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Original Study

# Process Mining on National Health Care Data for the Discovery of Patient Journeys of Older Adults

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ABSTRACT

*Objective:* Understanding the longitudinal patterns of health care utilization among older adults is crucial for designing effective patient journeys and enhancing care coordination across settings. This study aims to uncover the most common patient journeys of older adults.
*Design:* This explorative study used process mining techniques to analyze national health care data from 2017 to 2019, focusing on patient care journeys of older adults (aged ≥65 years) in the Netherlands.
*Setting and Participants:* Data were sourced from Statistics Netherlands, encompassing all residents aged ≥65 years as of January 1, 2017. Health care usage declarations from various care settings during 2017-2019 were included. Patient journeys were exclusively selected if their initiation points were certain.
*Methods:* Data underwent rigorous preprocessing, merging, and filtering to create a single event log file suitable for process mining. Patients were categorized by age and medication use, and differences in patient journeys were analyzed. Process mining techniques generated visualizations illustrating the connections between care forms and the impact of changes in one form on others.
*Results:* The study included 3,177,203 individuals aged 65 years and older, with 44% experiencing 1 or more patient journeys totaling 2,469,663 journeys in 2017-2019. Most care journeys for older adults were simple and short. The top 10 most frequent journeys had 4 or fewer care forms, with 95% of journeys for the 65+ population and 90% for the 85+ population having 4 or fewer care transitions. Long-term care forms, such as home care, personal care, and long-term care, accounted for the majority of time spent in the system.
*Conclusions and Implications:* This pioneering study used process mining to show that most older adults tend to have a straightforward health care need, often involving the emergency department and hospitalizations. However, a smaller group among the population requires more complex and prolonged care, especially in the 85+ population. Reducing the number of transitions for this population, although impacting fewer people, might result in a larger effect on the overall system.


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Most countries worldwide face challenges for the organization of health care. Major problems, especially for the health care of older adults, will arise or worsen because of a simultaneous aging population,[1,2] an increase in life expectancy,[3] and a decrease in the workforce of caregivers.[4] These demographic challenges raise the urgency for a

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better understanding of the health care usage of older adults. To make any improvements in the system, first an understanding of how the system is currently used is required. Such insights can be obtained from process mining, a method that uses advanced algorithms to analyze huge quantities of data. These analyses are presented as visualizations of patient journey patterns and show which health care forms are mainly used and in which order. This helps us to understand how patients flow through the health care system. For example, a patient can receive 3 health care forms, when the patient starts at the ED, then is admitted to the hospital, and finally receives home care. Process mining enables us to anticipate incoming challenges that the aging population, for example, would face. Thus far, process mining in health care has been used on health care data sets with a smaller scope, such as a hospital.[5,6] However, process mining has not been applied to health care in a systemwide manner. For that, a larger complete data set is required. Statistics Netherlands collects data on care declarations of all inhabitants of the Netherlands,[7] which enables us to map the complete care system.

In this article, we will answer the following 2 research questions: (1) What are the most frequently occurring patient journeys within the health care system of older adults? (2) Is there a difference in health care usage between various age groups and groups with different cumulative drugs use? The hypothesis is that older adults have long and intricate patient journeys, because most research often reports either long-term care pathways or depict the older adults as a frail population with recurrent health care usage.[8,9] It is expected that the length and complexity of these journeys will only increase as the age or drugs use of the subpopulations increases, because age and drugs use are both shown to correlate with an increase in health care usage and frailty, and drugs use is often seen as proxy for frailty.[10,11]

## Methods

### *Study Design*

For this study we used data containing the health care usage of the older adults of the Netherlands from 2017 until 2019. Throughout, we use the following definition of a *patient journey*: a sequence of transitions between different forms of care, allowing for a maximum gap of 4 weeks without professional health care. Health care usage is defined as older adults utilizing professional health care, ranging from personal home care to hospital care. This 4-week limit is based on research indicating that health care events within this time frame are often connected.[12] The data set used in this study originates from multiple health care data sets provided by Statistics Netherlands (CBS).[7,1] Permission was obtained to access the microdata via a secured portal. This study falls outside the scope of the Medical Research Subjects Act due to the complete anonymity of the data set, the retrospective nature of the study, and the public availability of the data within CBS.

The data set includes the following forms of care: Home Care (HC), Personal Home Care (PC), Long-Term Care at home or in an institution (NHH or NH), Geriatric Rehabilitation (GR), Short-Term Residential Care (distinction made between non-palliative and palliative, STC and STC-pall.), Emergency Department (ED) visits, and Hospitalizations (HOS). No Care at home (HOME) is used to define that a person used no declared care. Since the long-term care reforms of 2015,[13] several types of long-term and home care are paid using different budgets. The municipality is responsible for HC; this includes household help, personal support, and low-intensity personal care. PC comprises personal care based on medical diagnoses and is provided by registered nurses and paid for by health insurance companies under the Healthcare Insurance act. GR encompasses specialized interventions tailored to address the multifaceted needs of frail older adults and is also paid by Healthcare Insurance Act.[14] Long-term care can either be provided at home (NHH) or in a nursing home (NH); this care includes all-day-long care by a health care professional and is paid by the Long Term Care Act. Several health care activities fall beyond the scope of this research, for example, the general practitioner; this choice was made due to constraints in data availability and the need for clarity in large-scale analysis. Data limitations restricted access to comprehensive information for all older adults across every health care activity, and incorporating all activities would introduce numerous shorter paths relevant on a small scale but not aligned with the large-scale focus of this study. Preprocessing of the data sets was necessary to create a single event file suitable for process mining.[15]

The data set comprises data from 3,177,203 individuals aged 65 years or older on January 1, 2017. Data from 2017 to 2019 were selected to reflect the health care system, because of anomalies related to COVID-19 in 2020 and the health care reform in 2015.[13,16] Each row contains an activity and its start and end dates. Rows combined are seen as patient journeys. An example of such a patient journey could be the following: a patient has an emergency department visit (ED), a hospitalization (HOS), and returns home with personal care (PC). This journey then counts 3 care transitions and forms. The duration of this journey is then the length from the start date of ED until the end date of PC. In addition, persons could have multiple forms of care at the same time. Periods with multiple care forms were handled by removing overlap based on a ranking in which the most intense care form remains. The ranking is based on intensity in the following order: Death, ED, HOS, GR, STC, NH, NHH, PC, and HC.

The data contain health care usage from 2017 until 2019, since it is possible that journeys have already started before 2017, the choice was made to only focus on journeys of which we are certain that at least 4 weeks of no care pre-date the earliest health care form, meaning only care journeys after February 1, 2017, are considered. It is certain that these journeys are not continuations from journeys that have started before 2017 and, therefore, are certain we capture the beginning of the health care pathways. These *new* journeys are characterized by their number of care transitions (change of care form used by the patient), the used health care types, and the time spent per journey.

### *Process Mining*

The aim of process mining is what is called *process discovery*, that is, discovery of processes or paths in a system.[17,18] This is done by analyzing log files using the R-library named bupaR.[15] We first generate a table containing the number of persons and patient journeys of each subpopulation, after which we generate a table with the most frequently occurring patient journeys of each subpopulation. The journeys are then examined further, as we take a closer look at the distribution of the complexity of these journeys using a histogram and the time length using Lorenz curves. Finally, process maps are generated, which can provide a picture of the complexity of the care journeys taken by each group. These process maps are set to have a coverage of 0.8, meaning that 80% of the journeys are visualized. Increasing the coverage to 1.0 often creates maps containing a superfluous amount of flows, so-called spaghetti maps,[19] which are too detailed to be informative.

### *Age and Polypharmacy*

Finally, the population can be split based on age and drugs use. Specifically, the age ranges 65-74, 75-84, and 85+ years are distinguished, where the age of the person on January 1, 2017, is used. Similarly, a distinction is made based on drugs use of a person in 2017,

[1] The results are based on calculations by Centrum Wiskunde & Informatica using nonpublic microdata from Statistics Netherlands.

because drugs use can be seen as a proxy for frailty.[11] The population is split into individuals who use 0 to 4 distinct types of drugs, 5 to 9 types, or 10+ types. These subgroups enable comparisons between different demographic and drug profiles, with sample sizes of 100,000 persons per subpopulation facilitating meaningful comparisons. Comparisons will be made between the 65+ and the 85+ population; results for the other subgroups are provided in the appendix.

## Results

### Population Data

Table 1 provides an overview of the population used in this analysis. The majority of the population are relatively young: 58% are aged between 65 and 74 years and have little drugs use; only 21% have 10 or more drugs. The fraction of individuals with a care journey increases with age and drugs use, but quite surprisingly, the older subpopulation of 85+ consists of fewer patients with a care journey (44% compared with 52% in the patient group 75-84 years of age). This can be explained by the fact that many older adults aged 85 years or older are already in a care journey in January 2017. In this article, those journeys are omitted, which can be seen in the last column of Table 1; here it is also visible that the 85+ subgroup has relatively more omitted journeys, compared with the 75-84 subgroup. However, it should be noted that the 612,470 excluded journeys do not correspond with 612,470 excluded persons but with only 412,261 excluded persons, as persons with excluded journeys could also have an included journey. We also see that in terms of mean journey length, the subpopulation of 85+ differs most from the complete population, with an average of 2.45 care transitions compared with 2.06 overall. This difference also is clear when comparing journeys with a similar starting time, which can be seen in Supplementary Table 1 in the supplementary material.

### Frequently Occurring Journeys

Figure 1 illustrates the 10 most frequent patient journeys for the 65+ and the 85+ populations, respectively. In the supplementary material, the 10 most frequently patient journeys of all (sub-)populations are shown in Supplementary Tables 2-8. In both the figures and tables, many of these journeys involve fewer than 5 care transitions. The most frequently occurring journey for each (sub-)population is in all cases a journey containing only 1 health care form—the journey often consisting of an ED visit and afterward returning home without professional health care. This can be seen in Figure 1A, where we see that this specific journey occurs 24,350 times in a sample of 100,000 persons. However, for the 85+ subpopulation, the most frequently occurring journey is patients having PC and returning to home without care, also visible in Figure 1B, which occurs 12,008 times in our sample of 100,000 persons. The importance of ED and hospital is evident in the top 3 journeys of the complete 65+ subpopulation, as they can be described by only the hospital and ED. This can also be seen in other top 10 journeys of the other subpopulations.

### Care Transitions and Time Distribution

We observe that by far most care usage of older adults is simple and short when looking at the distribution of the number of care transitions per journey; see Figure 2A (see Supplementary Figure 1 for a distribution of all the subpopulations). Both the complete population and the older subpopulation exhibit a right-tailed distribution, with 59% of journeys for the 65+ subpopulation and 53% for the 85+ subpopulation involving only 1 care form. Additionally, 95% of the journeys for the 65+ subpopulation and 90% for the 85+ subpopulation have 4 or fewer care transitions. Figure 2B visualizes the amount of time spent in the health care system using a Lorenz curve (see Supplementary Figure 2 for the Lorenz curves of all subpopulations). In the 65+ group, the 90% shortest journeys account for only 27% of the total time. Hence, the 10% of the longest journeys account for 73% of the total time spent in the system; these 10% longest journeys consist mostly of long-term care forms, such as HC, PC, and LTC; 9 of the 10 most frequently occurring patient journeys of this 10% consist solely of HC, PC, and LTC. The 85+ group shows that the time inequality is less severe.

### Process Maps

Figure 3 presents process maps for individuals aged 65 years or older, whereas Figure 4 displays maps for those aged 85 years or older. The maps for the other subpopulations can be found in Supplementary Figures 3-7. These maps offer a complete view of health care usage patterns within these age groups. It shows that the majority of both groups have a short and straightforward health care journey (as can be seen in Figure 1A and B). However, by comparing 80% of the population of the 65+ and 85+ age groups, it can be seen that the older subpopulation has a more complex path (see Figures 3 and 4). Notably, the process map for the 85+ subgroup, with the same coverage (0.8), exhibits more transitions and a less structured layout compared with the map for the 65+ subpopulation, indicating that health care usage among the older age group is less predictable and cannot be easily categorized into distinct pathways. This disparity is visually depicted by the "lasagna process" appearance of the map for the 65+ subpopulation, contrasting with the "spaghetti process" observed in the map for individuals aged 85 years or older.

**Table 1**
Population Size as of January 1, 2017

| Group | Number of Persons (%) | Number of Patient Journeys* | Persons With a Journey (%) | Mean Number of Journeys per Person | Mean Journey Length (in are Transitions) | Number of Excluded Patient Journeys |
|---|---|---|---|---|---|---|
| All | 3,177,203 (100) | 2,469,663 | 44 | 1.78 | 2.06 | 612,470 |
| Age, y | | | | | | |
| 65-74 | 1,816,172 (58) | 1,241,416 | 39 | 1.73 | 1.89 | 150,243 |
| 75-84 | 969,814 (31) | 936,401 | 52 | 1.86 | 2.18 | 236,985 |
| 85+ | 357,172 (11) | 273,261 | 44 | 1.75 | 2.45 | 223,212 |
| Drugs use | | | | | | |
| 0-4 | 1,381,582 (44) | 605,638 | 30 | 1.48 | 1.81 | 160,857 |
| 5-9 | 1,122,587 (35) | 948,280 | 49 | 1.72 | 1.96 | 189,503 |
| 10+ | 673,034 (21) | 915,745 | 64 | 2.14 | 2.33 | 262,110 |

*Journeys are included only if their starting point is clearly identifiable, meaning that only journeys not present in January 2017 are considered. It should be noted that individuals may have both excluded and included journeys. The data indicate that frailer subpopulations tend to have a relatively higher proportion of excluded journeys.

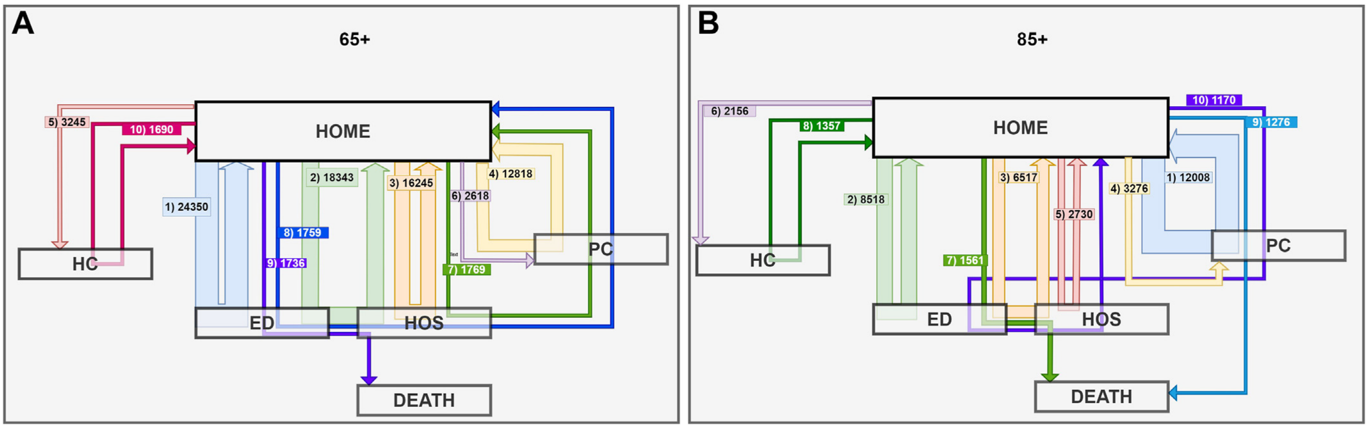


**Fig. 1.** The 10 most frequently occurring patient journeys for the (A) 65+ and (B) 85+ subpopulations (taken from a sample of 100,000 persons). It shows how often the specific journeys occur within the sample.

## Discussion

This is the first study to identify patient journeys over a large-scale health care system using process mining. It was found that the most frequently occurring patient journeys of older adults contain either 1 or 2 and often not more than 4 care transitions.

Similar to the simplicity, it was found that most journeys span a relatively short amount of time, as indicated in our Lorenz Curve. This confirms the previous observation that most older adults have simple and short health care journeys. Only a small part of the population covers more than half of the total time spent of all journeys, implying that this group requires more coordination in the system. Noteworthy is that this inequality diminishes for the 85+ subpopulation; this can be attributed to the fact that health care journeys that have started before February 1, 2017, are not included, and that this subpopulation often uses long-term care, either at home or at an institution.

Another interesting observation is the consistent presence of ED visits or hospitalizations in nearly all frequently occurring journeys across all (sub)populations. This underscores the important role of the ED and hospital as entry points into the health care system for older adults. Therefore, proper health care at the ED is crucial, and strategies to avoid ED visits should be studied. Additionally, it was observed that hospitalizations often followed ED visits, indicating the acute nature of these hospital admissions. Streamlining this transition is crucial given the prevalence of ED in health care journeys, as inefficiencies in ED transfers can limit its effectiveness and lead to more care utilization later in the patient journey.[20,21]

Notably, the process maps of the older subpopulation of 85+ depicted a more complex map than that of the 65+ subpopulation, suggesting a greater diversity of health care journeys among older adults aged ≥85 years. As more of the population of the Netherlands ages in the future,[22] the strain on the system will rise further. More specifically, it is expected that the number of older adults aged ≥80 years also would increase over the coming years, for which we show that this group is harder to capture using a few transitions. This makes it more difficult to predict, anticipate, and coordinate the journey an older adult aged ≥85 years will embark on in the health care system. Simplifying these journeys could minimize the efficiency loss in possible transfers, as transfers can be the source of a higher care demand, inefficiencies, or dangers.[23] Integrated care for this population might be essential to limit the number of transfers.[24] Additionally, integrated care can enhance the continuity of care, reduce redundancies, and improve overall patient outcomes by ensuring that all aspects of an older adult's health needs are managed cohesively, which is especially important for those aged ≥85 years. For this subpopulation, 4 of the 10 most frequently occurring journeys include PC,

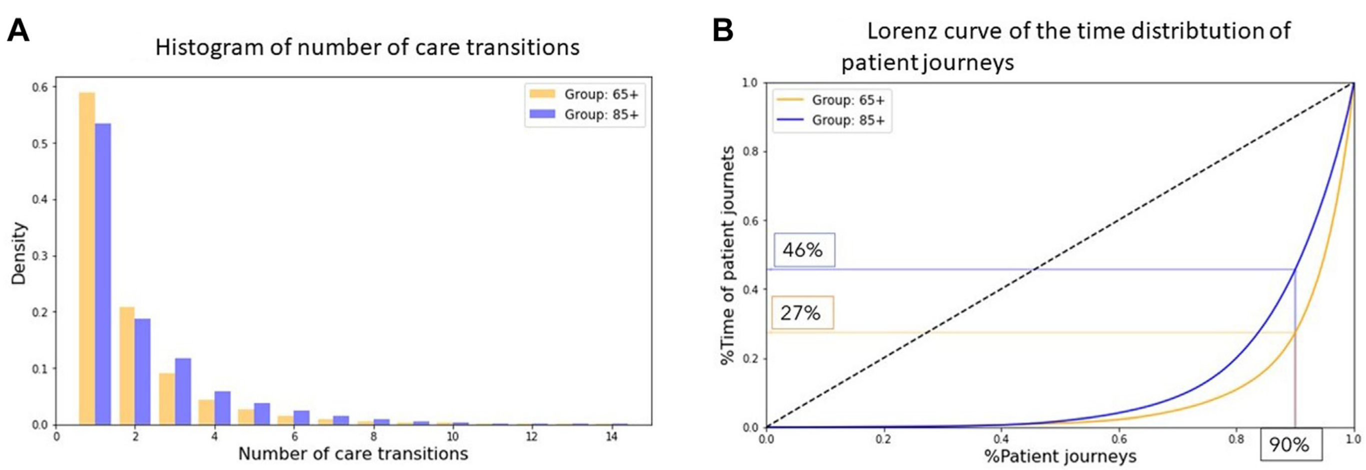


**Fig. 2.** Exploring variations in care transition frequency distribution: (A) a comparative analysis between the 65+ and 85+ age groups and (B) a Lorenz curve of patient journey time allocation between the 65+ and 85+ age groups. The curve illustrates the cumulative distribution of time spent across patient journeys, highlighting differences in health care utilization patterns among older adults.

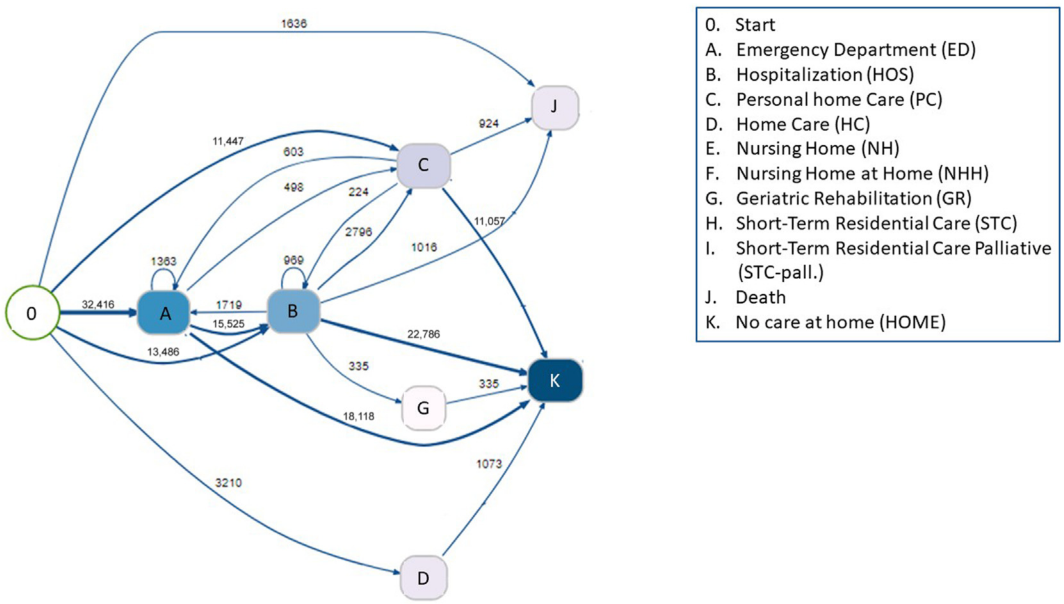


**Fig. 3.** Process map of 80% of the most frequently occurring journeys of the 65+ subpopulation (taken from a sample of 100,000 persons). The number above the lines show how often that transition occurs in the sample, given an 80% coverage.

providing policy makers with a clear entryway into how to target this part of the population.

*Strengths and Limitations*

This research distinguishes itself from previous research into patient journeys by providing a scope on the whole health care system, whereas previous papers often focus on only a small part of the health care system, for example, the hospital, as well as a small sample.[25-27] Previous research on patient journeys of health care usage is often focused on designing the patient journey,[28,29] whereas this article focuses on first understanding what the patient journeys of older adults are, because the system should first be understood before adaptions can be made.

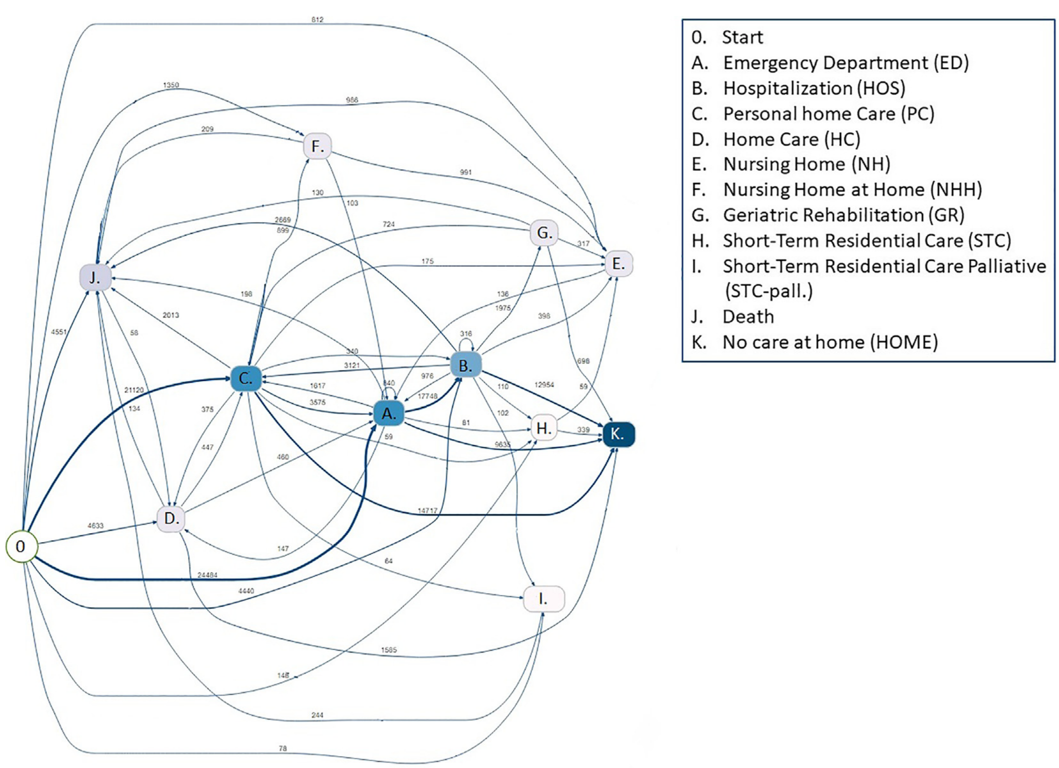


**Fig. 4.** Process map of 80% of the most frequently occurring journeys of the 85+ subpopulation (taken from a sample of 100,000 persons). The number above the lines show how often that transition occurs in the sample, given an 80% coverage.

The authors acknowledge that this research has also some limitations, and therefore the results should be used with caution. An example of a limitation is the fact that it is centered around the Dutch health care system. However, given the similarities in population demographics and health care structures between the Netherlands and countries in Northern Europe and Canada,[30,31] the findings are also applicable to these regions. In contrast, the markedly different health care systems in the United States and Asia present challenges for direct application of these results,[32,33] necessitating further investigation to determine their relevance in these contexts. Another limitation is that the analysis only includes patient journeys that begin after January 2017, which may exclude the longest and most intense patient journeys that started earlier. Additionally, we are limited to data from 2017 to 2019, potentially missing longer patient journeys that extend beyond this period. Furthermore, although the analysis differentiates between age and drugs use groups, it does not account for other important characteristics that could provide a more nuanced understanding of patient journeys. This limitation suggests that future research could benefit from incorporating a broader range of variables.

### *Future Work*

Some research opportunities fell beyond the scope of this study and could be topics of future research. Previous research done by the NZa that focuses on the health care usage 100 days preceding death or nursing home admittance shows that these journeys are often different and visualize a different part of the population.[34] This research approach is promising and could be examined further, especially given the importance of ED visits and hospitalizations. Another opportunity for follow-up research is to include other groups of the population and a longer time window. Future research could also zoom in into different factors such as patient comorbidity or geographical region; here the comparison between different regions with different types of health care is especially interesting, for example, how does the proximity of ED affect the patient journeys.[35] Another interesting aspect could be the inclusion of overlap; in this article, the authors chose to remove overlap of different care forms. However, overlap of care forms could signal that the provided care from one care form is insufficient and this could characterize a specific subpopulation.

## Conclusion and Implications

In conclusion, this study employs process mining on a data set from CBS to unravel the complexity of patient journeys of older adults in the Netherlands, addressing critical challenges in health care of older adults. The research aims to provide insights that can inform policy makers for more effective health care decisions, providing an overview into which and how different forms of care are used by the older adult population of the Netherlands.

In summary, our study highlights how most older adults tend to have straightforward health care needs, often involving short visits to the emergency department or brief hospital stays. However, a smaller group among them requires more complex and prolonged care. This suggests that when designing or adapting new health care policies, focusing solely on the complex cases might overlook the majority who rely on simpler health care services. Therefore, it is important for policy makers to consider the broader picture, including routine emergency and hospital visits, to ensure that any changes made benefit the majority of older adults accessing health care. However, the 85+ population has a longer and more complex health care pathway. This implies that reducing the number of care transitions or journey length for only this group might result in a larger effect on the system at large, because of the interconnectivity of the various forms of health care that this group requires.

## Disclosure

The authors declare no conflicts of interest.

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The sponsor of this research is NWO. NWO defined the subject ‘care for older adults’, but did not have any influence on the exact topic selection or execution of this research.

## Supplementary Data

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.jamda.2024.105333.

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