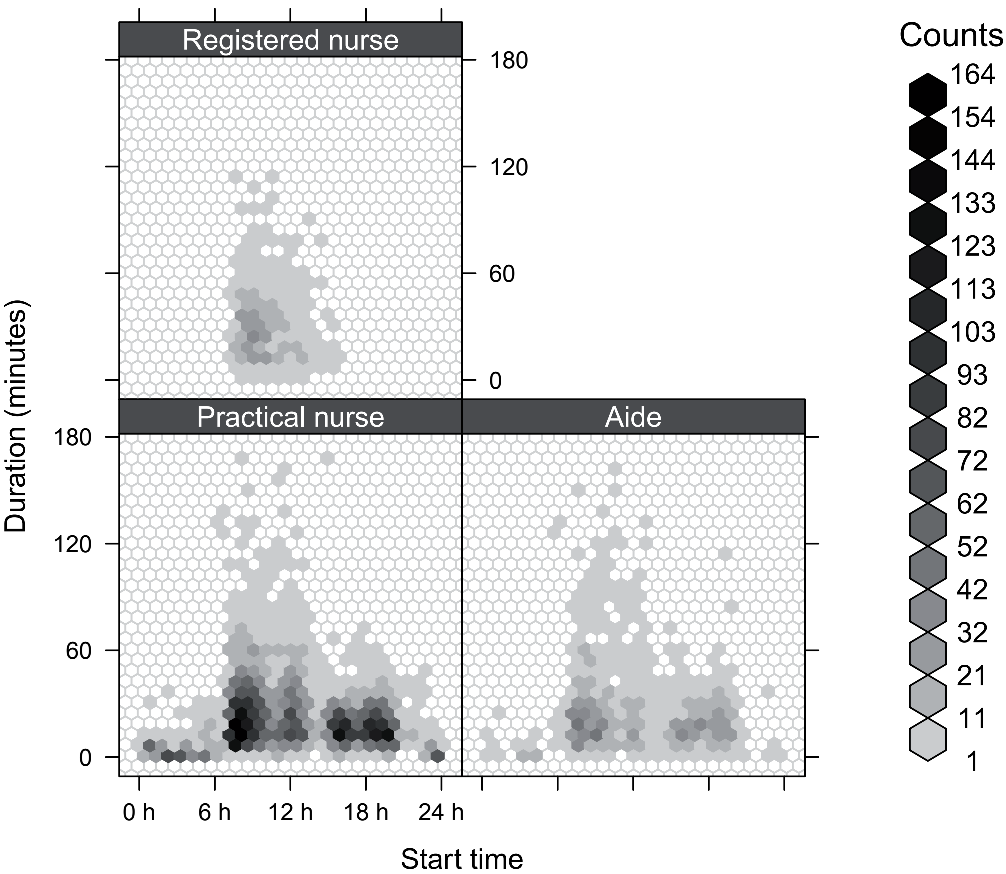

FIGURE 57 Home visit start times and durations in November 2011 one week data grouped by worker titles. Titles grouped by education level as presented in Table 5, e.g., registered nurses and public health nurses are both under the first category and the last category contains workers without vocational practical nurse degree. Darker color indicates higher concentration.

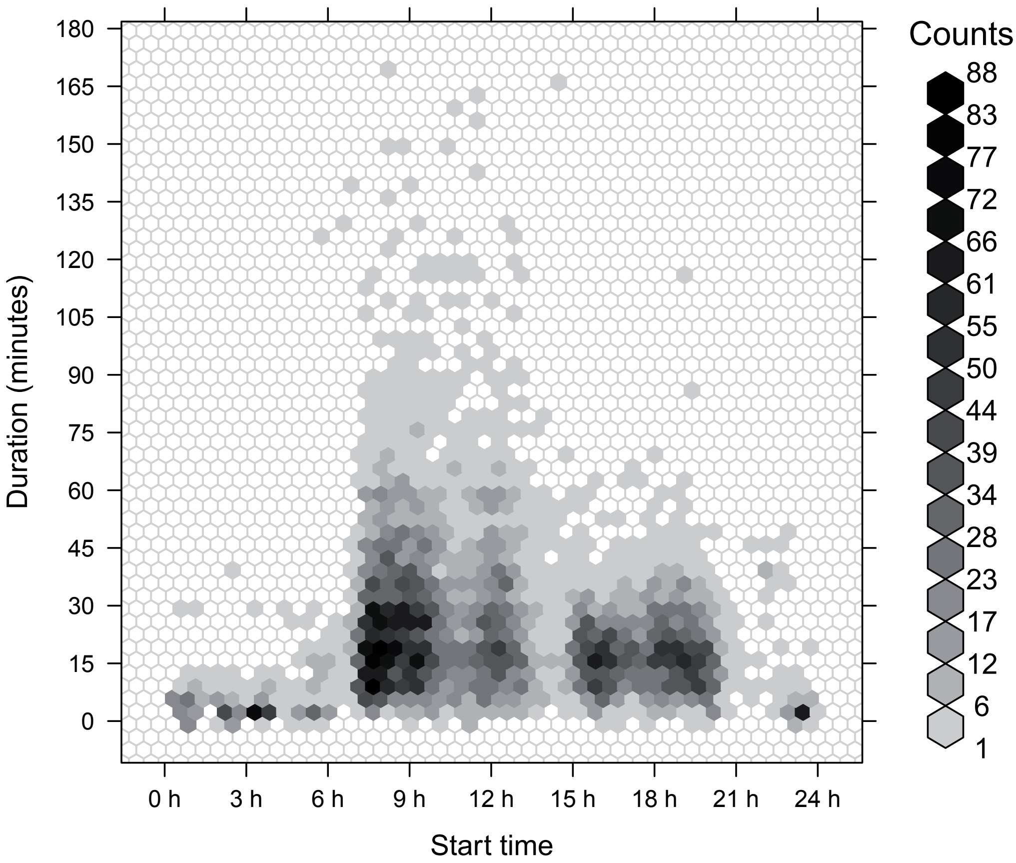

FIGURE 58 Home visit start times and durations in November 2011 one week data. Morning rush visible in the morning. Darker color indicates higher concentration. Morning rush is typical also in other home care organizations as well. [LV13]

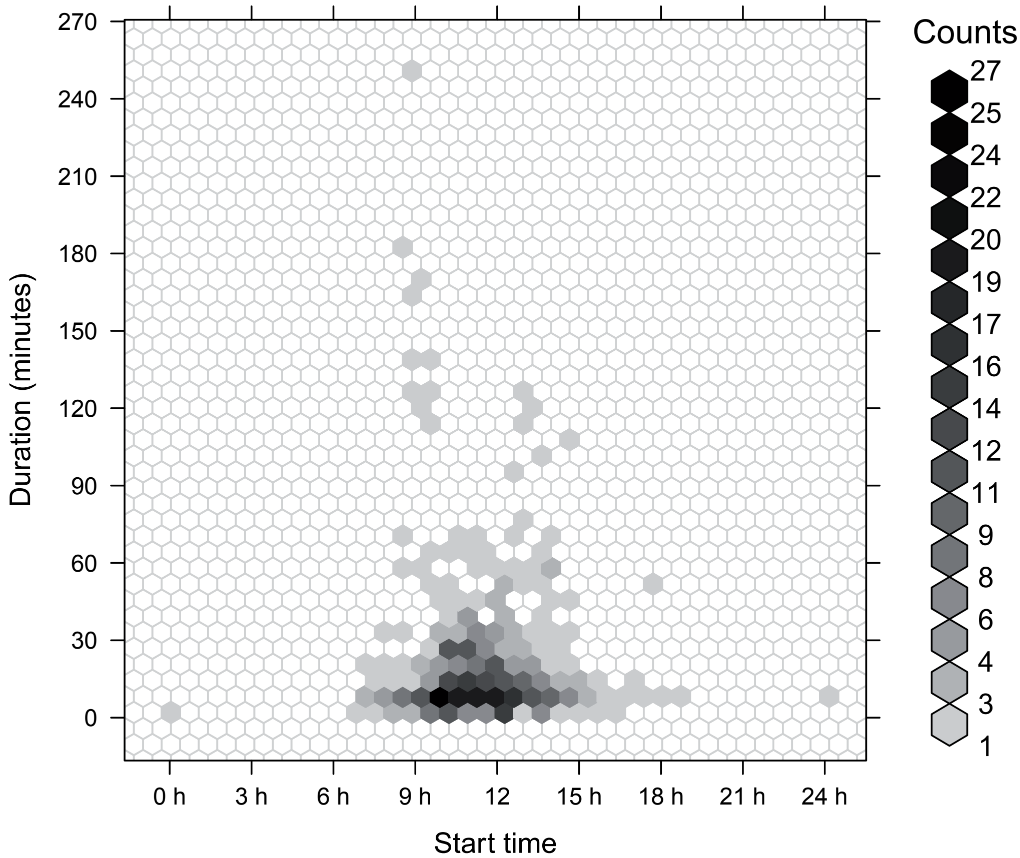

FIGURE 59 Field task visit start times and durations in November 2011 one week data. Darker color indicates higher concentration.

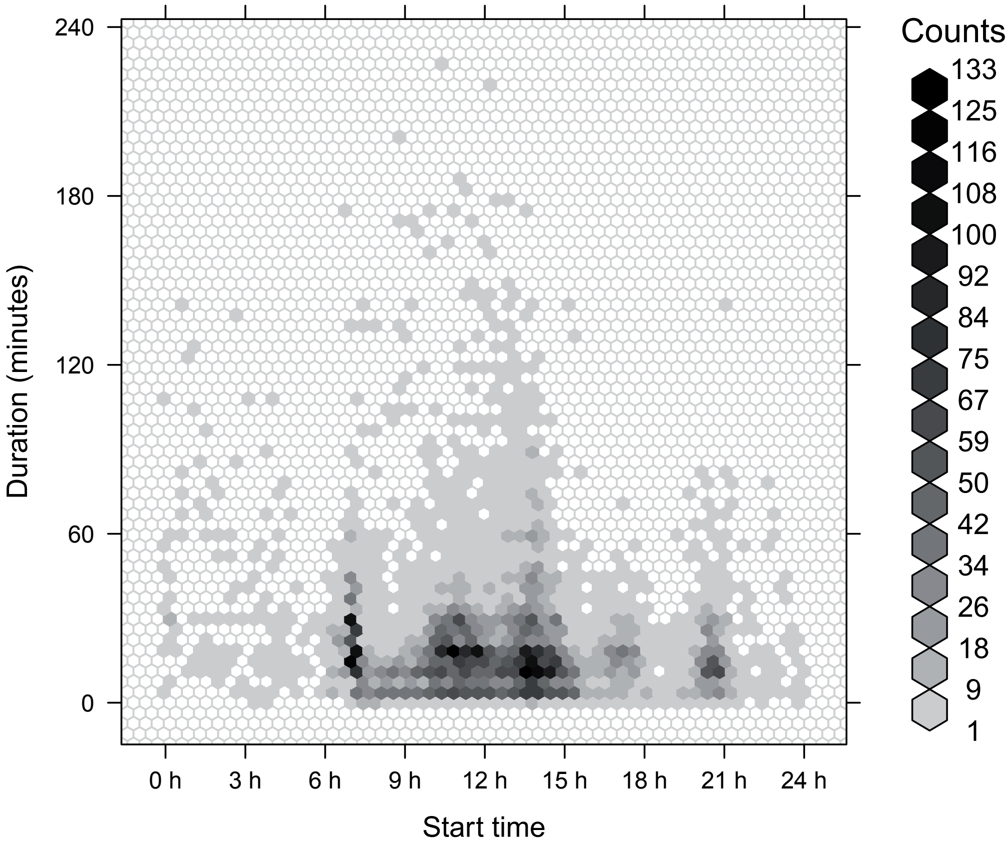

FIGURE 60 Office task start times and durations in November 2011 one week data. Shift start and end duties at shift switching times visible in the morning, afternoon and evening. Darker color indicates higher concentration.

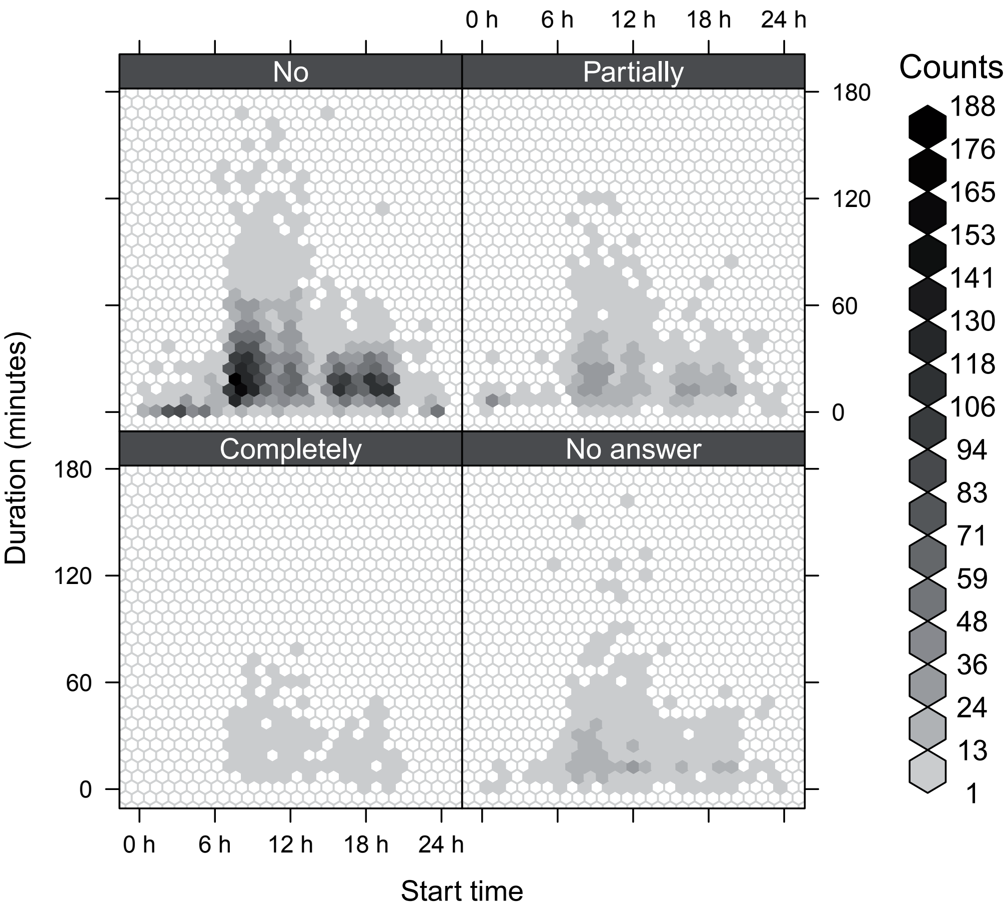

FIGURE 61 Home visit movability (according to the worker's judgement, the home visit could have been moved to another time *partially*, *completely* or *not at all*) as classified by workers.

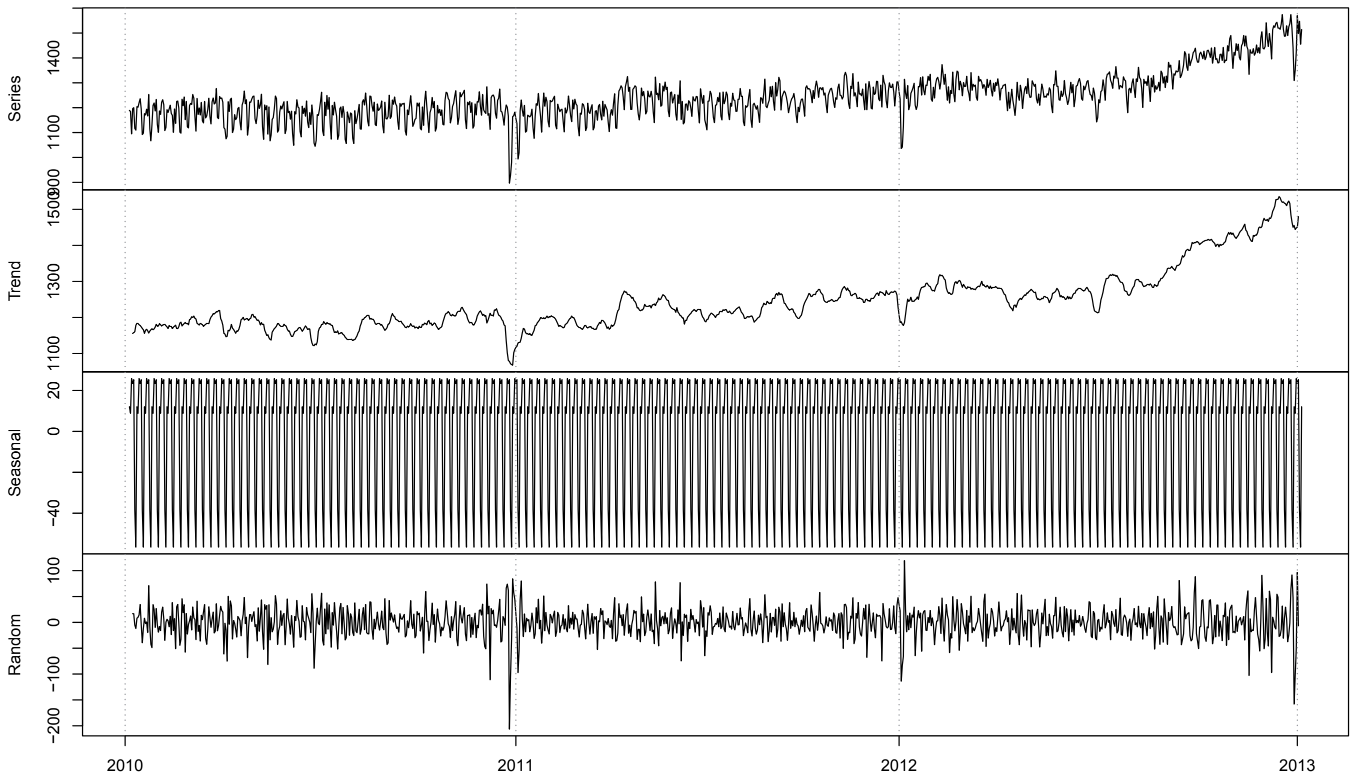

FIGURE 62 Additive time series decomposition of other home care visit frequencies in 2010–2012.

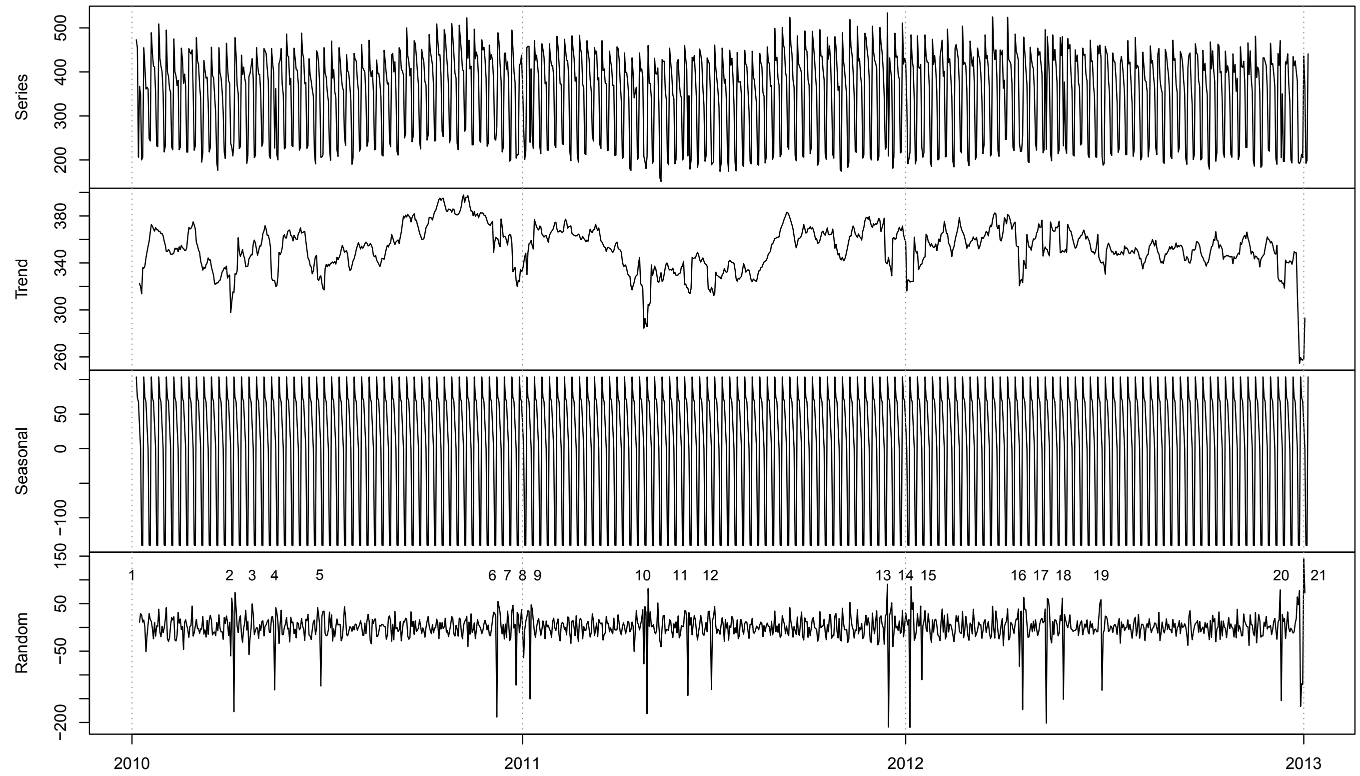

FIGURE 63 Additive time series decomposition of home health care visit frequencies in 2010–2012. Numbered peak signals are national holidays (New Year, Easter, May Day, Midsummer, Independence Day, Christmas etc.).

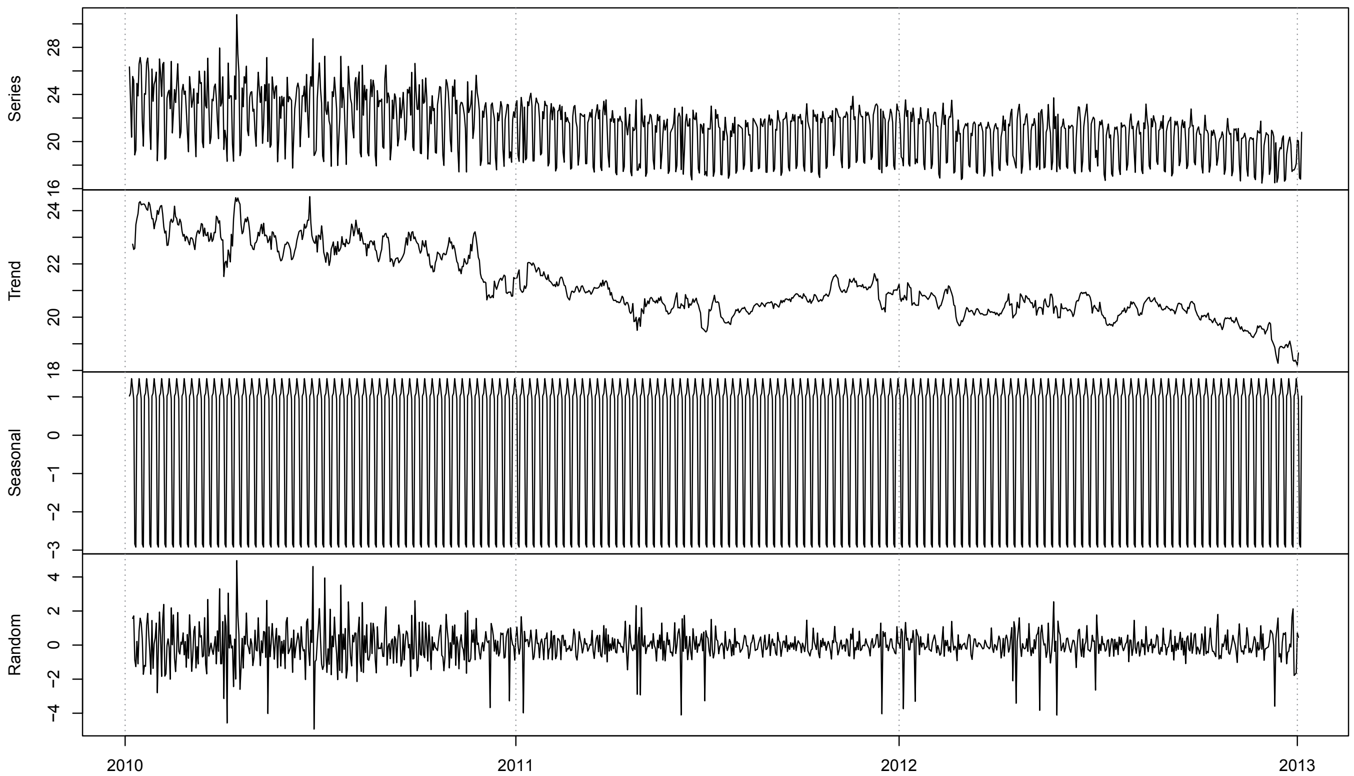

FIGURE 64 Additive time series decomposition of other home care visit mean durations (in minutes) in 2010–2012.

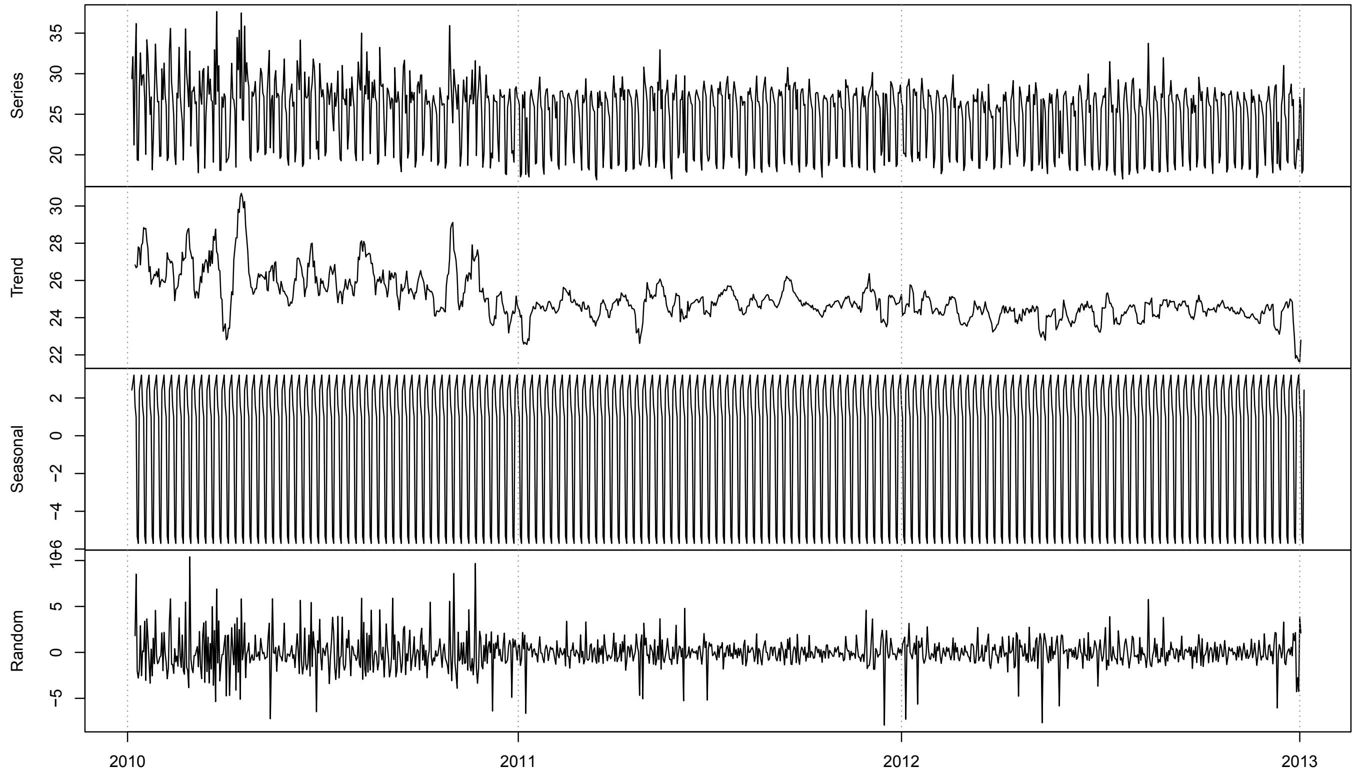

FIGURE 65 Additive time series decomposition of home health care visit mean duration (in minutes) in 2010–2012.

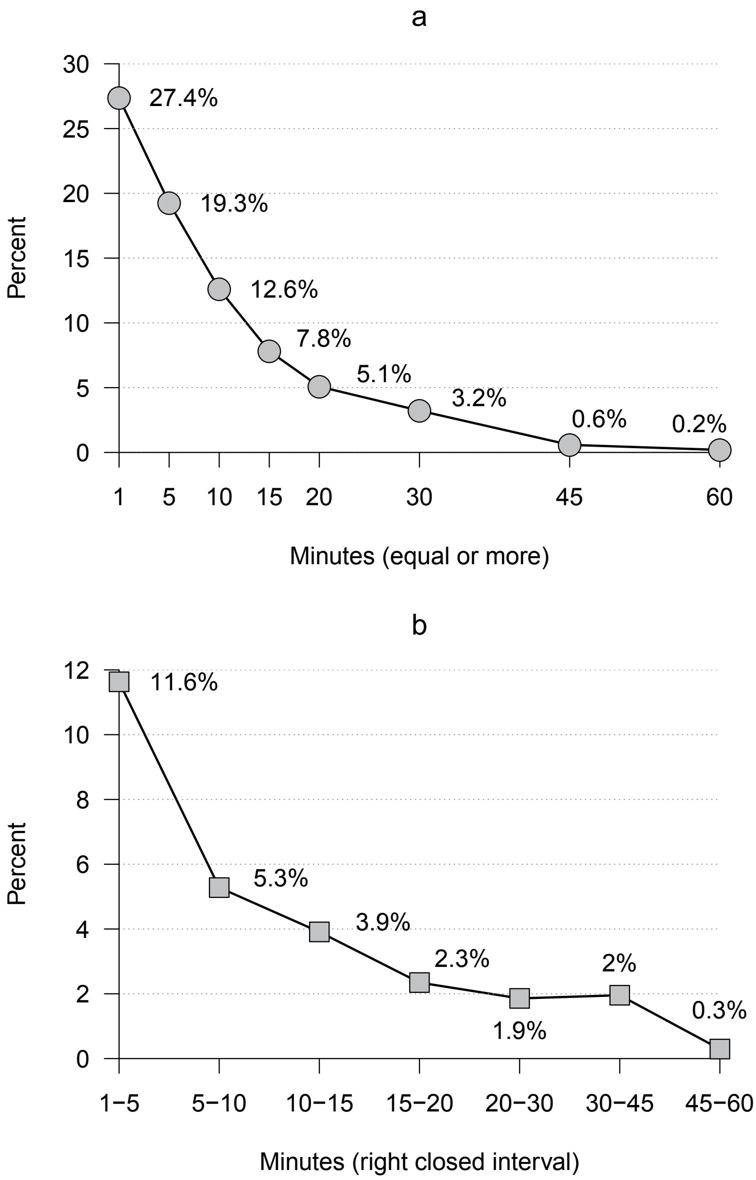

FIGURE 66 Frequencies of home visit duration exceedings (Eastern Finland data for ANN experiments, Section 7.1).

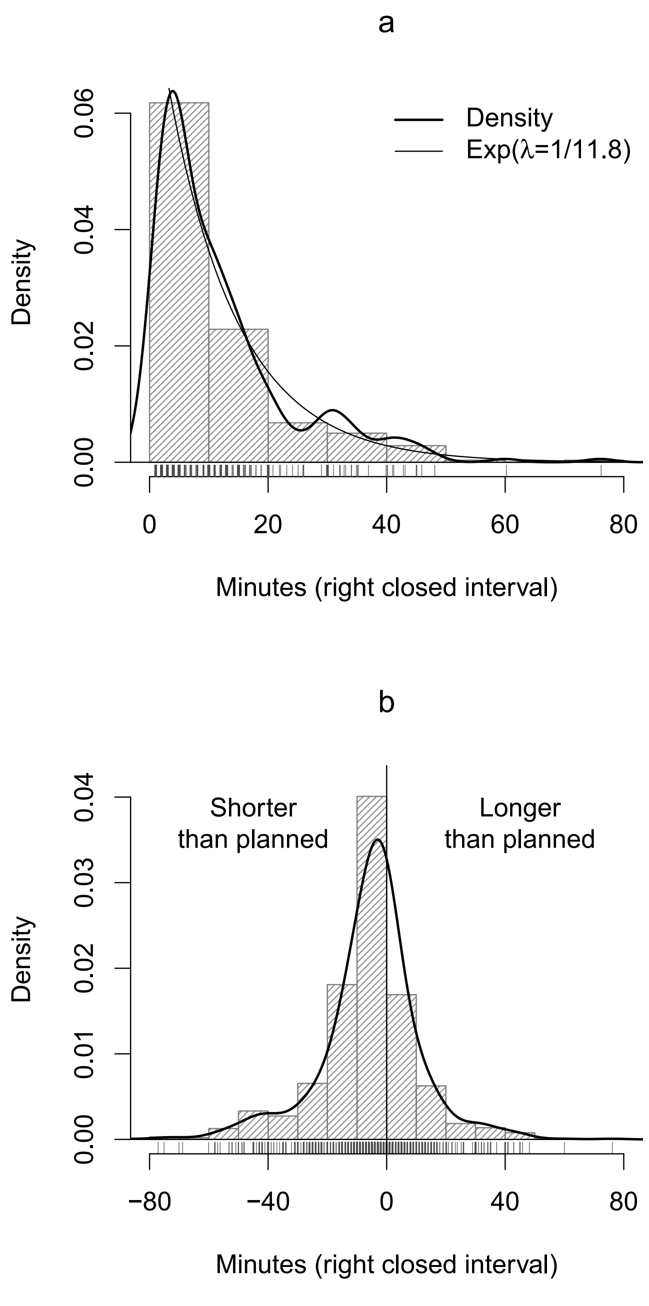

FIGURE 67 Distribution of home visit duration exceedings (Eastern Finland data for ANN experiments, Section 7.1).

Jyväskylän kaupunki

Kotihoidon työajan seuranta 31.10.-6.11.2011

Nimi ____

Käyttäjätunnus Efficassa ______________________________

Nimike____

Oman tiimin tunnus __________________________________

Työpäivän pituus____________tuntia_________minuuttia

Työpäivän aikana autolla ajetut kilometrit yhteensä_________________

Vuoro _____aamu ________ilta _______yö

Puh. mahdollisia tarkistuksia varten___________________________

1 = **Toimistolla päivän alku- tai lopputoimi ja muu työ** (esim. oman työn suunnittelu, päivän ohjelman tarkastelu, hoidon suunnittelu, laboratoriolähetteiden ja -vastausten tulostaminen (osoite, siellä aloitus ja lopetuskellonaika)
2 = **Lääkeasioiden käsittely toimistolla** (osoite, siellä aloitus- ja lopetuskellonaika)
3 = **Yhteistyötapaamiset asiakkaan asiassa eri tahojen kanssa** (esim. omaiset, srk., lääkäri, yhteistyökeskustelut; osoite, siellä siellä aloitus- ja lopetuskellonaika)
4 = **Effica -tilastointi ja -kirjaaminen** (osoite, siellä aloitus- ja lopetuskellonaika)
5 = **Laboratoriossa käynti** (lab. osoite, siellä aloitus- ja lopetuskellonaika)
6 = **Pyykinpesu muualla kuin asiakkaan kotona** (osoite, siellä aloitus- ja lopetuskellonaika)
7 = **Asiointikäynti** (esim. asiakkaan apteekki-, kauppa- yms. asiat; osoite, siellä aloitus- ja lopetuskellonaika)
8 = **Puhelin-, sähköposti-, fax-asiointi asiakkaan asiassa** (esim. asiakkaan, toisen työntekijän, muiden tahojen kanssa, kauppatilaukset; osoite, siellä aloitus- ja lopetuskellonaika)
9 = **Opiskelijan ohjaus** (esim. näyttöjen vastaanottaminen, palautekeskustelut, selkeä ajallisesti erotettava kokonaisuus; osoite, siellä aloitus- ja lopetuskellonaika)
10 = **Saunotukset muualla kuin asiakkaan kotona** (osoite, siellä siellä aloitus- ja lopetuskellonaika)
11 = **Kokoukset** (esim. tiimipalaveri, työpaikkakokoukset, kehityskeskustelut; osoite, siellä aloitus- ja lopetuskellonaika)
12 = **Koulutuksiin ja virkistystilaisuuksiin osallistuminen** (esim. varsinaiset koulutukset, henkilöstöinfot, syystartit; osoite, siellä siellä aloitus- ja lopetuskellonaika)
13 = **Ruoka- ja kahvi- ym. tauot** (osoite, siellä siellä aloitus- ja lopetuskellonaika)
14 = **Asiakaskäynti** (osoite; siellä aloitus- ja lopetuskellonaika)
15 = **Muu ajankäyttö** (esim. erilaiset hankinnat, tilaukset, auton- ja muut huollot, puhelut auton parkista, tähän seurantaan käytetty aika; osoite, siellä aloitus- ja lopetuskellonaika)

Viikonpv **MA**=(31.10.) **TI** = (1.11.) **KE** = (2.11.) **TO** = (3.11.) **PE** = (4.11.) **LA** = (5.11.) **SU** = (6.11.)	**Tapahtuman nro** (tehtävä, työkokonaisuus tms. ks.luokat) Vain yksi numero riville	**Milloin alkoi tapahtumapaikassa klo**	**Milloin päättyi tapahtumapaikassa klo**	**Kotikäyn. pääsisältö** **T**=turvahäl. **S**= sh,th **M**=muu	**Missä osoitteessa, kadun nimi ja talon numero** (paikan, esim. tiimitilan, asiakkaan, apteekin, huoltoaseman osoite)	**Postinumero**	**Tapahtuma paikkaan liikuttu** **A**= autolla **K**=kävellen **P**=pyörällä	**Onko siirtymisessä osoitteen sisälle esim.** parkin, hissin, vuoksi **yleensä viivettä**? **E**=ei **J**=jonkin verran **H**=huomattavasti	**Asiakkaan tiimin tunnus, jos muu kuin oma tiimi**	**Kotikäynti olisi ollut siirrettävissä ajallisesti** **E**=ei **O**=osittain **K**=kokonaan	**Kotikäynti alkoi** **S**=suunnitellusti **E**=etuajassa **M**=myöhässä	**Kotikäynti vei aikaa** **S**=suunnitellusti **E**=enemmän **V**=vähemmän

Kun siirryt osoitteesta toiseen, merkitse tarkoin tapahtuman alkamisen ja loppumisen kellonaika tapahtumapaikassa (kodissa, muussa tilassa). Saman osoitteen sisällä, pääasiassa tiimitilassa, tapahtumien väliin ei saa jäädä aikaa. Tapahtumille voidaan antaa vain yksi luokitus, vaikka käytännössä usein tehdään samanaikaista työtä. Matkoihin kulunut aika saadaan myöhemmin selville vähentämällä työpäivän kokonaispituudesta tapahtumiin (osoitteiden sisällä) yhteensä käytetty aika . **Täytettyjä lomakkeita käsitellään salassapidettävinä.** **Jatkolomake** ⟹

FIGURE 68 Visit data collection form.

Jyväskylän kotihoidon asiakaskäyntien sisällön seuranta 2013

TUNNUS: ______________________

TIIMI: ______________________

NIMIKE: ______________________

PVM: ______________________

PUHELIN: ______________________

VUORO: **1-Aamu** **2-Iltapäivä** **3-Yö**

Merkitse käynnin alkamisen ja päättymisen aika minuutin tarkkuudella ilman pyöristämistä. Merkitse sisältökoodit sen mukaan mitä tehtäväluokkia kotikäyntiin sisältyi. Koodeja voi olla useita. Muista täyttää myös tunnus, tiimi, nimike, päivämäärä, puhelinnumero mahdollisia tarkistuksia varten sekä ympyröi vuoro. Merkitse rasti sarakkeeseen S mikäli käynti on säännöllisesti päivittäin tehtävä (esim. asiakkaan aamu/ilta-avustus joka päivä samaan aikaan). Merkitse rasti sarakkeeseen M mikäli käynti kesti suunniteltua pidempään ja aiheutti aiheutti seuraavasta käyntiosoitteesta myöhästymisen. Mikäli käyntiin sisältyy merkittävä sisältökoodeista poikkeava työtehtävä, merkitse X. Kuvauksen ja rivinumeron voi kirjoittaa lomakkeen reunaan tai kääntöpuolelle.

Rivi	Käynti alkoi klo	Käynti päättyi klo	S	M	Käynnin sisältökoodit (kaikki käyntiin sisältyneet tehtävät)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

SISÄLTÖKOODIT

1	Nostaminen/siirtäminen
2	Ruokahuolto/ruoan lämmitys
3	Syöttäminen
4	Vaatehuolto/pyykinpesu
5	Pukeminen
6	Siistiminen (kodin)
7	Lääkkeiden antaminen
8	Lääkkeiden jako/dosetit
9	Hygienia/suihku
10	Ulkoilu
11	Puhelinasiointi käynnin aikana
12	Perusterv.huol./rasvaus/verenp. ym
13	Pistokset/verensokeri ym.
14	Muu näytteenotto (laboratorioon)
15	Haavanhoito
16	Muu sairaanhoito (esim. tikit)
17	Tarkistuskäynti
18	Turvahälytyskäynti

Lomaketta ja aineiston keräämistä koskevat kysymykset: pentti.nakari@jyu.fi

FIGURE 69 Visit content data collection form.