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Sustainable Urban Homecare Delivery with Different Means of Transport

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Abstract: Due to the increasing number of requests for homecare services, care institutions struggle to perform in urban traffic, which eventually makes travel times longer and less predictable and, therefore, leads to a declining service quality. Homecare delivery scheduling and planning tools must lead to efficient reliable routes that allow the nursing crew to make the least efforts and use the fewest institutional resources, and that consider urban sustainability goals. For the case study, a European city was selected with 58,000 people of whom 73 patients received long-term care at homes provided by 11 homecare nurses. While maximising patient satisfaction, a homecare planning algorithm considered many means of transport and minimised travel times. The study reduced the total nurses' working hours/day by a bus and walking combination, and by comparing if nurses ride e-bikes, which respectively reduced ~35–44% of the total time that nurses spent travelling. This result is applicable to an urban environment where the public transport network is sufficient and biking is allowed on a reasonable number of roads. Better homecare management can support the efficient use of resources of health care institutions, high-quality home care and aspirations towards livable communities and sustainable development.

Keywords: home care; sustainable and efficient transport; algorithm in an urban environment; sustainable communities

1. Introduction

Community care (home care) is rapidly increasing with ageing populations and the elderly's wish to receive care at home [1]. Home care (HC) can be manifested in two different, but still very similar, patient care ways: one is temporary HC after an acute health incident. It results from health problems from which the patient has a good chance of recovering, but still needs certain forms of care, but his/her health status does not require further hospitalisation; the other is long-term care (LTC). Here, care is provided for patients with a chronic, and even irreversible, illness or disability. The main goal of LTC is to maintain, or even improve, the quality of a patients' remaining life [2]. Although LTC is not restricted by age, recipients of long-term HC are mostly elderly people (some 80%), apart from younger disabled groups [3], who need assistance with activities of daily living (ADL), instrumental activities of daily living (IADL) and some nursing care [4]. Although health status is improving in OECD countries, the speed of the ageing process is likely to lead to an increasing demand for LTC services [3].

To make HC accessible to everyone who needs domestic care services, it has become a comprehensive intent of many organisations and professionals with different objectives and actions in their scopes: improving community care [5], developments in LTC service delivery and promoting policies to provide HC [6], removing the obstacles of, and facilitate, independent living [4,7–9]. The above improvements can be made through various instruments, such as telecare (telemedicine, e-health) [10], measuring health (physiological and psychological) and quality of life outcomes of interventions in healthcare systems [11,12], implementing in-home health aids and coaching [13], educating and training care personnel [14], and improving routing and scheduling [15–17].

In the last two decades, HC delivery has formed part of the research interest, often formulated as workforce routing and scheduling problems, and consists in multiple well-known problems in operations research [16,18]: Travelling Salesman and Vehicle Routing problems to grasp the routing part, and General Assignment and Knapsack problems to optimally assign care activities to caregivers. Given the complexity of HC services, it has become a quickly-evolving research area [19,20], and different approaches to daily and periodic HC scheduling have been frequently published. Cheng and Rich [21] use time windows to promote patient convenience. Bertels and Fahle [22] combine simulated annealing and constraint programming to schedule more nurses and jobs. Eveborn et al. [23,24] propose a decision support system that includes multiple transport modes (car, bicycle and walking), but not combinations of them. Several researchers apply Branch-and-Price Algorithms [25–27] and metaheuristics, such as variable neighbourhood searches [28–30]. Urban challenges are increasingly emphasised in recent studies: Hiermann et al. [31] apply their two-stage approach. It combines constraint programming with different metaheuristics to solve real-world scenarios of a HC provider in Vienna, where travel time data are based on estimates from public transport service providers and Floating Car Data. Fikar and Hirsch [32] present their pooled transport service concept with designated drivers to convey nurses from one operational area to another without encumbering nurses with the distress of driving and finding parking spots. Braekers et al. [33] report a trade-off between the often-contradicting nature of the highest possible patient convenience and optimal routing. These authors formulate the problem as a Bi-objective Homecare Routing and Scheduling Problem by defining a set of Pareto optimal solutions, from which decision makers can choose according to their individual preferences and institutional policies.

The reasoning behind ongoing HC service delivery improvements is that healthcare companies or institutions need to support last-mile care delivery as either a key driver of the company's overall profitability or a means to control costs. Nowadays, all healthcare systems are under enormous pressure to reduce costs, while they must maintain, or even increase, patient satisfaction at the same time [17,33]. Systems like HC are money-consuming, sometimes inefficient, or are simply not effective enough to provide all the required assistance to all patients. The delivered HC service has a direct impact on both the care chain and patients' experience: a good care service fulfils a variety of care-chain objectives, which ranges from low-cost and sustainability to high responsiveness.

As the predominant use of motor vehicles in cities will continue to have a strong environmental and socio-economic impact [34], increasing pressure on urban realities has led to much more interest being paid to all sustainability aspects in urban planning, its development, and all types of transport (goods, services and people). There is presently much concern about developing policies, programmes and projects that take sustainability into account [35] and refer to the Centre for Sustainable Transport, which defined the *Sustainable Transport System* requisites:

- It allows the basic needs of individuals and societies to be met *safely* and in a manner consistent with both *human and ecosystem health*
- It is *affordable*, operates efficiently and offers a choice of various transportation modes, which supports a booming economy
- It *limits emissions* and waste so that plants are able to absorb them. It minimises consumptions of renewable resources to a sustainable level, reuses and recycles its components, and minimises noise pollution and land use

Sustainability is a major issue for our society, and the development of an urban sustainability concept [36] implies many aspects. HC spells an urgent need to use transport systems that are less polluting in both noise and emissions terms, which is especially relevant in the urban logistics [37] that implies urban mobility. Therefore, in order to improve the sustainability of urban HC operations, three main streams are identified:

- *Technology*, for care to be delivered to homes. It is limited to the means of transport to be used by the nurses who provide the service
- *Policy*, at both the macro-level, where HC guidelines are defined by the authorities, and the health centre level, by setting a catalogue of feasible assistance and services to be provided in HC
- *Logistics*, designs that allow nurses to use the most enviro-friendly means of transport by planning the sequence of their use, reducing inoperative logistic times, etc.

These solution streams should be implemented separately, but not independently because, according to Taniguchi et al. [38], to achieve sustainable urban means of transport, it is necessary to use a combination of them. Moreover, the intention is to prioritise HC activity in all urban spaces inside the city. This compels the study of the spatial characteristics of the different points at which patients are located.

Sustainability in urban areas is understood in terms of perceiving the community, sensitivity to housing costs, defence against crime, and even environmental responsibility [39–41]. In 2005, Southworth [42] stated that a quality pedestrian environment is key to encouraging people to prefer walking instead of using vehicles. Forms of non-motorised transport are ecological, economic and reasonably quick for distances shorter than 3.5 km [43]. Urban areas that enable citizens to intrinsically walk have an economic value that favours economic transactions and social exchanges [44,45].

The idea of this study, presented herein, was to compare different transport facilities in an urban environment as a crucial entrance of an algorithm for scheduling HC activities by taking patient satisfaction as the highest priority. To fulfil this goal, the main concern was to propose a method that establishes links among HC factors in a modular manner so that the results would support perspicacity in various situations (e.g., decision making or policy development) by city authorities and HC institutions.

This paper now briefly presents the algorithm to schedule HC delivery, which is based on the combination of the *knapsack problem* and the *generalised assignment problem* (GAP), which provide the mathematical basis to develop the proposed algorithm. In the Results section, we indicate how it was applied to the urban area served by the Care Centre for the Elderly (CCE) in the city of Zalaegerszeg (Hungary) and we provide the results of the efficiency calculations. In the Discussion section, we explain the experiences acquired from studying sustainable transport by the devised algorithm.

2. Materials and Methods

The literature review on HC routing and scheduling presented in the Introduction shows that the focus on HC increasingly shifts towards the challenges generated by urban environments (and their organic evolution), such as traffic congestion, public transport schedules, lack of parking spots, etc., but the sustainability aspect is still not included. The following algorithm combines well-established goals with managerial aspects. The algorithm addresses these goals:

1. Maximising patient satisfaction. Punctual arrival and departure times to minimise patients' waiting time. Selecting the shortest possible routes so that nurses spend the least time on roads
2. Efficacy in HC services: maximising the number of services provided with the available resources
3. Management efficiency: as a way to control transportation costs and to correctly use available resources by also considering urban sustainability goals

The city, where the developed approximate algorithm was tested, has already made some steps towards a sustainable city core by restricting traffic, creating pedestrian-only zones and placing a few compressed natural gas (CNG) powered buses (low emission renewable fuel) in operation [46]. HC activities are organised by the CCE, an institution located in the city centre that acts as an umbrella to operate and coordinate LTC-related facilities and services. Their HC nurse crew's performance is strongly affected by changes in traffic, congestion, and whatever happens in the city, as their working time is partly spent travelling between patients' homes.

According to the CCE, the diversity of activities required in HC is very high: from administering medicines (standard time of 10 min), to making meals (standard time of 60 min), and cleaning and cooking (standard time of 120 min). Moreover, these activities require different skills. The busiest periods are the first couple of hours in the morning and around noon given the numerous requests to assist personal hygiene, administer medication and feeding. The algorithm has modelled all this by defining a time window in which such activities must be done. Other tasks, such as shopping, cleaning, picking up pharmaceuticals, are not as time-sensitive as the above-mentioned ones, which means they can be more freely scheduled. Most patients need daily care that lasts 10–120 min, and only on weekdays when family members are at work and they need to assign care tasks to someone else. Some patients need HC twice a week, and also with care needs that last 10–120 min. They do not usually require daily visits, but have certain issues that they cannot solve themselves (e.g., drug prescription/purchase, shopping, cleaning, etc.). Thus, they need regular help, but not necessarily on a daily basis. Table 1 summarises the frequency of the HC services to be delivered in the city under study.

Table 1. HC distribution in the city under study.

Frequency	Monday to Friday	Monday to Sunday	Tuesday to Friday
1 per day	34	7	1
1 per week	4		
2 per day	5	3	
2 per week	13		
3 per day		1	
3 per week	5		
Total		73	

Note: HC: Home care.

HC nurses start their shifts at the CCE, from where they visit a series of patients. Normally, there are several possible means of transport available to reach the next destination, while transport systems differ in terms of allowed speed, road requirements, etc. Therefore, travelling times vary depending on the chosen transit method. Selecting the shortest journey can be quite a complicated problem when there are many transport types. In this situation, it is convenient to apply an algorithm that quickly and correctly solves the problem [47–49]. The proposed algorithm works with multiple distance matrices that refer to the travel times between the addresses to be visited by bus, car, bicycle and on foot, measured in minutes. Each route has been calculated and referenced with the current transport system based on the vehicles presently related with the service (cars), which have municipal parking permits; they are considered the least sustainable and the costliest option because the CCE does not consider investing in cars that run on alternative energy. The possibility of using public transport or bicycles, rather than private vehicles, is subject to the following conditions:

- Public transport only uses the fixed routes in the city
- Bicycles are used on cycling lanes, or on roads where it is not forbidden such as pedestrian zones
- Routes, and their itineraries and possible variations, are agreed on jointly with the Head Office of the CCE
- Routes should be followed by the nurses after choosing the shortest itinerary decided by the CCE.

The algorithm presented herein is based on the technique by Branch and Bound [50,51]. This technique, when applied in conjunction with decision rules to a combined problem of transport, capacity and assignment, enables an algorithm to be developed that facilitates the provision of services to patients according to their requirements in the shortest possible time and at the lowest possible costs. This is ensured by also implementing the Travelling Salesman Problem solution. The algorithm provides the goal coordination possibility, such as optimising care resources and reducing transport costs. In this case it is also important to align the operational objective of the algorithm (to maximise the efficiency of using different nurses, and patient satisfaction) with the strategic goal of creating a sustainable enviro-friendly plan for HC delivery.

The algorithm combines different approaches to solve the generalised assignment and the knapsack problems following Albareda-Sambola, Van Der Vlerk [52], Li and Curry [53], Osorio and Laguna [54] and Martello and Toth [55], but also implements some findings indicated by Ross and Soland [56] and Fisher, Jaikumar [57]. In the constant search for optimal solutions to the GAP, the use of heuristics is most important, as shown in the works by Cattrysse and Van Wassenhove [58], Cattrysse, Salomon [59], Amini and Racer [60] and Lorena and Narciso [61], where it has accelerated the search for solutions to the optimisation problem. By developing the HC route assignment algorithm presented herein, we built on the results of Ribeiro and Pradin [62], who relied on a two-phase method: firstly, selecting and assigning similar HC assistance tasks (Phase 1); secondly, establishing a new division and reallocation to minimise possible inefficiency (Phase 2), similarly to the work presented by Hiermann and Prandtstetter [31]. Here the idea of Osorio and Laguna [54] was also implemented into the algorithm, with multiple resources or agents' different levels of efficiency after considering the assignment. The procedure and solution to assign loads (the HC services offered by the nurses) and orders to means of transport is discussed below. This assignment is determined according to the different capacities of the available care time options and patient services to minimise the division of services and to improve the efficiencies of HC services. The authors formerly presented the approximate algorithm developed to assign routes to nurses by considering their workloads [63]. Here we summarise the description of the most relevant information by focusing on the sustainable scheduling aspect.

The algorithm finds a set of m routes so that:

- Each route starts and ends at the CCE
- Each patient is visited by at least one nurse
- The total care demand of the patients assigned to a nurse does not exceed her care capacity
- Routes start and end in a pre-defined time window (to consider the activities that must be done in specific time windows)
- The sum cost of routes' is minimised

The algorithm constraints, which ensure the valid and feasible assignment of a caregiver to transport type and a sequence of HC orders, are related directly to the above-mentioned criteria.

C-1: Limitations of transport type i, understood as, e.g., length of walking or cycling. $Max\ (T_i)$

C-2: Number of skilled nurses of type o available. $Max\ (N_o)$

C-3: Maximum care time per nurse o: $Capacity\ (N_o) = [c_o]$

C-4: Maximum time available per Nurse o: $TimeAvailable(N_o) = [v_o]$

C-5: Maximum number of combinations of routes that can be followed by each nurse (N_o): $ComR(N_o) = [r_o]$

C-6: Maximum number of patients who can be visited by Nurse o on route k is denoted by w_{ok}. There is the matrix of a maximal number of patients per route: $W : [w_{ok}] = Matrix[Nurse\ \times routes]$

3. Results

Algorithm stage 1 starts with the initial routes devised by the CCE, to which patients are assigned, as we can see in the example of Route 5 of the real case studied (see Table 2).

Algorithm stage 1. Data were obtained for each arc on each pre-set route, and were then optimised to find the shortest route. Spatial data were collected, which referred to different means of transport.

The results can be presented as in Table 3 for the Route 5 example, defined in the selected case study (the calculation of the "bus ride" time considered the waiting times and the frequency of bus lines, depending on the time of day).

Table 2. An example route (R_5) as defined by the CCE.

Patients' Address	P_j	R_k	P_{jk}
Street 1, number 44	P_{27}	5	P_{275}
Street 2, number 20	P_{28}	5	P_{285}
Street 3, number 13	P_{29}	5	P_{295}
Street 1, number 30	P_{30}	5	P_{305}
Street 1, number 28	P_{31}	5	P_{315}
Street 4, number 12	P_{32}	5	P_{325}
Street 5, number 21	P_{33}	5	P_{335}

Notes: CCE: Care Centre for the Elderly; P_j: j-th is the patient (j = 1, 2, . . . , b), who requires home care services form CCE; P_{jk}: j-th patient assigned to route k by CCE, where the patients' assignment to each route is carried out according to the proximity between patient and route; P_{jk}: j-th patient assigned to route k by CCE, where the patients' assignment to each route is carried out according to the proximity between patient and route.

Table 3. Spatial data that refer to Route 5 of the studied case (R_5).

From	To	Walking Distance (Minutes)	Public Transport				Cycling (Minutes)	Car (Minutes)
			Distance to Bus Stop (Minutes)	Distance from Bus Stop (Minutes)	Bus Ride (Minutes)	Walk + Bus (Minutes)		
CCE	P_{335}	16	2	3	5	10	4	4.5
P_{335}	P_{315}	20	2	5	3 + 4	14	8	5.3
P_{315}	P_{295}	3	-	-	-	3	1	2.1
P_{295}	P_{305}	2	-	-	-	2	1	1.8
P_{305}	P_{275}	3	-	-	-	3	1	2.2
P_{275}	P_{325}	4	-	-	-	4	2	2.5
P_{325}	P_{285}	5	2	4	2	8	2	2.8
P_{285}	CCE	20	2	1	13	16	8	5.8
Total		73				60	26	27

Algorithm stage 2. The load per route and the load per day were calculated by considering neither the algorithm constraints nor travel times. In the studied city, 231 h/week were required to provide all the patients.

The constraints were implemented into *Algorithm stage 3*, which was where realistic modelling was done for allocating nurses to HC by setting the maximum number of available nurses, types of possible means of transport (car, e-bike, public transport, taxi, walking, etc.), the maximum care time available per potential nurse for assignment (depending on their qualification), and the maximum time available per nurse and the maximum number of accepted combinations per nurse (number of routes to be followed and number of patients to visit). According to the algorithm rules, some routes were divided and some were joined. One example of the results for Thursday are shown in Table 4.

Algorithm stage 4. It creates a routing plan per nurse for the available transport options and the associated transit times, like the example provided in Table 5.

By this described procedure, we obtained the best-scheduled route per nurse daily for the constraints and operation principles of the CCE. The observable time differences in the schedules shown in Table 5 are the results of the individual route planning for passenger vehicles, e-bikes and public transport, and their attainable speed. Table 6 summarizes the corresponding workload, transit time and number of nurses by transport means.

Table 4. An example of the results of all the routes scheduled on Thursday.

R_k	Route Time Load (Minutes)	N_0	R_k's
R_{10a}	355 (divided)	N_1	R_{10a}
R_{1a}	325 (divided)	N_2	R_{1a}
R_{10b}	312 (divided)	N_3	R_{10b}
R_4	300	N_4	R_4
R_7	207	N_5	$R_7 + R_{1b}$ (combined)
R_3	190	N_6	$R_3 + R_6$ (combined)
R_2	187	N_7	$R_2 + R_8$ (combined)
R_5	186	N_8	$R_5 + R_9$ (combined)
R_9	190		
R_8	177	Total care time	2628 min (~44 h)
R_6	165	Travel time	
R_{1b}	90 (divided)	Bus + walking	739 min (~12 h)
		Bikes	309 min (~5 h)
		Cars	350 min (~6 h)

Table 5. Example of a nurse's daily timetable.

Transport by Car			
Patient Location (P_j)	**Arrives at Patient's Home**	**Care Time**	**Leaves the Patient's Home**
CCE			06:58
Patient 1	07:00	1:00	08:00
Patient 2	08:02	0:25	08:27
Patient 3	08:31	0:30	09:01
Patient 4	09:03	0:40	09:43
Patient 5	09:47	1:00	10:47
Patient 6	10:49	1:00	11:49
Patient 7	11:51	0:40	12:31
Patient 8	12:33	1:00	13:33
Patient 9	13:36	0:20	13:56
Patient 10	13:58	1:00	14:58
CCE	15:00		

* The points on the map represent patients' homes (P_j).

	E-Bikes			Buses + Walking		
Patient Location (P_j)	**Arrives at Patient's home**	**Care Time**	**Leaves Patient's Home**	**Arrives at Patient's Home**	**Care Time**	**Leaves Patient's Home**
CCE			06:58			06:58
Patient 1	07:00	1:00	08:00	07:00	1:00	08:00
Patient 2	08:02	0:25	08:27	08:02	0:25	08:27
Patient 3	08:35	0:30	09:05	08:33	0:30	09:03
Patient 4	09:07	0:40	09:47	09:08	0:40	09:48
Patient 5	09:51	1:00	10:51	10:05	1:00	11:05
Patient 6	10:53	1:00	11:53	11:10	1:00	12:10
Patient 7	11:54	0:40	12:34	12:12	0:40	12:52
Patient 8	12:36	1:00	13:36	12:56	1:00	13:56
Patient 9	13:40	0:20	14:00	14:10	0:20	14:30
Patient10	14:02	1:00	15:02	14:34	1:00	15:34
CCE	15:03			15:35		

To verify if the assignment of transport type to each HC route was acceptable, efficiency was calculated in *Algorithm stage 5*. The definition of efficiency depends on the CCE's requirements; a threshold of 70% efficiency on the chosen sustainable transport plan (e-bikes, or walking and public transport) is set in relation to the number of nurses required to provide the care associated with each route. The results are shown in Table 7.

Table 7 shows that average daily efficiency is 0.76 on weekdays, which is more than that initially set by the CCE. However, this did not apply to weekends, when routes had to be defined differently as a further step to improve the algorithm. By using the routes defined for weekdays, but with a reduced workload, the spatial design of the HC routes became infeasible. The efficiency calculated for e-bikes was better on average, and this means of transport also required fewer nurses to visit all the scheduled patients.

Table 6. Example of assigning patients to nurses with the corresponding workload and transit time.

MONDAY	Car (Minutes)		Bikes (Minutes)		Bus + Walking (Minutes)	
	Workload	Travel	Workload	Travel	Workload	Travel
Nurse 1	382	38	382	22	382	73
Nurse 2	305	35	426	43	305	80
Nurse 3	278	35	300	14	300	44
Nurse 4	421	37	278	32	278	79
Nurse 5	401	63	401	68	236	88
Nurse 6	421	63	426	68	357	90
Nurse 7	397	80	392	77	207	86
Nurse 8					190	69
Nurse 9					350	110
Total	2605	350	2605	324	2605	719

Table 7. Average efficiency of the routes obtained by the algorithm.

Day	Public Transport		E-Bikes	
	Number of Nurses Needed	Average Efficiency	Number of Nurses Needed	Average Efficiency
Monday	9	0.77	7	0.87
Tuesday	9	0.79	7	0.89
Wednesday	8	0.85	7	0.85
Thursday	9	0.78	7	0.87
Friday	9	0.78	7	0.88
Saturday/Sunday	2	0.76	2	0.53

4. Discussion and Conclusions

The results of the algorithm and the case study showed considerable differences in the overall performance for the different means of transport (Table 7) used to deliver HC services. Although biking was calculated to be slower than cars or public transport (15 km/h), it still outpaced public transport on all the routes, and also outpaced cars on a number of occasions. Finding the shortest route between patients implies creating distance matrices and considering the city's specific urban characteristics for each transport mode so that the earliest arrival of nurses depends not only on their average attainable speed, but also on the routes they are allowed to use. For example, the characteristics and infrastructure of urban design often force motor vehicles to make detours, while bikers and pedestrians can quickly and easily cross, for example, a park, a flight of stairs, areas restricted for motor vehicles, etc. From experience, biking and walking are less affected by urban congestion, while buses and cars can be delayed during rush hours, and bike lanes and sidewalks are still permeable. From the cost and environmental sustainability viewpoints, walking would be the commendable mode of transport, and the algorithm also found a sequence of patient addresses that could be visited on foot only that did not violate any algorithm constraint. However, the efficiency of that routing plan was worse than the predefined acceptance limit. Another observation was made while creating and analysing the routes: the combination of public transport and walking (walking time to reach the closest bus stop, riding and walking again to reach an address) often took longer, even without waiting for the bus, than merely walking to the next address altogether.

The applicability of this algorithm to other cities and HC institutions was a key point of its development. So, it was created in a modular structure, where each constraint can and must be adjusted to local circumstances. Distance or cost matrices must be developed for each city or urban area that is to be studied, linked to a HC service. This applicability also has its human side: the designed routes and chosen transport modes must be agreed on and accepted by the person in charge of planning HC activities and the nurses who provide care. The nurses in Zalaegerszeg have used public transport and walked for years, so switching to bikes implies having to spend less transport time, which means a great deal in bad weather.

The solution presented herein reinforces sustainable transport system guidelines by consistently accessing more humanised health and the ecosystem that is more efficiently operative and at a lower cost. This means less pollution, an aspect whose expansion, and the possibility of applying it to other sectors, make it relevant, but it lies beyond the scope of the present study.

The work presented herein compared several transport possibilities by developing a method that established connections with HC elements so that different situations could be considered in the decision making of the HC institutions included in the case study represented by the CCE.

The study reduced total nurses' working hours a day by the bus and walking combination, and by comparing if nurses ride e-bikes, which respectively reduced ~35–44% of the total time that nurses spent travelling. This result is applicable to an urban environment where the public transport network is sufficient, and biking is allowed on a reasonable number of roads. Better HC management can support the efficient use of resources of health care institutions, high-quality HC and aspirations towards livable communities and sustainable development.

As the algorithm results depend on the traffic conditions and infrastructure of each city, further analyses are required in this field. Nowadays, there is a general trend to make urban services more sustainable, especially in denser inner-city areas. This paper provides an algorithm that contributes to this aim. Further studies can derive generalisable conclusions on the key elements of HC provision in urban areas, where sustainability aspirations fall in line with improved working conditions for nurses, and better service experience for patients. As a future approach, incorporating GPS tracking of bikes will allow researchers to retrieve real-time data (speed control, localisation of HC and each nurse) and to improve the algorithm and, eventually, the HC service.

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References

1. Carpenter, I.; Gambassi, G.; Topinkova, E.; Schroll, M.; Finne-Soveri, H.; Henrard, J.-C.; Garms-Homolova, V.; Jonsson, P.; Frijters, D.; Ljunggren, G.; et al. Community care in Europe. The aged in home care project (AdHOC). *Aging Clin. Exp. Res.* **2004**, *16*, 259–269. [CrossRef] [PubMed]
2. Blomqvist, A.; Busby, C. Long-term care for the elderly: Challenges and policy options. CD Howe Institute Commentary. *SSRN Electron. J.* **2012**. [CrossRef]
3. OECD. *Health at a Glance 2015: OECD Indicators*; OECD Publishing: Paris, France, 2015.
4. Social Protection Committee and the European Commission. *Adequate Social Protection for Long-Term Care Needs in an Ageing Society*; Publications Office of the European Union: Luxembourg, 2014.
5. Community Care Behavioral Health Organization. The Community Care Story. Available online: http://www.ccbh.com/aboutus/story/index.php (accessed on 15 August 2017).
6. OECD. *Ageing in Cities*; OECD Publishing: Paris, France, 2015.
7. De Oliveira Alves, B. *Blueprint on the Digital Transformation of Health and Care for the Ageing Society*; European Innovation Partnership on Active and Healthy Ageing (EIP AHA): Brussels, Belgium, 2016.
8. European Commission. Innovation for Active & Healthy Ageing. In Proceedings of the European Summit on Innovation for Active and Healthy Ageing, Brussels, Belgium, 9–10 March 2015.
9. Wehmeyer, M.L.; Abery, B.H.; Mithaug, D.E.; Stancliffe, R.J. *Theory in Self-Determination: Foundations for Educational Practice*; Charles C Thomas Publisher: Springfield, IL, USA, 2003.

10. Santoso, F.; Redmond, S.J. Indoor location-aware medical systems for smart homecare and telehealth monitoring: State-of-the-art. *Physiol. Meas.* **2015**, *36*, R53. [CrossRef] [PubMed]
11. Makai, P.; Brouwer, W.B.; Koopmanschap, M.A.; Stolk, E.A.; Nieboer, A.P. Quality of life instruments for economic evaluations in health and social care for older people: A systematic review. *Soc. Sci. Med.* **2014**, *102*, 83–93. [CrossRef] [PubMed]
12. Sørbye, L.W.; Garms-Homolová, V.; Henrard, J.-C.; Jónsson, P.V.; Fialová, D.; Topinková, E.; Gambassi, G. Shaping home care in Europe: The contribution of the Aged in Home Care project. *Maturitas* **2009**, *62*, 235–242. [CrossRef] [PubMed]
13. Russell, D.; Mola, A.; Onorato, N.; Johnson, S.; Williams, J.; Andaya, M.; Flannery, M. Preparing Home Health Aides to Serve as Health Coaches for Home Care Patients With Chronic Illness: Findings and Lessons Learned From a Mixed-Method Evaluation of Two Pilot Programs. *Home Health Care Manag. Pract.* **2017**, *29*, 191–198. [CrossRef]
14. Larson, S.A.; Sedlezky, L.; Hewitt, A.; Blakeway, C. Community Support Services Workforce in the U.S. In *Public Administration and Disability: Community Services Administration in the U.S.*; Racino, J.A., Ed.; CRC Press: Boca Raton, FL, USA, 2014; pp. 235–254.
15. Rest, K.-D.; Hirsch, P. Daily scheduling of home health care services using time-dependent public transport. *Flex. Serv. Manuf. J.* **2015**, *28*, 495–525. [CrossRef]
16. Fikar, C.; Hirsch, P. Home health care routing and scheduling: A review. *Comput. Oper. Res.* **2017**, *77*, 86–95. [CrossRef]
17. Bennett, A.R. *Home Health Care Logistics Planning*; Georgia Institute of Technology: Atlanta, GA, USA, 2010.
18. Issaoui, B.; Zidi, I.; Marcon, E.; Laforest, F.; Ghedira, K. (Eds.) Literature review: Home health care. In Proceedings of the 2015 15th International Conference on Intelligent Systems Design and Applications (ISDA), Marrakech, Morocco, 14–16 December 2015.
19. Rest, K.-D.; Hirsch, P. Supporting Urban Home Health Care in Daily Business and Times of Disasters. *IFAC-PapersOnLine* **2015**, *48*, 686–691. [CrossRef]
20. Trautsamwieser, A.; Hirsch, P. A Branch-Price-and-Cut approach for solving the medium-term home health care planning problem. *Networks* **2014**, *64*, 143–159. [CrossRef]
21. Cheng, E.; Rich, J.L. *A Home Health Care Routing and Scheduling Problem*; Contract No.: TR98-04; Department of Computational and Applied Mathematics, Rice University: Houston, TX, USA, 1998.
22. Bertels, S.; Fahle, T. A hybrid setup for a hybrid scenario: Combining heuristics for the home health care problem. *Comput. Oper. Res.* **2006**, *33*, 2866–2890. [CrossRef]
23. Eveborn, P.; Rönnqvist, M.; Einarsdóttir, H.; Eklund, M.; Lidén, K.; Almroth, M. Operations Research Improves Quality and Efficiency in Home Care. *Interfaces* **2009**, *39*, 18–34. [CrossRef]
24. Eveborn, P.; Flisberg, P.; Rönnqvist, M. Laps Care—An operational system for staff planning of home care. *Eur. J. Oper. Res.* **2006**, *171*, 962–976. [CrossRef]
25. Bredstrom, D.; Rönnqvist, M. A branch and price algorithm for the combined vehicle routing and scheduling problem with synchronization constraints. *SSRN Electron. J.* **2007**. [CrossRef]
26. Dohn, A.; Rasmussen, M.S.; Justesen, T.; Larsen, J. (Eds.) The home care crew scheduling problem. In Proceedings of the 1st International Conference on Applied Operational Research (ICAOR'08), Yerevan, Armenia, 15–17 September 2008.
27. Rasmussen, M.S.; Justesen, T.; Dohn, A.; Larsen, J. The Home Care Crew Scheduling Problem: Preference-based visit clustering and temporal dependencies. *Eur. J. Oper. Res.* **2012**, *219*, 598–610. [CrossRef]
28. Mankowska, D.S.; Meisel, F.; Bierwirth, C. The home health care routing and scheduling problem with interdependent services. *Health Care Manag. Sci.* **2013**, *17*, 15–30. [CrossRef] [PubMed]
29. Bredström, D.; Rönnqvist, M. Combined vehicle routing and scheduling with temporal precedence and synchronization constraints. *Eur. J. Oper. Res.* **2008**, *191*, 19–31. [CrossRef]
30. Trautsamwieser, A.; Gronalt, M.; Hirsch, P. Securing home health care in times of natural disasters. *OR Spectr.* **2011**, *33*, 787–813. [CrossRef]
31. Hiermann, G.; Prandtstetter, M.; Rendl, A.; Puchinger, J.; Raidl, G.R. Metaheuristics for solving a multimodal home-healthcare scheduling problem. *Cent. Eur. J. Oper. Res.* **2015**, *23*, 89–113. [CrossRef]
32. Fikar, C.; Hirsch, P. A matheuristic for routing real-world home service transport systems facilitating walking. *J. Clean. Prod.* **2014**, *105*, 300–310. [CrossRef]

33. Braekers, K.; Hartl, R.F.; Parragh, S.N.; Tricoire, F. A bi-objective home care scheduling problem: Analyzing the trade-off between costs and client inconvenience. *Eur. J. Oper. Res.* **2016**, *248*, 428–443. [CrossRef]
34. Haghshenas, H.; Vaziri, M. Urban sustainable transportation indicators for global comparison. *Ecol. Indic.* **2012**, *15*, 115–121. [CrossRef]
35. Gilbert, R.; Irwin, N.; Hollingworth, B.; Blais, P. *Sustainable Transportation Performance Indicators (STPI)*; Transportation Research Board (TRB): Washington, DC, USA, 2003.
36. Childers, D.L.; Pickett, S.T.; Grove, J.M.; Ogden, L.; Whitmer, A. Advancing urban sustainability theory and action: Challenges and opportunities. *Landsc. Urban Plan.* **2014**, *125*, 320–328. [CrossRef]
37. Haghshenas, H.; Vaziri, M.; Gholamialam, A. Evaluation of sustainable policy in urban transportation using system dynamics and world cities data: A case study in Isfahan. *Cities* **2015**, *45*, 104–115. [CrossRef]
38. Taniguchi, E.; Thompson, R.G.; Yamada, T. *Modelling City Logistics*; Thompson, R.G., Taniguchi, E., Eds.; City Logistics, I; Institute of Systems Science Research: Kyoto, Japan, 1999; pp. 3–37.
39. Gilderblooom, J.I.; Meares, W.L.; Riggs, W. How brownfields sites kill places and people: an examination of neighbourhood housing values, foreclosures, and lifespan. *J. Urbanism* **2014**, *9*, 1–18. [CrossRef]
40. Gilderbloom, J.I.; Riggs, W.; Meares, W.L. Does walkability matter? An examination of walkability's impact on housing values, foreclosures and crime. *Cities* **2015**, *42*, 13–24. [CrossRef]
41. Desouza, K.C.; Flanery, T.H. Designing, Planning and managing resilient cities: A conceptual framework. *Cities* **2013**, *35*, 89–99. [CrossRef]
42. Southwork, M. Designing the walkability city. *J. Urban Plan. Develop.* **2005**, *131*, 246–257. [CrossRef]
43. Rietveld, P. Non-motorised modes in transport systems: A multimodal chain perspective for the Nederlands. *Trans. Res. Part D* **2000**, *5*, 31–36. [CrossRef]
44. Litman, T. Economic value of walkability. *World Trans. Policy Pract.* **2011**, *1828*. [CrossRef]
45. Leinberger, C.B.; Alonso, M. *Walk This Way: The Economic Promise of Walkable Places in Metropolitan*; The Brookings Institution: Washington, DC, USA, 2012.
46. Official Website of the City of Zalaegerszeg. There Are Four Eco-Buses Passing the Streets of the City Instead of One (Video). Available online: http://zalaegerszeg.hu/cikk/21825/Egy_helyett_mar_negy_okobusz_jarja_a_varos_utcait_Video (accessed on 17 August 2017).
47. Even, S.; Itai, A.; Shamir, A. On the complexity of time table and multi-commodity flow problems. *SIAM J. Comput.* **1975**, *5*, 691–703. [CrossRef]
48. Garey, M.R.; Graham, R.L.; Johnson, D.S. The complexity of computing Steiner minimal trees. *SIAM J. Appl. Math.* **1977**, *32*, 835–859. [CrossRef]
49. Karp, R.M. *Reducibility among Combinatorial Problems*; Miller, R.E., Thatcher, J.W., Eds.; Complexity of Computer Computations; Plenum Press: Reno, NV, USA, 1972.
50. Clausen, J. *Branch and Bound Algorithms-Principles and Examples*; Department of Computer Science, University of Copenhagen: Copenhagen, Denmark, 1999; pp. 1–30.
51. Rouillon, S.; Desaulniers, G.; Soumis, F. An extended branch-and-bound method for locomotive assignment. *Trans. Res. Part B Methodol.* **2006**, *40*, 404–423. [CrossRef]
52. Albareda-Sambola, M.; Van Der Vlerk, M.H.; Fernández, E. Exact solutions to a class of stochastic generalized assignment problems. *Eur. J. Oper. Res.* **2006**, *173*, 465–487. [CrossRef]
53. Li, V.; Curry, G.L. Solving multidimensional knapsack problems with generalized upper bound constraints using critical event tabu search. *Comput. Oper. Res.* **2005**, *32*, 825–848. [CrossRef]
54. Osorio, M.A.; Laguna, M. Logic cuts for multilevel generalized assignment problems. *Eur. J. Oper. Res.* **2003**, *151*, 238–246. [CrossRef]
55. Martello, S.; Toth, P. An algorithm for the generalized assignment problem. *Oper. Res.* **1981**, *81*, 589–603.
56. Ross, G.T.; Soland, R.M. A branch and bound algorithm for the generalized assignment problem. *Math. Program.* **1975**, *8*, 91–103. [CrossRef]
57. Fisher, M.L.; Jaikumar, R.; Van Wassenhove, L.N. A multiplier adjustment method for the generalized assignment problem. *Manag. Sci.* **1986**, *32*, 1095–1103. [CrossRef]
58. Cattrysse, D.G.; Van Wassenhove, L.N. A survey of algorithms for the generalized assignment problem. *Eur. J. Oper. Res.* **1992**, *60*, 260–272. [CrossRef]
59. Cattrysse, D.G.; Salomon, M.; Van Wassenhove, L.N. A set partitioning heuristic for the generalized assignment problem. *Eur. J. Oper. Res.* **1994**, *72*, 167–174. [CrossRef]

60. Amini, M.M.; Racer, M. A hybrid heuristic for the generalized assignment problem. *Eur. J. Oper. Res.* **1995**, *87*, 343–348. [CrossRef]
61. Lorena, L.; Narciso, M.G. Relaxation heuristics for a generalized assignment problem. *Eur. J. Oper. Res.* **1996**, *91*, 600–610. [CrossRef]
62. Ribeiro, J.F.; Pradin, B. A methodology for cellular manufacturing design. *Int. J. Prod. Res.* **1993**, *31*, 235–250. [CrossRef]
63. Szander, N.; Ros-McDonnell, L.; de la Fuente, M.V. *Algorithm for Efficient and Sustainable Home Health Care Delivery Scheduling*; Mula, J., Barbastefano, R., Díaz-Madroñero, M., Poler, R., Eds.; Lecture Notes in Management and Industrial Engineering: New Global Perspectives on Industrial Engineering and Management; Springer: Berlin, Germany, 2017.