Impact of Population Ageing on Hospital Demand

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Abstract: This paper explores the consequences of demographic changes on future access to hospital beds. It is based on the situation in a Polish administrative region called the Wrocław Region (WR). The aim of the paper is to quantify the impact of population ageing on hospital demand with particular emphasis on neurological patients. A computer simulation model was used to project the population evolution during the period 2016-2030 and forecast the number of neurological patients to be admitted to the WR hospitals. We found that the growth of the WR population will have a large impact on the number of elderly patients, including persons with diagnosed neurological disorders. The simulation experiments predict a continuous rise in the demand, and the ageing alone will increase the number of neurological patients in WR, on average, by 8.5 % between 2016 and 2030.

1 INTRODUCTION

Forecasting hospital demand is essential when developing long-term healthcare policies on the national or regional level. The available resources are usually limited and choices have to be made between different interventions, treatments, diagnostic procedures, and care processes. Effective planning also requires adjustments in the number of beds assigned to different medical specialties to cover the future needs of the population inhabiting the region. The common practice is to perform an analysis of the previous utilization of hospital beds, develop forecasts describing the predicted demand, and plan the allocation of the available resources in accordance with the forecasted needs of the population.

The demand for healthcare services is driven by a range of different factors, from which the epidemiological and demographic trends have the most significant influence on the number and type of medical needs expressed by the population. The demographic ageing in the developed countries is described by a shift in the age structure towards the older cohorts. As the population of elderly grows, the demand for healthcare services is expected to increase considerably (Strunk et al., 2006; Burkett et al,. 2017; Aboagye−Sarfo et al., 2016). The effect of ageing varies across the major groups of healthcare services and is strongly connected to a type of medical condition and disease group (Vrhovec and Tajnikar, 2016). The observed morbidity trends force adjustments to be made in the capacity of hospital wards to better map the distribution of inpatient utilization rates.

With the growing complexity of policy issues, there is a pressing need for computer-aided modelling tools that can enable rational resource-related decisions for hospital bed planning in the short- and long-term. Such a possibility is offered by simulation modelling. Simulation techniques have been extensively employed to analyse and design healthcare systems for a long time, but an extensive increase in use of simulation in healthcare studies has been observed since 2000 (Chahal et al., 2013). According to Mielczarek (2016), the main fields of applying simulation approaches in healthcare management may be categorised as health policy, healthcare system operations and improvements, forecasting and healthcare system design, medical decision-making, and healthcare planning involving extreme events. Hospital bed optimization, a subgroup of system operations and improvements group, has also been addressed by simulation modelling methods (Cochran and Bharti, 2006; Harper and Shahani, 2002; Harrison et al., 2005). The object under study is usually a single unit or a complex of mutually related clinics. The models are used to study the influence of the changes in demand

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on the healthcare units' standards of service and try to suggest improvements to the internal organisation of the unit, assuming a certain level and structure of demand.

The overall aim of this paper is to describe the construction of a hybrid simulation model to investigate the impact of population ageing on the growing demand for inpatient hospital services in neurological wards in south-western part of Poland.

Hybrid simulation refers to the combination of continuous and discrete modelling methods (Mustafee et al., 2015). The term *hybrid* describes an approach that integrates methods and techniques hitherto occurring independently. The reason for using a hybrid model is an expectation to gain some additional benefits that are unobtainable when using the particular methods independently. Arisha and Rashwan (2016) confirm that hybrid simulations are becoming more popular because of their ability to overcome the limitations of a single-approach paradigm. Moreover, a hybrid simulation in healthcare decision making could assure the balance between strategic and operational management (Chahal and Eldabi, 2008), particularly at the regional level.

2 DATA AND METHODS

2.1 Study Design and Setting

The Wrocław Region (WR) is in the south-western part of Poland and constitutes the core area of the 4th biggest Polish administrative region – Lower Silesia. The population of WR was approximately 1.22 million in 2016, about 3.2% of the nation's population and 42.1% of Lower Silesia's population. It is projected to increase to 1.25 million in 2030.

The inpatient healthcare system of WR is based on 17 public hospitals that can be freely selected by insured inhabitants of WR, as well as patients from other Lower Silesia subregions and citizens from other Polish provinces. There are 8 neurological wards in WR (general, paediatric, and rehabilitation wards) out of 19 situated in Lower Silesia area. In 2016, there were 220 neurological beds (out of 522 in Lower Silesia) and the average length of stay (LOS) was 6.7 days. The annual utilization, calculated as the quotient of the product of the number of patients and LOS by the number of beds, then rescaled for 365 days, is very high, that is 86% in 2015 and 82% in 2016. The average waiting time for admission ranges between 70 and 300 days.

The official projection prepared by Polish Ministry of Health (2018) forecasts that number of neurological patients between 2016 and 2029 will increase by 5.4%.

2.2 Data Sources

The historical data describing the WR population was extracted from Polish Central Statistical Office (GUS 2017) for the period 2010 – 2016, separately for 36 age-gender groups (0–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–105): 18 female and 18 male cohorts.

Beyond the year 2016, the trends describing the expected changes in the WR population were elaborated based on the official projections prepared by the Polish Government (Waligórska et al., 2014). There are four main variants of the possible demographic changes of Polish population (Table 1). These variants predict different but probable trends according to which the WR population is expected to evolve. The variant no. 2 is officially considered to be the most probable one.

The data on arrivals to WR hospitals were obtained from the National Health Fund (NHF) database, routinely collected and managed by NHF regional offices. It contains patient-level data covering all hospital stays, mode of arrivals, and the courses of the treatment processes while staying in the hospital wards. De-identified data were requested to preserve patient privacy. The basic data sets include information on 183,517 admissions in 2010 to 17 hospitals located in WR.

Table 1: Four main variants of the possible demographic changes of Polish population.

	Fertility rate	Mortality rate	Life expectancy	Migration
1	Low	Low	High	Medium
2	**Medium**	**Medium**	**Medium**	**Medium**
3	High	Medium	Medium	Medium
4	V. High	V. High	Low	Medium

2.3 Methods

We have constructed a hybrid simulation model using two simulation methods to predict the influence of population ageing on hospital demand.

The demographic changes of the WR population were projected using the well-established methodology (Forrester, 1968) of system dynamics and the algorithm developed by Eberlein et al. (2013) to precisely model the ageing population. We have applied the extended version of our model described in detail in (Mielczarek and Zabawa, 2018). That model generated numerically appropriate and validated forecasts. However, it was characterized by some drawbacks. For example, tedious calculations had to be made each time new data were added to the input database to recalculate the maturation times between consecutive age-gender cohorts. The improved version of our demographic forecasting model divides the population under study into 210 elementary cohorts (105 cohorts per each gender). One cohort simulates one year of ageing of males and (separately) females.

In order to speed up the simulation experiments, we grouped 210 elementary cohorts into 36 main cohorts (18 per each gender). Each main cohort encapsulates five elementary cohorts (see Figure 1). For simplicity, it was assumed that demographic factors are constant for each elementary cohort being a part of the main cohort.

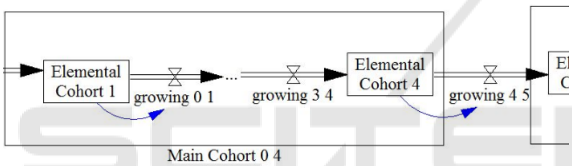

Figure 1: Demographic model: main cohort decomposes into the chain of elementary cohorts.

To model the demand for hospital services we constructed discrete event simulation model (DES). Flows of patients are generated separately for every age-gender cohort and arrival rates change according to calendar month (see Figure 2). Arriving patients acquire individual attributes, like the district the patient comes from, the diagnosis code according to ICD-10 (International Classification of Diseases), the hospital she selects to be treated in, the treatment she receives when staying in a hospital ward, length of stay, and many others. The attributes are interrelated and mutually dependent. For example, the ICD code of the main diagnosis determines the ward the patient will be treated in.

Patient pathways and times between activities are described by random values sampled from parametric and empirical distributions. We used random variable distributions to model the arrival processes, hospital choices, morbidity trends, service times, likelihood of intervention, number and type of services delivered to patients, and others.

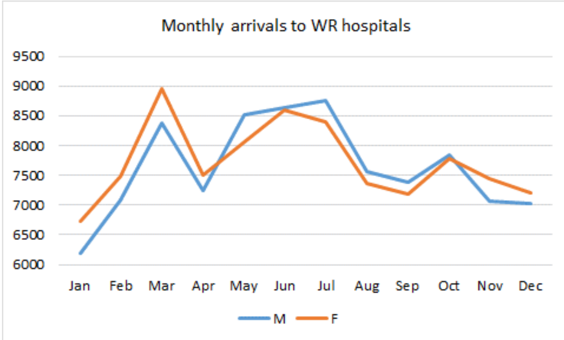

Figure 2: Seasonal changes in total monthly admissions to WR hospitals.

The model was tested using a historical validation and a comparative analysis between model output and actual performance of the system. The results of the simulation are consistent with the historical data and acceptable for the estimation of WR demand (Table 2).

Table 2: Historical validation performed for total monthly number of patients as registered in the WR in 2010: comparison of current system performance and results of simulation (10 replications) – values of mean percentage errors (MPE).

Month	Historical	Simulation	MPE(%)
January	460	457	-0.66%
February	570	573	0.52%
March	612	609	-0.45%
April	535	533	-0.40%
May	588	586	-0.31%
June	629	631	0.36%
July	604	607	0.54%
August	526	535	1.65%
September	526	526	0.01%
October	552	549	-0.45%
November	531	528	-0.54%
December	498	500	0.32%

3 SIMULATION MODEL

3.1 Overall Algorithm

The challenge was to create the credible framework that would enable us to link the demographic evolutions of WR population with future hospital demand. We have elaborated the four-phases algorithm described below.

First, using the SD model, we performed the demographic simulation for the years 2010-2016, based on historical parameters that describe the WR population. Starting from 2016, we applied the extrapolated fertility, mortality, and immigration rates 15 years into the future, that is until 2030. The most probable variant (scenario 2 as described in par. 2.2) is considered as the *base scenario*.

Second, following Strunk et al. (2006), we calculated age-gender specific WR demand indexes using 2010 demographic data and 2010 hospital arrivals data. There are 36 values describing the varying effect of ageing of WR population on total inpatient hospital demand (Figure 3). The youngest and the oldest cohorts are likely to generate higher demand compared to middle-aged groups. We assumed the demand indexes remain constant and may be used to estimate the volume of demand corresponding to the simulated changes in the structure of WR population. We also assumed that all other drivers of hospital demand remain stable.

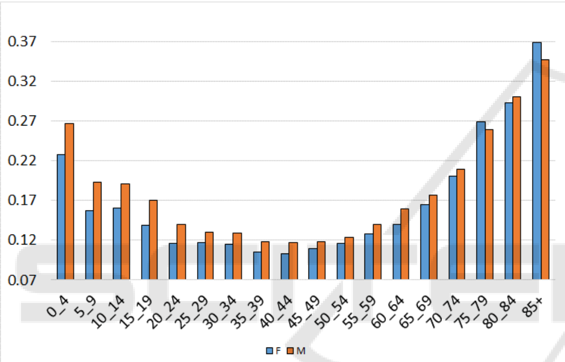

Figure 3: Calculated hospital demand indexes per age-gender cohort [patients/population].

Third, given the population projections and hospital demand indexes describing the needs for hospital treatment that correspond to each age-gender cohort, we estimated the number of future inpatients. This enabled us to calculate the values of new arrival rates for every year beyond 2016.

Fourth, DES simulation was performed to follow individual patients as they pass through the healthcare system, and their progress depends on uncertainties associated with admission and the length of delays in internal processes. During simulation, every patient receives the ICD code used to classify this patient to a medical speciality and direct her to the corresponding hospital ward. Figure 4 and Table 3 demonstrate the probabilities of being classified as a neurological patient. The older the patient, the higher probability of being admitted to a neurological ward. Although the values for both genders are very similar, a small difference may be observed between female and male cohorts. For the oldest cohort (85+) this difference is even more visible.

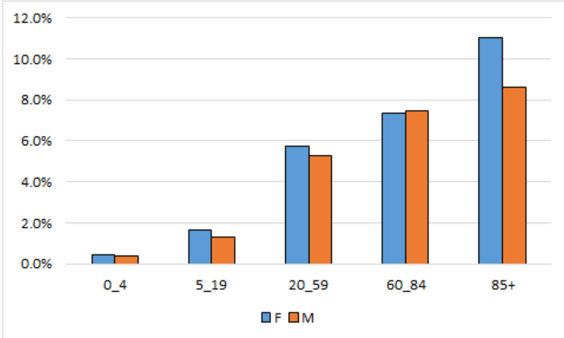

Figure 4: Probabilities of being diagnosed as a neurological patient within given age-gender group.

Table 3: Percentage of being diagnosed as a neurological patient within given age-gender group [%].

	0_4	5_19	20_59	60_84	85+	All
F	0.47	1.65	5.76	7.35	11.06	5.39
M	0.36	1.32	5.29	7.46	8.63	4.59

3.2 Experiments

Simulation experiments were conducted according to three officially published demographic scenarios (see Table 1): scenario 2 (*base scenario*), scenario 1, and scenario 4. According to scenarios 1 and 2, the WR population will record the initial growth period. However, around 2025, a stable and decreasing trend will be observed (Figure 5). Scenario 4 predicts the continuous increase of the WR population until 2030. However, the speed of this growth begins to weaken around 2025.

Although all three examined scenarios forecast the initial demographic growth, the region is characterized by an ageing population. It is expected that by 2030, the percentage share of the eldest among the WR population will increase from 22.95% in 2016 to 25.18% (Scenario 4), 25.46% (Scenario 1), or 25.64 (Scenario 2) (see Figure 6).

Population projections obtained from the simulation demographic model were used to estimate future healthcare demand through discrete simulation. Two main outcome measures were applied: the overall demand for healthcare services in WR and the number of neurological patients arriving to WR hospitals, stratified by age group and sex. Every experiment was replicated 10 times and covered the period from 2016 to 2030.

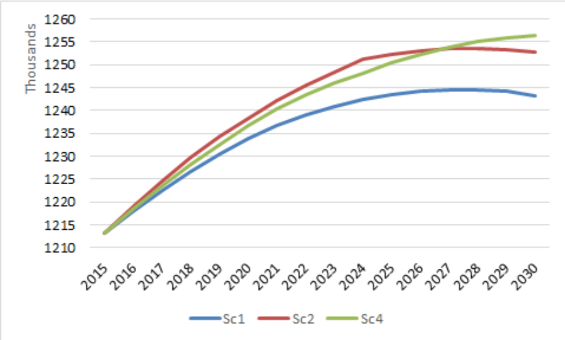

Figure 5: Predicted total WR population trends according to three scenarios: scenario 1, scenario 2, and scenario 4.

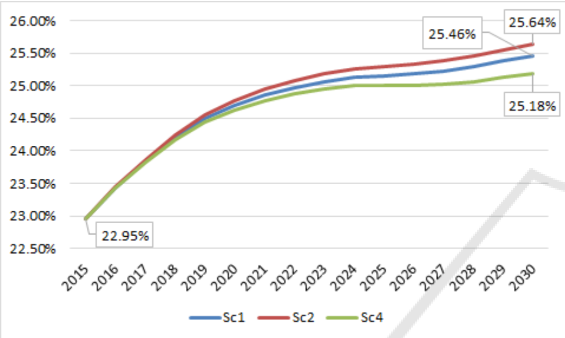

Figure 6: Predicted percentage share of the oldest persons (60+) among total WR population, according to three scenarios: scenario 1, scenario 2, and scenario 4.

4 SIMULATION RESULTS

4.1 Ageing Effect on Total Hospital Admissions

The results of the impact of three scenarios on the estimated number of patient arrivals to WR hospitals are presented in Figure 7. It is predicted that there will be a 4.15% (Scenario 1), 5.17% (Scenario 2), and 5.82% (Scenario 4) increase in overall WR admissions from 2016 to 2030 (Figure 7). Population growth over this period will be 2.46% (Scenario 1), 3.25% (Scenario 2), and 3.56% (Scenario 4). It means that the growth rate in overall arrivals will exceed that of population growth.

The growth of overall demand is observed across all age groups, except the two youngest cohorts, for which the stable and significant decrease in the number of arrivals is predicted, Figure 8.

According to scenario 2, the demand generated by the oldest female population was estimated to grow by 19.6% over the next 15 years. During the same period, the number of the oldest male patients will increase by 16.49%. This would translate to over 42 300 female patients and 27 800 male patients in 2030 from the current level of 35 400 and 23 900 female and male patients in 2016.

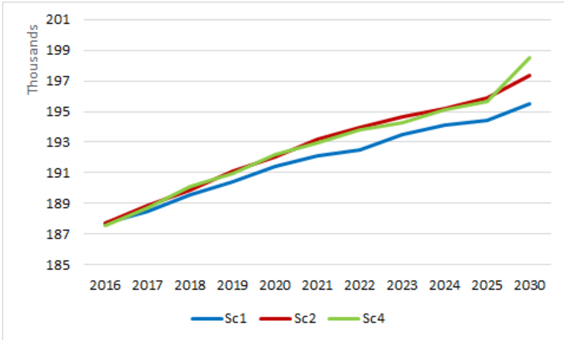

Figure 7: Projected total WR arrivals according to three scenarios.

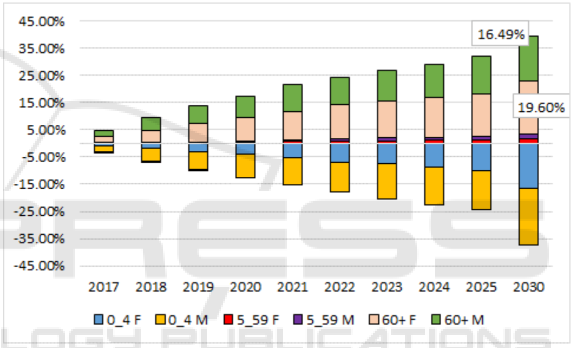

Figure 8: Percentage changes of healthcare arrivals by age-gender groups - in relation to 2016 and according to Scenario 2.

4.2 Ageing Effect on Neurological Admissions

Neurological disorders are diseases of the brain, spine, and the nerves that connect them. There are more than 600 diseases of the nervous system, such as brain tumours, epilepsy, Parkinson's disease, stroke, and others. Neurologic diseases are the major cause of death and disability in elderly patients (Nentwich and Grimmnitz, 2016). They are more common in geriatric patients because of the physiologic changes and comorbidities that occur when people age.

The strategic analysis published by Polish Ministry of Health (2018) recommends immediate increase in the availability of neurological beds. Based on the methodology we have developed, we ran simulation experiments to predict future demand for neurological beds in WR hospitals. The

Table 4: Predicted number (in thousands) and compound annual growth rate (CAGR) of neurological patients demand in WR by 2030, overall and by age-gender groups. Historical data and simulation output.

	2010 - Historical data			2030 - Scenario 1				2030 - Scenario 2				2030 - Scenario 4			
	Total	Female	Male	CAGR(%)	Total	Female	Male	CAGR(%)	Total	Female	Male	CAGR(%)	Total	Female	Male
WR population															
All ages	1 173.6	609.9	563.7	0.29%	1 243.1	650.1	594.2	0.33%	1 252.7	657.8	595.5	0.34%	1 256.5	655.8	600.0
0_4	59.1	28.4	30.6	-0.61%	52.3	25.8	26.5	-0.51%	53.3	26.3	27.0	-0.10%	57.9	28.6	29.3
5_59	887.2	446.3	440.9	-0.06%	876.1	438.4	437.7	-0.04%	879.8	441.1	438.7	-0.03%	882.4	441.5	440.9
60+	227.4	135.2	92.2	1.66%	315.9	185.9	130.0	1.73%	320.2	190.4	129.8	1.65%	315.5	185.7	129.8
Overall demand															
All ages	179.8	90.0	89.8	0.23%	188.0	94.8	93.2	0.26%	189.4	96.0	93.5	0.28%	190.0	95.8	94.3
0_4	15.9	7.1	8.7	-1.07%	12.8	5.8	7.0	-0.96%	13.1	6.0	7.1	-0.51%	14.3	6.5	7.8
5_59	115.2	54.0	61.2	-0.08%	113.4	53.0	60.4	-0.05%	114.0	53.4	60.7	-0.02%	114.7	53.6	61.1
60+	48.7	28.8	19.8	1.80%	69.5	41.6	27.9	1.86%	70.4	42.5	27.9	1.80%	69.5	41.6	27.9
Neurological demand															
All ages	10.2	5.5	4.7	0.20%	10.6	5.9	4.7	0.23%	10.7	5.9	4.7	0.23%	10.7	5.9	4.8
0_4	0.1	0.0	0.0	-2.09%	0.1	0.0	0.0	-1.86%	0.1	0.0	0.0	-1.33%	0.1	0.0	0.0
5_59	6.1	3.0	3.1	-0.80%	5.2	2.6	2.6	-0.78%	5.2	2.6	2.6	-0.75%	5.3	2.6	2.6
60+	4.0	2.4	1.6	1.46%	5.4	3.3	2.1	1.49%	5.4	3.3	2.1	1.46%	5.4	3.2	2.1

projections for overall demand in all the tested scenarios were similar. However, some discrepancies were observed, as shown in Table 3.

Following (Aboagye−Sarfo et al., 2016), we calculated compound annual growth rate (CAGR) of neurological demand (Formula 1),

$$CAGR = \left(\frac{V_{2010}}{V_{2030}}\right)^{\left(\frac{1}{20}\right)} - 1 \qquad (1)$$

where V_{2010} and V_{2030} are the values of neurological demand in 2010 and 2030, and 20 is the number of years between 2010 and 2030, (see Table 4).

Between 2010 and 2030, the number of neurological patients in WR hospitals will rise, according to Scenario 2 (*base scenario*), from 10 198 to 10 670, that is by 4.6%. Looking at the period between 2016 and 2030, this growth is even more significant and is equal to 8.5%. Between 2010 and 2030, the increase in the number of the oldest patients with neurological disorders will be from 4 008 (2010) to 5 393 (2030), which gives an extremely high value of increment, that is 34.5%.

The values of CAGR calculated for neurological demand in the oldest cohorts are between 1.46% (scenario 1 and 4) to 1.49% (scenario 2). When comparing to CAGR values for overall demand (1.86% in scenario no 2 and 1.80% in scenarios no 1 and no 4) during the same period, it is clear that the increase in neurological demand in the oldest population is almost as high as the increase of the overall healthcare demand. Knowing that older patients require more complex and more costly treatments, these predictions show a significant economic effect of ageing on the whole healthcare system.

4.3 Ageing Effect on Neurological Beds

Based on the estimated level of the demand for neurological hospital admissions, we calculated the number of neurological beds needed to keep the annual utilization coefficients on the desired level. The recommended value of this coefficient for neurological departments is 80%. Figure 9 presents three simulations for three demographic scenarios.

The population aging will have a relatively large effect on admissions to neurological wards. The projected number of neurological beds in WR will have to be increased by 8%−9%, according to all three scenarios, to cover the desired level of annual bed utilization. It means that at least 20 more

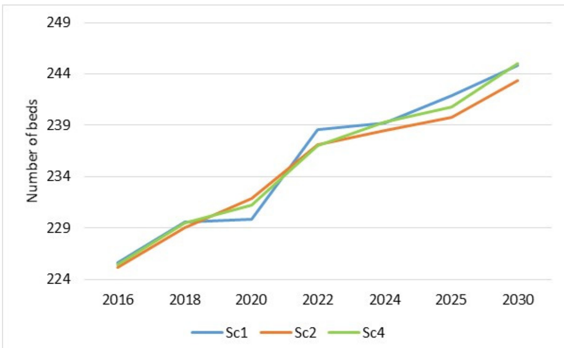

Figure 9: Projected number of neurological beds in WR to cover the desired level of annual bed utilization according to three scenarios.

neurological beds is required in 2030 compared to 2016. It should be noted that these forecasts do not contain data about neurological patients older than 85+ who were treated on cardiology or geriatric departments. The real needs are therefore even greater than it is shown by our simulations and the gap between predicted demand and the current supply might be even more significant.

5 DISCUSSION AND CONCLUSIONS

The findings of the present study indicate that simulation approach is a powerful and effective tool for modelling health service demand. It was proved to be a useful predictive method when estimating an overall demand stratified by diagnosis groups, and by age-gender cohorts. Although, the contribution of simulation to healthcare management is well known, the potential for combining different simulation techniques and using data from different sources within one hybrid simulation model has not been sufficiently emphasized. We have attempted to demonstrate this by building the model to test the impact of different demographic scenarios on overall demand for healthcare services and on demand for one type of hospital bed.

Our study shows a significant growth of WR healthcare demand, especially in the oldest cohorts. Additionally, the simulation experiments predicted that population ageing alone increases the demand for neurological beds during the next 15 years by about 8%−9%. This will put substantial pressure on the Polish healthcare system.

Our approach is scalable and it could be used by regional authorities to plan across the small administrative unit or across the large area. Although our estimates are based on the validated and best available data, there are some limitations that we would like to overcome in our future research. In particular, the assumptions relating to the constancy of demand indexes should be reconsidered.

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