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Long-Term Care Sustainable Networks in ADRION Region

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Abstract: The Long-Term Care (LTC) industry mainly comprises networks managed by providers of services other than informal caregivers and government agencies. Among the providers are the local providers of community-based services. The segment still consists of mostly small businesses. As such, it needs many improvements in logistics, information and communication technology (ICT) support, and educational programs, specifically in the ADRION region, where the rural areas require a high percentage of travel time in a working day for service providers. The demand for LTC services must be known early enough for providers to adapt to the growth of these demands, and they also need methods to support decisions on how to optimize the number of care workers to be able to plan the necessary human resources in the long term. The results are based on the authors' previous studies of sustainable hierarchical spatial systems. The paper presents the achievements of these research activities and policies, governance and financing in the hierarchically organized services and networks of educational programs for human resources and ICT innovations in LTC, which are currently in short supply. Projections of capacities from facilities are necessary. Logistic networks to human resources are based on geo-gerontological projections, such as the multistate transition model, which is a new achievement in this area, and the adequate norms and standards of these services. The optimal number of human resources is based on the combination of the Patterson-Albracht algorithm and Multiple Travelling Salesman Problem (mTSP), as a new Home Health Care Routing and Scheduling Problem (HHCRSP), which helps in ensuring the inclusion of travel time in the concept of norms and standards, to achieve a work balance and care schedule according to the wishes of clients. The proposed approach might help professionals adapt in advance to the coming changes caused by the growing number of seniors and rapid changes in technology, and might also help in considerations as to whether the priorities of clients should be included in the basic national insurance programs or additionally charged as a higher standard of home care services. The aim is to make care and supply networks as sustainable as possible.

Keywords: long-term care; spatial dispersion; sustainable networks; logistics; social value; human resources; multiple transitions; forecasting; rural areas; HHCRSP

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1. Introduction

1.1. Promoting Affordable, Sustainable, and High-Quality Services

The global Long-Term Care (LTC) market is expected to reach 1.7 trillion dollars (USD) by 2028. Home and community care which improve supply chain logistics and its sustainability are one of the fastest-growing segments of the LTC sector. As Famakinwa [1] wrote, the home care industry is one of the faster-growing industries, dominated by small providers who need to:

(a) plan capacities, especially their human resources (HRs) in the functional area concerning the fast-growing number of very old inhabitants and

(b) find the optimal schedule for their service providers, which changes according to the increasing number of elderly users and the changing locations of their homes, which determines the location of LTC services.

 i How to plan the necessary capacities of the social infrastructure for LTC in the long term requires acknowledging the fact that the different levels of functional capabilities of the care recipients (the ability of residents to take care of themselves in daily activities, leading to the categorization of care as described in: https://www.zps.si/images/stories/trg/domovi2015.pdf accessed on 3 January 2021), require different adaptations in building environments to cater to their needs.

 ii How to plan the necessary human resources should optimize the number of these resources based on knowing the standards of care in advance (from the LTC Act and by-law).

These challenges are equally present in the United States, Canada, Australia and the European Union. Following the 'Operational Programme for the implementation of the European Cohesion Policy for the period 2014–2020′ [2] as a key area, Slovenia suggested promoting the availability of affordable, sustainable, and high-quality services, including logistics, health, and social services of general interest, for old and very old inhabitants. The potential users are dispersed mostly throughout rural areas, where the challenges are excessive distances between LTC users. As such, it needs many improvements in logistics, ICT support, and educational programs, specifically in the ADRION regions (Italy, Greece, Slovenia, Croatia, Serbia, and Bosnia and Hercegovina) [3], where rural areas require a high percentage of travel time from service providers in their working day. These services should be optimally included in the LTC networks, but the allocation of users is changing rapidly, influencing optimal schedules.

The key issues yet to be addressed are the following:

i. developing a quantitative model for the forecasting of the needs of social care services and measuring their quality regarding older adults,
ii. forecasting the necessary facilities and human resources and
iii. optimally scheduling available activities in accordance with demand, for the needs of seniors.

Slovenia does not yet have a compact system for the regulation of the LTC advocated in the 'Operational Program'. Until the enactment of the new Long-term Care Act [4] users' services and rights arose from existing insurance systems, namely, health, pension, and disability insurance, as well as from the social welfare system which created many constraints.

The data we needed to develop and use models to support decision-making in this area, so that the social infrastructure required for spatial planning could be successfully planned for the long term, were available from the responsible government agencies and ministries. Data on place of residence and age of inhabitants are managed by the Ministry of the Interior (MNZ), data on demographic projections (excluding gerontological projections) are managed by the Statistical Office of the Republic of Slovenia (SURS), data on services for older adults are managed by the Social Protection Institute of the Republic of Slovenia (IRSSV), and data on spatial units are managed by the Surveying and Mapping Authority (GURS); see also Table 1 and Figure 1. The spatial processing of the data and the spatial analyses, including the calculation of the time spent on traveling the distances between the considered locations, were carried out with the GIS tool ArcGIS.

Table 1. Data needed to develop and use models to support decision-making for the long-term spatial planning of social infrastructure and sources.

Data	Source of the Data	Abbreviation of the Source
Data on the age of residents per location of residence	The Ministry of the Interior of the Republic of Slovenia [confidential]	MNZ
Data on demographic projections of the population	The Statistical Office of the Republic of Slovenia	SURS
Data on the long-term services	The Social Protection Institute of the Republic of Slovenia [confidential]	IRSSV
Data on spatial units	The Surveying and Mapping Authority	GURS
Data on time-spending distances between the locations considered	Own calculation in GIS tool ArcGIS.	

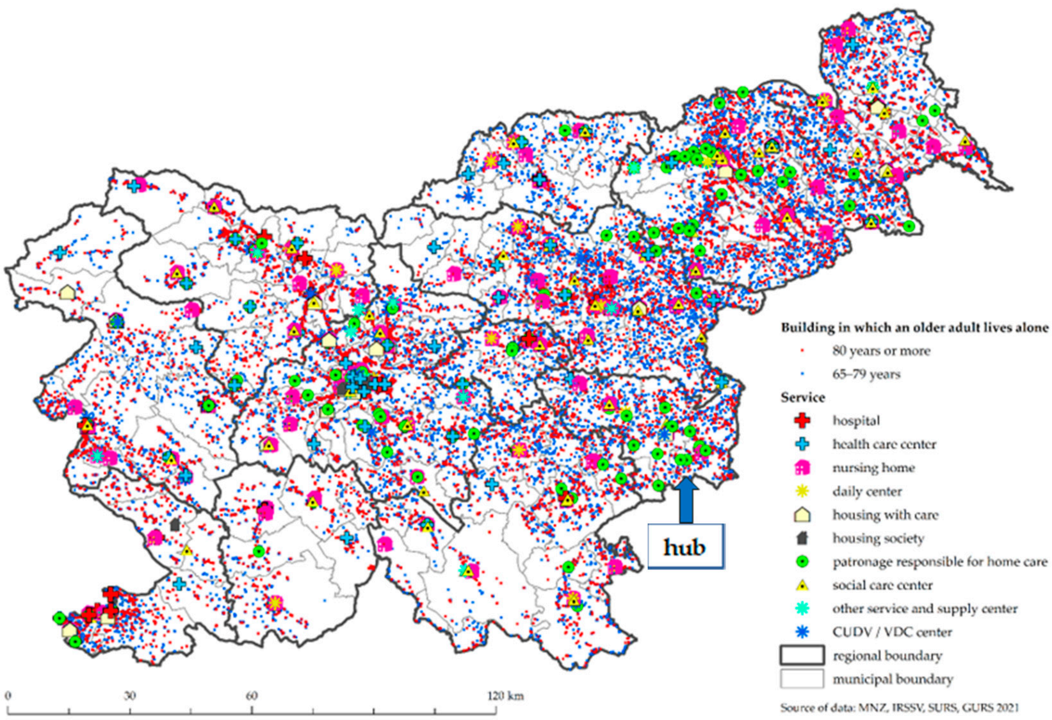


Figure 1. Locations of buildings where older adults live alone without younger people, and locations of hubs from which services are provided in Slovenia.

Given the demographic structure and projections developed by the European Commission and presented in The Ageing Report 2021 [5], there is a need for reform that enables the establishment of a uniform system of high-quality community-based services (a) for ageing in one's place of residence and (b) for those who need institutional forms of care.

The new by-laws also have to consider location of different types of facilities and networks where LTC services are to be provided. However, the norms and standards have not yet been adapted to the LTC Act, and the distances between LTC users (as demonstrated in Figure 1), are not yet considered part of the packages of norms and standards. There is a similar situation in other countries of the ADRION macro-region [3].

Providing new norms and standards of public care and supply networks requires the development of a model for projections of needs and eligibility for integrated health and social services, monitoring of recipients of services and funds for LTC and coordinating the development of integrated community-based services, as required in the 'Operational

Programme' for the implementation of the European cohesion policy for 2014–2020 [2]. In these packages of norms and standards, the distances in rural areas have to be considered carefully; therefore, the home health care routing and scheduling problems (HHCRSPs) should be modified or newly developed to include the integrated activities in the network.

In the project titled 'Social Innovation for integrated health care of ageing population in ADRION Regions' (SI4CARE), we are developing a model for forecasting the capacities of facilities and human resources necessary to enable measuring the quality of the integrated system of health and social care in LTC networks for persons with declining functional capacities and dependent on others, for which even the documents of the European Commission [6,7] state have not yet been developed. To forecast the needs of human resources, we suggested including the travel time between users in rural areas in the standardization of activities in the care and supply networks.

Based on our previous studies of functional regionalization, using CURDS and Intramax methods [8,9], we point out that the optimal policy requires the provision of technologies and facilities for older adults in communities where the minimum required workers are determined by optimizing their daily routes between care and supply recipients in spatially very dispersed homes in rural areas, which is where most of the participants of the SI4CARE project face challenges. For these purposes, we suggested an approach similar to the Patterson-Albracht (P-A) algorithm [10], which replaces classical HHCRSP, running on the delineated service areas, as is presented in Section 3.

1.2. Development of Social Innovation Ecosystems in the ADRION Region

According to the European population projections 2021 [11], the share of older adults (65+) will increase by 30% and the 80+ population will double in the next half of the century, even in the ADRION areas (states around the Adriatic Sea). Developers of supply chains and service systems for the ageing population should take into consideration the growth of human resources and facilities needed to manage the rapid decline in functional capacities of their ageing customers. To mitigate the risks to which seniors are exposed, developers of LTC logistics should embed ambient assisted living technologies in age-friendly facilities and amenities. Therefore, digital support systems for older adults and digital social infrastructure should be incorporated into the development of smart villages and communities, and the impact on the scheduling of care and supply networks should be evaluated.

This impact of new technologies and rehabilitation procedures can be considered a social value of technological improvements. Information and communication technologies incorporated in products, services and systems providing support to seniors form an important part of the emerging Silver Economy.

Due to the rapid ageing of the population in the developed world, governments and the private sectors alike should consider the digital transformation of social infrastructure and incorporate it into the development of new products, policies, technologies, management and control of processes subject to public expenditure. Digital transformation also influences the impact of distances in rural areas and, therefore, the optimal arrangements of supply and care networks and the optimal results of HHCRSP, as well as their adaptation to the changing demography and available human resources. These challenges were exposed when we wrote the SI4CARE proposal for solutions in the ADRION region.

2. Literature Review and Some Improvements

2.1. Forecasting Affordable and Sustainable Services by Developing a Multistate Transitions Model

The paper's first objective is to present how to develop an actuarial model for forecasting adequate services and care in different types of facilities in the LTC system, services for inhabitants requiring various levels of care and regarding cases of possible improvements in functional capacities of clients. A case study for Slovenia is presented, which is based on data from Eurostat, the Statistical Office of the Republic of Slovenia (SORS) and the National Health Insurance Institute (NHII), which are not published as open source due to personal data protection. Slovenia has the following demographic projections forecasting the level of services and care needs, grouped into three categories (CATs) as determined by the norms and standards of community care (Figure 2), knowing that category 4 (CAT 4) is available only in institutional care. The categorisation of functional capacities follows (see: https://www.zps.si/images/stories/trg/domovi2015.pdf, accessed on 3 January 2021):

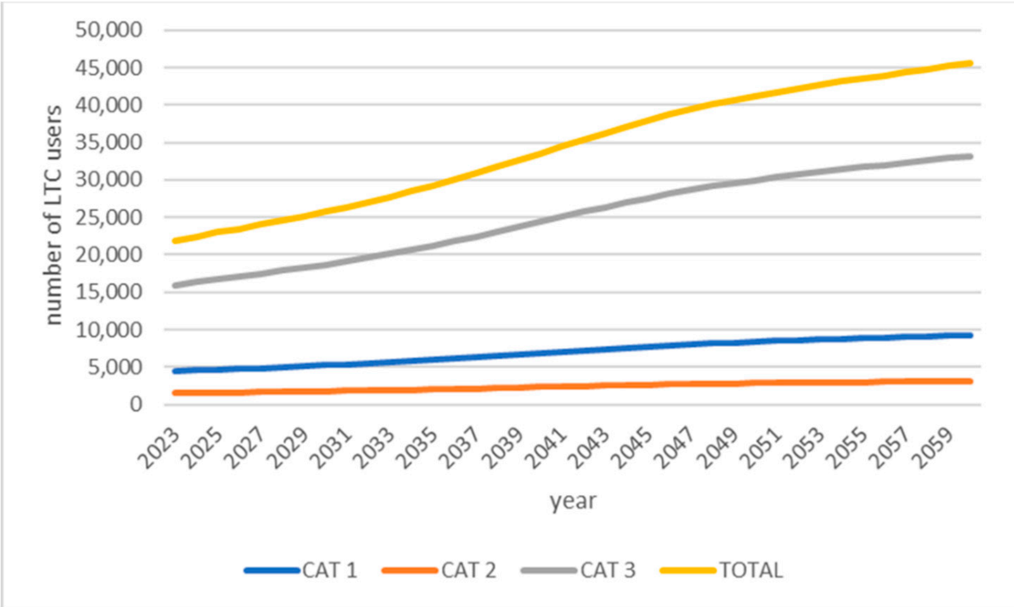


Figure 2. Geo-gerontological projections for Slovenia 2022–2060. Source: Eurostat, SORS and NHII—internal data (2022) and authors' calculations based on the model developed in (1)–(5) and categorization described in https://www.zps.si/images/stories/trg/domovi2015.pdf, accessed on 6 January 2021).

CAT 1: The resident does not need direct assistance in carrying out basic life activities. He/she needs room cleaning, laundry and food. Required daily hours of direct service on average is supposed to be 30 min.

CAT 2: The resident needs partial assistance with basic life activities, such as washing, dressing, bringing food to the room, and partial help in getting out of bed and the like. Required daily hours of direct service on average is supposed to be one hour.

CAT 3a: The resident needs direct personal assistance in fulfilling all basic life needs. CAT 3b: The resident needs constant supervision and care. Required daily hours of direct service on average is supposed to be two hours (a) to two and a half hours (b).

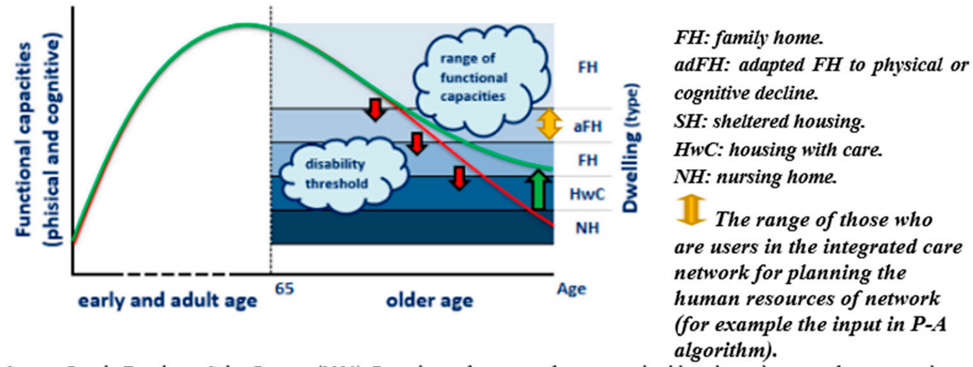
CAT 4: The resident is mostly mobile, but needs help due to senile dementia or similar conditions requiring partial or full assistance, but above all supervision.

The main gap found in the literature and our studies was the fact that the multiple decrement model does not consider possibilities of returning to a lower category of care. The integrated home care pilot project, MOST, in the Posavje region [12] showed that proper activities in care and supply networks can improve the functional capacities of older adults to the extent that the care recipients can return to a lower category of care, requiring a lower intensity of care and, therefore, fewer caregivers. Based on this we decided to change the previously developed multiple decrement model of functional capacities dynamics to the multistate-transition model, where the triangular matrix obtains values higher than 0 on places under the diagonal, and where the probability of moving to a lower category of care is higher than 0. For this, the survival analysis was extended. Figure 2 shows demographic projections in Slovenia and forecasts the number of inhabitants in each category of care. Such projections are called geographical–gerontological projections [13] or geo-gerontological (GG) projections, if the analysis is focused on specific spatial units.

This new research field is defined as "a burgeoning multidisciplinary subject that encompasses the application of geographical perspectives, concepts, and approaches to the study of ageing, old age, and older populations" [13]. Human geography and social gerontology have influenced the development of the very new field of geographical gerontology. Still, to optimize GG systems, knowledge of modelling supply chains, optimization of human resources (and other fields where activities over long distances need to be managed) and actuarial methods are crucial. The analysis of time-to-event data (survival analysis) has evolved into a well-established application of advanced statistical methodology in health and supply networks. Survival methods have evolved over the past 40 years from occasionally used techniques to the leading statistical procedures of today [14]. Competing risk techniques allow for a more specific analysis in that they enable modelling time until the combined endpoint and endpoint type occur. The relevance of competing risks in medical research is highlighted by methodological papers in various medical fields, as presented by [15]. Still, as suggested in our proposal, theirs and other approaches do not combine the built environment into the proposals.

The key to an adequate competing risks analysis is that there are as many hazards as there are competing risks. Unless all of these hazards, often called cause-specific hazards, have been analyzed, the analysis remains incomplete. In particular, only a complete analysis allows for the predicting of event probabilities [14]. When the built environment is not been included in the studies, time-to-event research, connected with change in the functional capacities of residents, their health status and the influence of change on tenure in certain built environments, is novel when studying the following: (a) competing risk matrices; (b) trajectories of functional capacities of residents; and (c) disability thresholds. Some specifics of competing risk multistate-transition models have been presented in [16]. None consider the environmental housing issues. To determine potential home-care users, and exclude locations of those more suitable for other forms of care, such as green farming or concentrated housing units with care in a separate supply network, adequate competing risk matrices were first developed first, where the additional dimension was the set of available facilities. Residential relocation decision-making in old age is complicated; modelling this complex course of actions requires careful scrutiny of different aspects. The relocation decision comprises several partial decisions, which include the following: (a) the reason for the relocation; (b) relocation timing (age of the resident); and (c) attributes of the desired residence. Quality of the built environment of neighborhoods and homes, available integrated services, support networks, assistive technologies, functional decline, and family status are important factors that can influence the timing of relocation to a nursing home. This timing may be accelerated or decelerated by the quality of the built environment, support networks, and assistive technologies that together influence the disability threshold (see Figure 3). In Figure 3, the ages of those who need home care are determined in case sheltered housing units (SH) or housing with care (HwC) are available. From the GG projections of inhabitants in a given functional area of a care and supply network the optimal results of HHCRSP or, in our case, the P-A algorithm can forecast the needed number of human resources. [17] gives a detailed literature review with the demonstration of transitions in Figure 3.

Functional capacities decrease with age. However, the environment a person lives in can affect the risk of falls and other events requiring higher care categories. Relocation usually occurs because of a multiplicity of reasons, necessitating using a multivariate model of decision-making, jointly modeled with the timing decision for relocation. After the substantial decline of functional capacities, there is a threshold (Figure 3) when an older adult needs to improve his/her dwelling accessibility and adaptation and accessibility to his/her environment, or move to an assisted living facility and, finally, to a nursing home. They must choose between these two options. When the risk of falls becomes unacceptable, older adults must accommodate their homes or they must move to a safer environment to mitigate it.



Source: Rogelj, Temeljotov Salaj, Bogataj (2021). Digital transformation of community health and social services for ageing cohorts

Figure 3. Decline of functional capacities of older adults in various age-friendly environments (see [17]).

Figure 4 shows possible transitions between different types of environments in cases of proper rehabilitation procedures, first studied here. In the case of good rehabilitation, the functional capacity could rise, and transition back is enabled, as was obvious from the results of the MOST applied project [12]. Physical, age-friendly environments can make the difference between independence and dependence for all individuals but are of particular importance for those growing older. Based on the paper by Bogataj et al. [18,19], further extended by [20–22], in multiple decrement models with m environments (dwelling options) for those with reducing functional capacities, there are possibilities of m states and $m-1$ transitions from one dwelling type to another, which can influence the slope of the curves in Figure 2. We denoted the initial state as state 0 (family home) and the decrement requiring dwelling of type j by the line of the graph from the parent node to a state (child node) $j,\ j = 1,\ 2,\ \ldots,\ m-1\ (= adFH,\ SH,\ HwC,\ NH,\ D)$, where D meant dead. This graph describes the probabilities of transition from the state 0 and further states to the child node (state) $j \in H$ or, in general, from the parent node to the child node j, at various ages.

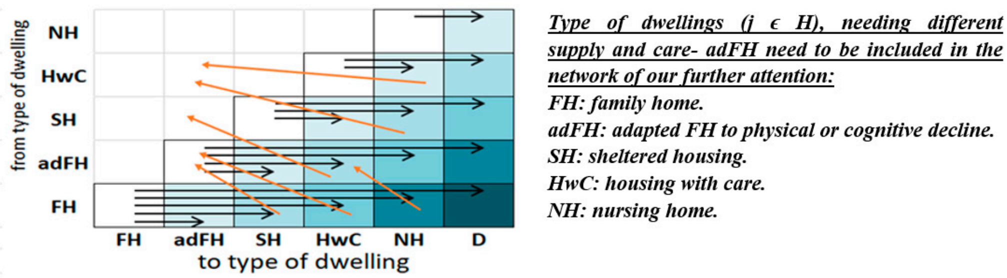


Figure 4. From the multiple decrement model (only black lines) to our multi-state transition.

2.2. Preview Models

All paths to j determine the needed dynamics of constructing the proper capacity of type j buildings. This necessitates inventories of adapted housing units in the process, which should be completed on the time horizon of our projections (see also [18,23]). In the multiple decrement setup, transitions between any two states from i to j, $i > j = 1,\ 2,\ \ldots,\ m-1$ are not possible (directed graph) [24]. This is in contrast to a multistate transition (which is a novelty in our research, due to possible improvement of functional capacities after the rehabilitation process). We can also assume transitions between any two states from i to j where $i > j = 0,\ 2,\ \ldots,\ m-2$.

Let us consider an older adult aged x, denoted by (x). We denote the future tenure of older adults in the environment (dwelling) of type $i \in H$ by $T_i(x)$. Thus, $x + T_i(x)$ is the age when an older adult moves out of his/her current dwelling of type i and enters a new type of environment (dwelling) $j,\ j \in H$, entailing transition to a more accommodative type

j environment (dwelling) or a nursing home. The future tenure of the resident in the type i environment (dwelling), $T_i(x)$, is a random variable with a probability distribution function:

$$G_i(t) = Pr(T_i \leq t),\ t \geq 0 \quad (1)$$

The function $G_i(t)$ gives the probability that the older adult will die or move to a more accommodative type j environment (dwelling) within t years for any fixed value of t. We assume that $G_i(t)$, the probability distribution of T_i, is known. We also assume that $G_i(t)$ is continuous and has a probability density $g_i(t) = G_i'(t)$. Thus, one can state the following:

$$g_i(t)dt = Pr(t < T_i < t + dt,\ j \epsilon H) \quad (2)$$

where (2) describes the probability that an older adult will move from a type i environment (dwelling) to a type j environment (dwelling) or hospital in an infinitesimal time interval from t to $t + dt$. Therefore, the probability that an older adult aged x and living in a type i environment (dwelling) will move into a type j environment (dwelling) within t years is denoted by the symbol ${}_tq_x\ (i, j)$. We have, thus, a known relationship:

$${}_tq_x(i, j) = G(i, j : t) \quad (3)$$

Similarly, one can write the following:

$${}_tp_x(i) = 1 - \sum_{j=1+1}^{m} G(i, j : t) \quad (4)$$

which denotes the probability that an older adult aged x will remain in his/her current environment (dwelling) for at least t years. The graph begins at the initial state $i = 0 = FH$ (family home). We can observe all possible paths from FH through some of the identified child nodes, $j \epsilon H$, which enable different exits from existing states, as presented in Figure 4.

2.3. Planning the Home-Care Routing and Housing Needs—Literature Review

We aim to distribute the activities among caregivers so that their working day is balanced inside a time window of eight hours. The worktime of each caregiver is eight hours, with extra pay for brief overtime, and the waiting time to eight hours is to be paid as working, including traveling time. In doing so, we want to take into account, as much as possible the time of day when the client needs care from a care network. If we consider these additional limitations, higher transport costs are incurred. Following this criterion, the multiple Traveling Salesman Problem without substantial extension and combination with other approaches, as known in the literature, could not properly balance the caregivers' worktime.

Till the end of 2021, there were only 124 papers in Web of Science Core Collection considering HHCRSP, when we searched for 'Home Health Care' and 'scheduling' and 'routing' (See dynamics of publishing in Table 2).

Table 2. Dynamics of articles with 'Home Health Care' and 'scheduling' and 'routing' indexed in the Web of Science Core Collection.

Years of Publishing	Before 2016	2016	2017	2018	2019	2020	2021
No. of articles	16	9	18	16	23	17	25
Including 'precedence'	1	1	0	2	3	4	5

In the HHCRSP articles, various objectives were introduced, for example:

1. Minimizing working hours for caregivers [25–27], but less focus on workload balancing,
2. Minimizing overtime [28,29],
3. Minimizing travel cost [30–32],

while Huvent et al. [33] randomized and generated instances fitting with the home health care problem subjected to certain constraints.

In the literature referred to in Table 2, the authors were often satisfied with good, not necessarily optimal, solutions to be achieved in a reasonably short time. However, the dynamics of publishing show that these topics received more attention in the last five years (see Table 2).

Combining the 'precedence matrix', counted as a constraint in our procedures, also yields no results. Still, some precedences have been considered in recent years, as presented in Table 2. In the model which includes precedence requirements, only Decerle [34] considered workload balance, which is important when organizing supply and care to older adults in their home. In their paper, the authors addressed the routing and scheduling of human resources in a home health care problem. They considered skills, time windows, and synchronization constraints. They also exposed that the workload must be roughly the same to obtain fairness to the caregivers. To solve this challenge, they applied the ant colony optimization algorithm. As a result, an original combination with memetics achieved a work time balance.

In our formalisation of a traveling problem, pairwise sequences' requirements are generalized by transferring the data on time windows to a P-A sequencing. The number of nurses required to care for the growing number of seniors with decreasing functional capacities is not sufficiently increasing. Therefore, this approach is essential for sustainability of LTC, allowing work for up to 480 min (8 h) per day and minimizing differences of worktime over eight hours, thereby assuring fairness for the caregivers.

3. Improving Methods and Models

3.1. New Approach to the Multistate Transitions in Geo-Gerontology

In the case of the development and implementation of the community fall prevention and rehabilitation program in LTC procedures, the multiple decrement model presented in Formula (5) is no longer suitable and presents a gap in the literature. This is because such a model, currently used to model transitions of ageing residents between different types of environments due to functional decline, does not foresee rehabilitation and, therefore, does not allow for improvement in residents' functional capacities [18,21–23]. In such cases, the multistate transition model should be used for the functional area of LTC provision.

Therefore, we developed such a model and implemented it. This model is presented in Formula (6), where improvement in functional capacities, due to a rehabilitation program, is possible. It entails an appropriate rehabilitation process facilitated by proper health and social infrastructures for falls and other risk prevention. Using a multistate transition model is a novelty in evaluating LTC programs. We can then use the risk-weighted present value of public expenditures to understand the impact of such investment on savings arising from lower expenditures related to geriatric health care (e.g., hip fractures, frequent falls, etc.) and LTC. Such an impact is termed social value [35].

As stated in 'Active Ageing: A Policy Framework' [36], special attention should be paid to smart lifetime neighbourhoods. Interventions that create supportive environments (e.g., lifetime neighbourhoods) and ICT embedded in homes to provide ambient assisted living could foster healthy choices and, therefore, are important at all stages of life for older adults. Furthermore, improvements of the environment can lower the disability threshold (as seen from Figure 3) and, thus, decrease the number of disabled individuals in a given environment and, consequently, the human resources needed in the care networks.

The probability of transition from state $I > 1$ back to home care ($I = 1 = adFH$) is higher than 0. The novelty is the possibility of returning to the community due to timely intervention after events leading to injuries and ill health, as well as an appropriate rehabilitation process facilitated by proper health and social infrastructure for falls, or other risk prevention and rehabilitation. Let us denote with $S_{x,}$ the allocation of residents of a functional region of the LTC by type of housing for the studied cohort in the year $\tau+1$ (when they are $x+1$ years old). The multiple decrement model, written as:

$$S_{x+1,\tau+1} = S_{x,\tau} \cdot P_{x,\tau} = \begin{bmatrix} S_x^{(0)} & S_x^{(1)} & S_x^{(2)} & S_x^{(3)} & S_x^{(4)} \end{bmatrix}_\tau \cdot$$
$$\cdot \begin{bmatrix} p_x^{(0)} & q_x^{(0,1)} & q_x^{(0,2)} & q_x^{(0,3)} & q_x^{(0,4)} & q_x^{(0,5)} \\ 0 & p_x^{(1)} & q_x^{(1,2)} & q_x^{(1,3)} & q_x^{(1,4)} & q_x^{(1,5)} \\ 0 & 0 & p_x^{(2)} & q_x^{(2,3)} & q_x^{(2,4)} & q_x^{(2,5)} \\ 0 & 0 & 0 & p_x^{(3)} & q_x^{(3,4)} & q_x^{(3,5)} \\ 0 & 0 & 0 & 0 & p_x^{(4)} & q_x^{(4,5)} \end{bmatrix}_\tau = \begin{bmatrix} S_{x+1}^{(0)} & S_{x+1}^{(1)} & S_{x+1}^{(2)} & S_{x+1}^{(3)} & S_{x+1}^{(4)} \end{bmatrix}_{\tau+1} \quad (5)$$

is now replaced with a multistate transition model, where (because of much better organized home care in a good rehabilitation program in the case of $I > 1$) the older adults can move back to well organized home care ($I = 1 = adFH$). Therefore, we suggest in this article that the mathematical Formulation (5) changes to (6).

The multistate transition model (6), as demonstrated in Figure 4, can be written as:

$$\begin{aligned} S_{x+1,\tau+1} &= S_{x,\tau} \cdot P_{x,\tau} = \\ &= \begin{bmatrix} S_x^{(0)} & S_x^{(1)} & S_x^{(2)} & S_x^{(3)} & S_x^{(4)} \end{bmatrix}_\tau \cdot \begin{bmatrix} p_x^{(0)} & q_x^{(0,1)} & q_x^{(0,2)} & q_x^{(0,3)} & q_x^{(0,4)} & q_x^{(0,5)} \\ 0 & p_x^{(1)} & q_x^{(1,2)} & q_x^{(1,3)} & q_x^{(1,4)} & q_x^{(1,5)} \\ 0 & q_x^{(2,1)} & p_x^{(2)} & q_x^{(2,3)} & q_x^{(2,4)} & q_x^{(2,5)} \\ 0 & q_x^{(3,1)} & 0 & p_x^{(3)} & q_x^{(3,4)} & q_x^{(3,5)} \\ 0 & q_x^{(4,1)} & 0 & 0 & p_x^{(4)} & q_x^{(4,5)} \end{bmatrix}_\tau = \\ &= \begin{bmatrix} S_{x+1}^{(0)} & S_{x+1}^{(1)} & S_{x+1}^{(2)} & S_{x+1}^{(3)} & S_{x+1}^{(4)} \end{bmatrix}_{\tau+1} \end{aligned} \quad (6)$$

where $q_x^{(2,1)} \geq 0$; $q_x^{(3,1)} \geq 0$; $q_x^{(4,1)} \geq 0$ and, therefore, it increases the value of $S_{x+1,\ \tau+1}^{(2)}$ and all further values of $S_{x+k,,\ \tau+k}^{(2)}$ which influence the optimal schedule given by the P-A algorithm or some other HHCRSP results for home care and supply logistics in a given geographical area (functional region of the LTC).

3.2. On the Optimal Utilization of Human Resources in the Network

In Europe, more than 70% of senior citizens aged 60–80 live in owner-occupied housing (Eurostat, 2021). We should investigate how environmental factors in their homes influence their relocation decisions. In other words, "What is the value of $q_{x,\tau}^{(2,3)}$?" Indoor and entrance accessibility and technical housing features, like bathroom safety characteristics, influence relocation within the community or residential care facilities. According to our recent study, as well as reports of many authors [37], more than 8% of US citizens aged 65+ move within the community, and nearly 4% move to less-dispersed residential care facilities or retirement communities. The survey in Slovenia shows similar features and preferences [38].

Many older adults would like to stay in their homes for as long as possible. Therefore, from a sustainable population growth perspective, delivering value by making family housing and care networks for seniors more adjustable can be useful. It influences effective health interventions and daily care, regarding frequency and time spent on the intervention, daily care and other services [39–41]. The location of new service hubs and other facilities particularly influence travel arrangements, influencing costs of health and social services in LTC.

To support European directions towards the deinstitutionalization of LTC [42], optimization models for networks of facilities for senior citizens, and services for them, should be better developed, where the wishes of seniors as to when to be served and costs of services are the subjects of criteria and constraints. Also, the working day of workers should be close to 8 h and, as much as possible, equal for all. Furthermore, these services are very work-intensive and widespread. For this purpose, optimization methods on graphs should be developed. To consider all these requirements, investments in facilities should be properly located and adapted to the dynamics presented in Figure 2.

In the literature, all these requirements are not considered together to find a global optimum under the mentioned constraints. There are papers published in the last five years which consider some of the constraints and criteria, but none consider all of them together (Laesanklang et al.: costs and time preferences [43]; Szander et al.: number of caregivers and preferences of timewindows [44]; Lin et al. cost and preferences in service time [45], Decerle et al.: time balancing and synchronizing [46]; Denzig et al.: time of work and service time window, giving preferences as constraints [47]).

Therefore, we examine to what extent the mathematical model for line balancing introduced by Patterson and Albracht (P-A) [10] could be used in these mathematical formulation and optimization procedures. For this, a vehicle routing problem with time windows (VRPTW) is modified and combined with the P-A priority matrix, based on previous studies of the functional area of care, the dispersion of potential beneficiaries of home care at a selected moment and, over a wider time horizon, the availability of human resources for this care. Figure 5 shows the relationships between activities from recognizing the dispersion of potential users in the functional region, the projections of care needs in the area of dispersed users and the optimization of care.

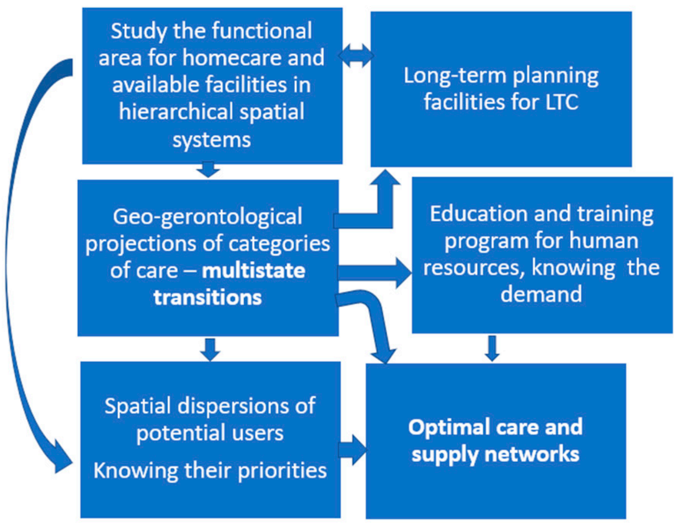


Figure 5. From the study of the functional area of the homecare network to the planning of human resources, infrastructure and optimization of network activities.

Caregivers, who perform services in a network, should be optimally utilized. The number of users increases, which means that the value $S^{(2)}_{x+k,\ \tau+k}$ grows. Therefore, the optimal schedule changes very rapidly. The system should be based on the multistate transition model for proper forecasting of needs in a functional area, as described in Section 3.1, at given norms and standards and potential self-paying superstandards. Namely, the system must dynamically adapt in a timely manner to changed user locations and growing demand. Such rapid rescheduling of services needs a proper computer assisted decision support model. Therefore, we developed an innovative model to support these needs with the minimum number of caregivers who balance activities in the time window of their working day.

The model developed was based on the modification of the nonlinear assembly balancing algorithm of Patterson and Albracht for an assembly line balancing. As the location and distance were not subject to the original P-A algorithm, this algorithm combined the multiple Traveling Salesman Problem in the programming language R.

In our formalization of a traveling problem, pairwise sequences' requirements were generalized by transferring the data on time windows to P-A sequencing. As the number of older adults with decreased functional capacities grows fast (see Figure 2), this approach was essential for better projection of human resources needed and, therefore, for sustainability of LTC, allowing caregivers to work only up to 480 min per day, with 30 min break time allowed, and minimizing the differences of time over eight hours, which assures fairness for the caregivers.

3.3. The Basic Requirements

The paper provides a new method to determine the costs of supply and care in very scattered villages in the functional area of a central care and supply hub if geo-gerontological characteristics and further projections are known. Thus, the method also requires local authorities, social care and spatial planners to study senior citizens' logistics and other services and care, including investments in new facilities or renovation of seniors' housing units. Good supply design also includes determining the functional areas of individual supply networks, having central facilities, like in Figure 1, for each functional area. Once this was determined, we could tackle the issue of the optimal care schedule. Furthermore, the method considered dispersion in the supply areas, as presented in Figure 1, showing how logistics and other services depend on the dispersion of activities in a functional region. Finally, the paper also investigates the opportunity for facility managers to organize new services on the instrumental activities of daily living, due to the presence in the districts of community centers, residential places, offices, etc.

The model is based on the following requirements:

- total working time of all caregivers, including service providers (potential facility managers), should be balanced,
- the timing of servicing individual clients in all areas should be close to the desired time windows of servicing (including travel and idle time) reported by users,
- the costs of caregivers when they work eight hours or less should be the same. When work over eight hours per day is increasingly more expensive, it should be minimized, reducing the necessary number of caregivers,
- The number of caregivers in employment grows according to $q_{x,\tau}^{(i,1)}$ and, consequently, to $S_{x+k,\tau+k}^{(1)}$, where k means the number of years before initiating this planning and τ is the initial year.

For this reason, the network optimization model was combined with Patterson and Albracht's line balancing algorithm, which had not been used in articles considering home care and services.

3.4. Dispersion of Housing Units in a Functional Region Regarding Category and Time Windows of Care

Good care and supply network design requires determining the functional areas of individual supply networks, as described by Drobne and Bogataj [8,9]. In these two papers, we suggested assuming FRs as (local) labor market areas for caregivers of fragile older adults in the region. FRs were modeled using two well-known methods: the CURDS method, which is an internal rule-based multilevel clustering method for grouping basic spatial units (BSUs) into FRs, and the Intramax method, which is based on a numerical approach for hierarchical clustering of spatial units into groups. FRs were modeled for selected spatial levels. The hierarchical systems of spatial units were proposed. Three systems of (functional) regions were analyzed for each analyzed spatial level using the fuzzy set theory. In papers by Drobne and Bogataj, the numerical examples presented were for Slovenia, but instructions can be used for any geographical area.

Once this was determined, we could tackle the issue of the optimal care schedule. We assumed that we had n clients in villages, dispersed in a functional region (as in Figure 1) covered by the homecare network. Their functional capacities were in one of three categories of care (cat I, cat II, cat III, while cat IV went to nursing homes) from low disabilities (cat I) to very high disability (cat IV). For this dispersion of users, we had the current data as well as the expected number, given in GG projections, as in Figure 2.

In the current norms and standards of health and social care, a time of care is prescribed for each category (Ministry of Labour, Family, Social Affairs and Equal Opportunities, 2010–2022). We denoted these norms with ncatI to ncatIV such that ncatI = 0.5 h, ncatII = 1 h, and ncatIII = 2 h. In our paper, we assumed that more detailed measurements on time spent with each old person who needed the support of caregivers (client) had been taken. The future schedules of care could be improved based on collected data on time of care provided in the past for each client. New technologies enabled more reliable estimations of needed service times for each client. The time of care could also be differentiated depending on housing characteristics, and, therefore, on the pair of data of category and accessibility). The number of categories of care and services, and, therefore, the time spent for care and supply, should be known and final for any care and supply client.

Each client reports his preferences on the preferable period of service. For example, let us take the morning program, lasting eight hours from 7 a.m. till 3 p.m. Their preference could be to start the service at 7 a.m., at 8 a.m. and so on, until 3 p.m. In the first step of this algorithm, we transferred the service time windows to the preference matrix to determine a certain dispersion of clients in the service areas (see for example the red dots in the map of Figure 1, from where the area covered with our care and supply network is delineated). Using GIS procedures, we could calculate the road distance and the time distance between a pair of clients. The clients report when they prefer the services; therefore, we obtained a quality factor for each service area regarding the time window of service. Of course, the exact time of service requested is not always achieved. Still, the sequences can be achieved properly based on the P-A optimization procedure, even in cases of varying service times, depending on housing characteristics. This means that in the model each point in the chosen area in Figure 1 could be assigned a different care and supply time.

3.5. Multiple Traveling Salesman Problem

We used the multiple Traveling Salesman Problem approach so that every client was visited once along the shortest possible route regarding the service preferences of the clients in LTC. The multiple Traveling Salesman Problem was modified and formalised as described in [43]. The procedure was used to find the shortest route for visiting the clients. Equations (1)–(3) describe the assignment part, complemented with the sub-tour elimination constraint (4) based on the Miller–Tucker–Zemlin formulation [48].

The integer programming for the Multiple Traveling Salesman Problem is described as:

Consider a graph $G = (A, L)$ where A is the set of n nodes $(i, j = A, B, C, \ldots)$, presenting n clients in LTC of the assistance hub as a facility, known by geocodes on the map, and L is the set of edges $(l_{i,j} \epsilon L)$, marked on the roads of map between all the possible pairs (i, j) of nodes, on which the minimum values of time spent by traveling in-between $c_{i,j}$ are calculated by GIS analytics. Therefore, to each pair of nodes (i, j) the shortest edge $l_{i,j} \epsilon L$ is allocated and evaluated by the travel time $c_{i,j}$. The notation c_{ifk} means the travel time back to the hub from any node i of each caregiver k. Each service provider moves between the clients' homes, starting from, and returning to, the assistance hub. The caregiver's working day lasts from 7 a.m. to 3 p.m., traveling so that the time preference of clients to be served are as close as possible to their wishes and each village is served only with one caregiver and only once in this time window.

The objective of the sub-function (7) is to minimize the total number of caregivers at the constraint (8)–(12), where the duration of routes is equal to, or smaller than, the caregivers' morning workload (8 h). The total travel time of caregiver k is the sum of time distances between clients (c_{ij}) and prescribed care time at the client j (t_j), plus the outbound and inbound travel time from/to the hub facilities.

Minimize m where the working time of the caregiver k, denoted $c(k)$, is limited to 480 min:

$$c(k) = \sum_{j=0}^{n} \left(\sum_{i=0}^{n} c_{ij} x_{ijk} + x_{ijk} t_{jk} \right) + c_{ifk} x_{ijk} \leq 8 \times 60 - t_o = 480 - t_o \quad (7)$$
$$k = 1, 2 \ldots\ m$$

$$x_{ijk} = 0,\ 1,\ j = 1,\ 2,\ 3, \ldots,\ n\ , \quad c_{ij} = s_{ij} * d_{ij} \tag{8}$$

Variable x_{ijk} equals 1 if the kth caregiver goes immediately from i to j, and 0 otherwise. The value d_{ij} is the shortest distance between i and j by road and s_{ij} is the optimal speed possible on the given road, so, therefore, c_{ij} is the time distance. All m caregivers start their daily circular route at the municipal CCE hub, which is a facility serving as a hub, denoted here with the node 0 at the beginning and f for the final destination. The caregivers return to the same location after at least eight hours of work, after visiting the last client. In Equation (7), service time is needed for the j-th client, serviced by k-th caregiver denoted by t_{jk}. Equations (9) and (10) were added to the traditional TSP formulation, to ensure that precisely m caregivers depart from, and return to, the CCE. The caregiver has to leave location i after the care tasks are performed and goes on to only one location j out of the remaining areas, as described by (11).

$$\sum_{k=1}^{m} \sum_{j=1}^{n} x_{0jk(T)} = m \tag{9}$$

$$\sum_{k=1}^{m} \sum_{i=1}^{n} x_{i0k} = m \tag{10}$$

$$\sum_{j=1}^{n} x_{ijk} = 1 \quad \forall\, i,\ \forall\, k \tag{11}$$

$$\sum_{i=1}^{n} x_{ijk} = 1 \quad \forall\, j, \quad \forall\, k \tag{12}$$

Equation (12) requires that if the caregiver is at a particular location at a given moment, then they could have come from only one of the previous places to the present site. The sub-tour elimination constraint (13) is a vital; it is included to have only one tour, a Hamiltonian circuit for each caregiver covering all locations to which the caregiver is allocated, instead of two or more separate trips adding up to serve all clients. Therefore, 'dummy' variables u_i are introduced, which represent the sequence in which location i is visited, while values of u_i are arbitrary real numbers and p denotes the maximum number of nodes visited by any caregiver.

$$\begin{gathered} u_i - u_j + p x_{ijk(T)} \leq p - 1 \\ u_s \geq 0; \quad s = i, j \\ x_{ijk} = 0,\ 1 \\ i = 0 \ldots n - 1 \\ j = 1 \ldots n \\ \forall k;\ k = 1, 2, \ldots, m \end{gathered} \tag{13}$$

3.6. Patterson–Albracht Algorithm to Introduce Users' Preferences in Time Windows

The following mathematical formulation is based on the Patterson–Albracht (P-A) algorithm [10] and considers the following assumptions in the production processes, which are considered for servicing old people:

- Single-product assembly line—here the single functional region of home care is a specific case of LTC with one hub.
- Fixed cycle time—fixed planned worktime cycle of caregivers from 7 a.m. till 3 p.m., which might be extended for ω time units which costs much more.
- Deterministic and integral operation times—here the same (in minutes), relaxed with ω if so decided.
- No assignment restrictions beside the precedence constraints—no choice as to which caregiver serves which client, but the preference matrix regarding when to serve is subject to the optimization procedure.

- Serial line layout—the route of services on the graph.
- All stations equally equipped—all caregivers are equally trained and equipped (have the same capacities to serve any client).

Generally, starting time from the data regarding the tasks, the precedence diagram calculated from the average time determined by clients and the balancing procedure follow these phases:

1. determination of cycle time (c),
2. determining the number of caregivers and/or other service providers (m),
3. identification of earliest and latest activity (here from central facilities location and back),
4. description of constraints,
5. optimization procedure.

Step 1: the determination of cycle time is very simple, here $c \leq 8 \times 60 = 480$ min. Also, ω can be added. In this case we should write:

$$c \leq 8 \times (60 + \omega) \tag{14}$$

Step 2: the determination of the number of caregivers. The theoretical value m^* is calculated as the ratio between the total time to serve all clients $t_j = \sum_{s(j)} t_{j,s}$ plus the total travel time determined in the first procedure, plus given prolongation from the optimal travel time without preferences $c(k)_{max} + \omega$ when to serve and the cycle time:

$$m^* = (\sum j t_j + c(k)_{max} + \omega)/c \tag{15}$$

Minimum chosen ω in which the solution with P-A sequences exists is the value which goes to further procedure. We simulate ω value and add the costs of $C\ (\omega) \times \omega$ to the criterion function.

The next higher integer is chosen to define the real number of caregivers m.

In step 3, precedence relations are used to restrict the number of activities to which a task can be assigned, delimited by the earliest activity E_j and the latest activity L_j using the following equations for positive integer values:

$$E_j = \left\lceil \frac{\left(t_j + \sum_{h \in P_j^*} t_h\right)}{c} \right\rceil \tag{16}$$

$$L_j = m + 1 - \left\lceil \frac{\left(t_j + \sum_{h \in F_j^*} t_h\right)}{c} \right\rceil \tag{17}$$

The final criterion function is:

$$\begin{gathered} f = [C_{cg} * m * 8 + C(\omega)] + \sum_{j=1}^{n} C_{d,j}\delta_j \\ \mathrm{F}* = \min f \end{gathered} \tag{18}$$

where C_{cg} is workload cost of 1 h of servicing and travel of all involved caregivers, $C_{d,j}$ is the cost of evaluated delays for each client separately, and $C(\omega)$ is the cost of additional time needed for relaxation which enables adoption of the service time to seniors' wishes. This means including the preference matrix with the algorithm procedure. In this way, we could also consider the cost of each preference.

In case of evaluation of an investment in a new facility (home) with a client in different possible locations and/or different qualities of construction, we run the procedure for each location h and quality of adaptation to the senior citizen q, (investment $INV\ (h, q)$) at the locations available, and the quality of the dwelling according to the characteristics of accessibility and safety of residence for the senior citizens.

Therefore, at the end, we have a list of pairs: $[INV\ (h,\ q),\ NPV\ (f*\ (h,\ q)]$ which should be presented to the investors. The rational choice would be:

$$Min\ [INV\ (h, q) + NPV\ (f*\ (h, q)] \tag{19}$$

Note that $f\ *(h, q)$ could also depend on increasing demand on the time horizon; therefore, the optimal investment policy on the time horizon should be carefully determined.

When considering dynamics of the number of those who would like to be included in home care, we also have to forecast the availability of human resources in the future, not only in the present. Therefore, the impact of investments on:

$$q_x^{(2,1)} \geq 0;\ q_x^{(3,1)} \geq 0;\ q_x^{(4,1)} \geq 0 \tag{20}$$

increases the value of $S_{x+1,\ \tau+1}^{(2)}$ and all further values $S_{x+k,\ \tau+k}^{(2)}$ should be considered to assume the changes in dynamics of categories and their intensities of care. Therefore, the GG projections, as given in Figure 2, should be improved, depending on these environmental factors.

4. Numerical Example

Scheduling the Caregivers to the Clients

In order to study the necessary number of carers in the long term and attract them in advance to LTC systems (for example with a scholarship policy), it is necessary to study the optimal allocation of carers to the optimal schedules in the area under consideration. By studying the optimization of care schedules, we can estimate the required number of caregivers. We can forecast this number if we know in advance what the conditions of care are, and what the limitations of these services are, determined by norms and standards and dictated by the wishes of the people being cared for, if we want to include them in the care programs. In this numerical example, we show how we estimated the required number of caregivers per care day and how the additional limitation affected this case, if we considered the wishes of the care recipients as to what time windows they want to be cared for in. We also show how these additional preferences affected the total cost of the supply network.

The first step was studying the functional area; therefore, the care and supply network design also included the determination of the functional areas of individual supply network. For this phase of study, we used CURDS and the Intramax method which convinced us that the Posavje region in the NUTS3 delineation was equally good as the CURDS method [8,9]. Once this was determined, we could tackle the issue of the optimal care schedule. In the service area with the hub denoted in Figure 1, there were 28 senior citizens in the LTC network, served by m caregivers who were visiting an optimal set of clients. Here m was not constrained (there were enough human resources on the market). At the final node (centre of facilities as a hub), they must write the report and leave the bag with their tools and medicines there. Therefore, the report should be completed inside the eight-hour window. Thirty minutes were assigned for lunch and communication with the hub. For simplicity, relaxations over eight hours were not assumed. In this first case, $m = 6$ if there were no priorities of clients in terms of care time and, therefore, the precedence matrix was as presented in Figure 6, or described in Equations (16) and (17). The set of constraints in the multiple Traveling Salesman Problem was not included.

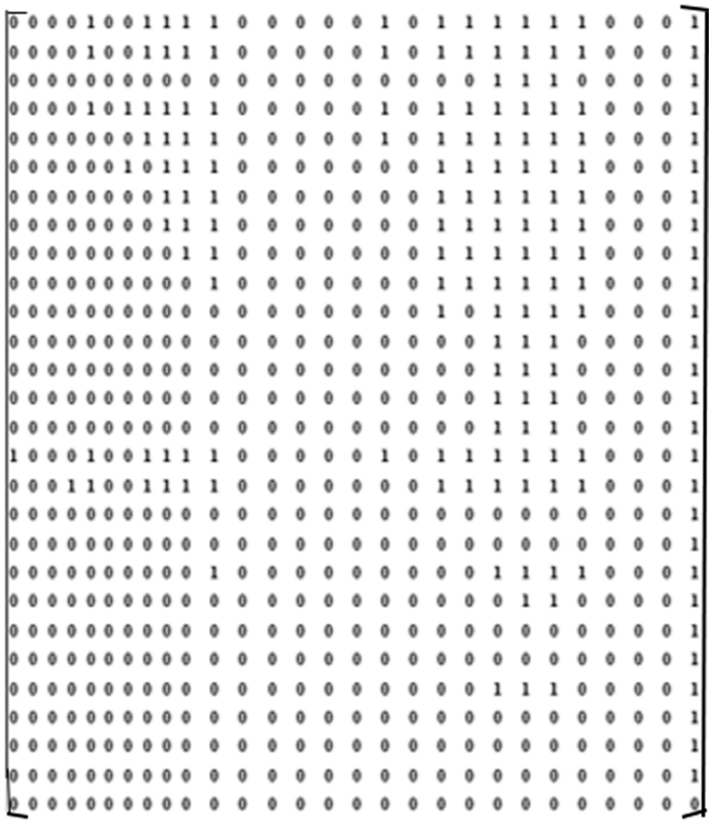


Figure 6. Precedence matrix for nodes (which denote a user) $i = 1$ to 28 as parent nodes and $j = 1$ to 28 as potential child nodes.

However, we later considered that some clients preferred to be served early in the morning and some later. Therefore, their wishes were translated into a precedence matrix in Figure 6. Since the cycle time was eight hours (=480 min) and half an hour was needed for lunch and communication with the hub, the available maximum total service and travel time per caregiver per day was 450 min. All caregivers' total service and travel times (2153 min) were calculated in the case of no priority requirements.

In the next step, let us assume that the precedence matrix in Figure 6 should be accepted. Therefore, the Patterson–Albracht algorithm (P-A) was linked to $mTPS$ in the programming language R. In this step, the total service and travel time was 500 min longer, which required at least one more worker. The travel time from the parent node to the client (resident) j is described in Table 3. In this case six caregivers were needed, as calculated by the P-A algorithm with the requirements that the caregivers were working in balanced time intervals.

Table 3. Travel time (in minutes) from a parent node to the next user, as determined by the mTSP.

User	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Travel time	5	10	5	15	15	10	5	12	10	15
User	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Travel time	15	5	10	10	10	5	10	5	10	13
User	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**		
Travel time	10	5	5	15	2	10	5	10		

Travel times and service times are given in Tables 3 and 4, respectively. Table 4 shows us that the total workload of the five workers was 257 min of working with users of these services.

Table 4. Service time at each client (in minutes).

User	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Service time	86	136	15	144	124	38	50	43	177	58
User	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Service time	109	46	49	118	177	14	98	8	51	88
User	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**		
Service time	204	24	52	126	24	189	44	54		

Table 3 tells us that in the case concerned no constrains of time windows as to when the client would be served were given. The caregiver travelled from the client in a parent node to the client with index 1 for 5 min, from the parent node to the second client for 10 min, . . . and from the parent node to the 28th client for 10 min. Total daily travel time was 257 min (4 h and 17 min).

According to Table 4, the first patient received care for 86 min, the second for 136 min, the third for 15 min, and so on. The care time was determined based on the average time from experience, by category. Despite the norms, it happened that we did not always achieve the exact amount of care time that the norms specified, but remained close to what was set. Among the care recipients, there was also a small percentage of those who urgently needed care in a nursing hospital, but because of waiting times they were still waiting. In our case, these were residents 4, 9, 15, 21 and 26.

Tables 3 and 4 together show us that the total workload of the six workers in the case where priorities in care time windows were not included in constraints, was 2603 min, which was 7.23 h daily, on average, per worker. In eight hours of daily workload, there were 37 min of idle time, on average, if the desired time windows of servicing were not considered.

If we added the precedence matrix to the constraints, the travel time from parent to the child node is explained in Table 5. In this case the total travel time of all caregivers increased from 4 h and 17 min to 5 h and 7 min. Since an individual carer may not work more than 8 h a day, which also included a 30-min break and the return to the hub, the employer must employ an additional carer.

Table 5. Travel time needed from the child nodes when priority precedence matrix was introduced as the additional set of constrains.

User	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Travel time	5	10	5	15	15	10	5	12	20	15
User	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Travel time	15	5	10	20	20	5	20	5	10	13
User	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**		
Travel time	10	5	5	15	2	20	5	10		

Tables 4 and 5 shows us that the total workload in the case of including the priority matrix in the system, and in case that the workload of all workers needed to be balanced, requirea a new caregiver. In this case the total costs increased to cover the yearly salary of an additional caregiver (25,000 €). It meant that the yearly additional cost for following the priority matrix was 20% higher than the services without priority choices. Finally, the allocation of caregivers to the clients in cases without priority constraints is given in Table 6.

For example, caregiver A would be allocated to the 1st, 2nd, 12th, 14th and 16th clients. Caregiver E would be allocated to 13th, 21st, 22nd and 24th clients in the LTC network.

Table 6. Allocation of caregivers A, B, C, D, E, F to the clients (marked with **x**).

User	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
A	**x**	**x**										**x**		**x**
B				**x**	**x**	**x**	**x**							
C								**x**	**x**	**x**				
D			**x**								**x**			
E													**x**	
F														
User	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
A		**x**												
B				**x**							**x**			
C			**x**											
D	**x**					**x**								
E							**x**	**x**		**x**				
F					**x**				**x**			**x**	**x**	**x**

The balanced total travel and servicing time for the caregivers is given in Table 7, where the free time in the 8 h working day is presented and 30 min was assumed for lunch and other breaks.

Table 7. The optimal balancing using P–A algorithm and the mTSP procedure in the spatially dispersed housing units.

Workers	**A**	**B**	**C**	**D**	**E**	**F**
Free daily working time * [min]: x	35	40	37	38	37	40

* 480 − x.

From Table 7 we see that the maximum difference in the daily workload of the caregivers was only 5 min if the P-A algorithm was included. Working time was well balanced and the priority matrix satisfied the clients.

We can additionally conclude that if we allowed the extension of the working day beyond the 8-h limit with a 30-min break, the solution would also be cheaper in the case of restrictions in the time window of care, even if overtime was well overpaid (for example 50% higher). This numerical example is based for the case in Posavje region, as known today. The requirements change, and should be forecast assuming a higher density of clients in the same spatial area. Therefore, simulations are suggested, based on GG projections, using model (6) and ArcGIS calculation of distances.

5. Discussion, Conclusions, and Guidelines for Further Research

Home and community care, and improving the supply chain logistics in LTC, are one of Europe's fastest-growing segments of the LTC sector. However, the segment still consists of mostly small businesses. As such, it needs many improvements in logistics, ICT support and educational programs, not yet well developed in the ADRION regions (Italy, Greece, Slovenia, Croatia, Serbia and Bosnia and Hercegovina), where the rural areas require s high percentage of travel time in the working days of service providers. Therefore, the optimal organization of care and other services is needed, and travel time needs to be reduced as much as possible. Good programs reduce human resources, but in the LTC sector the number of human resources will have to rise because of the rapidly growing number of LTC users, as presented in Figure 2. Therefore, this number should also be forecast for a longer time horizon and adaptations to the education capacities for human resources in these networks conducted, as sketched in the numerical example. The number of human resources can also be reduced by good organization of supply and care networks. HHCRSP models and also the P-A approach could support gauging the optimal number of human resources in rural areas. A good care and supply network design also includes determining the functional areas of individual supply networks. Once this is determined, the issue of the optimal care schedule can be tackled.

HHCRSP models for care scheduling are known for having a long list of constraints. These constraints are attached to caregivers, home care users, some actions in the network or to the basics of HHCRSP itself. We concentrated on the priorities of time-windows of servicing, as required by clients, and equalizing the workload for all providers as much as possible. For this reason, we introduced the Patterson-Albracht requirements in the previously simple mTPS model. Furthermore, introducing the P-A algorithm in the model helps in evaluating what additional costs appear if priorities according to the time window of care are factored in.

We have demonstrated how the Patterson–Albracht algorithm enabled us to consider the desired time windows of services and, consequently, the construction of a priority matrix in the case of spatially dispersed activities, to include service sequences in minimization of travel time and equalization of daily workload. Including mTPS enabled us to examine the outputs of various scenarios very rapidly and to evaluate the costs of following priorities in the sequence of care. This is particularly useful in ensuring a fair workload for all caregivers and other service providers.

From the GG projections, we were able to see how the number of clients was rising fast on the time horizon and, therefore, the individual functional area which belonged to a supply and care network. Therefore, such a procedure must be run frequently because the optimal results change fast. Such an approach is necessary when the number of clients $S^{(2)}_{x+1,\,\tau+1}$ is growing fast and probabilities to stay in, or to return to, home care are denoted by $q_x^{(2,1)}$, $q_x^{(3,1)}$, $q_x^{(4,1)}$ as well as $q_x^{(0,1)}$.

In the numerical example, we only showed the case when the hub was already known, and the demand was also known. As we saw in Figure 2, this demand is growing rapidly and is concentrated in a certain area. Therefore, the following questions arise:

- how can the number of caregivers be reduced by using digital solutions for the older adults included in LTC?
- how does the choice of the location of a new care center (as a new unit in Figure 1) affect the required number of care providers and the costs of care in the rural area of highly dispersed users?
- how can investment and operational costs in dynamics of demand be balanced, as presented in Figure 2?
- how does the spatial demarcation of local administrative units affect the optimization of service areas?

The proposed approach might help professionals adapt in advance to the coming changes caused by the growing number of seniors and rapid changes in technology, but also to consider if the priorities of clients are to be included in the basic national insurance programs or additionally charged as a higher standard of home care services, with the aim of making these care and supply networks as sustainable as possible. The costs of these constraints can be easily calculated using this approach and comparing the basic mTSP with the P.-A. can include constraints.

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