University of Strathclyde Business School

LEARNING-BASED DYNAMIC SCHEDULING WORKFORCE SYSTEM

Optimizing the Workforce Across NHS Scotland

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1. Introduction

NHS Scotland has reached a sustainability crisis due to its crescent capacity and demand imbalance due to multiple factors like system inefficiencies, insufficient workforce, low government investment and lack of infrastructure. However, each problem should be approached independently. This study aims to offer a solution to the elevating patient waiting times that the GPs in Scotland are increasingly facing.

Waiting time standards specify how long a patient must wait at each stage of the process, from referral to treatment. The stats make for concerning reading: 90% of patients receive therapy referrals after 18 weeks. Regardless of the severity of their medical conditions, patients are experiencing unacceptably prolonged waiting periods, undermining the efficiency and effectiveness of healthcare delivery. This growing concern demands immediate attention as it jeopardizes the quality of health care, patient satisfaction, and most importantly the health of Scotland's people.

This report describes the creation of a learning-based dynamic scheduling workforce system; whose objective is to optimize the labour force within each Health and Social Care Partnership (HSCP) across NHS Scotland; tendered as a solution to decrease waiting times for patients.

This learning-based dynamic scheduling workforce system takes an input of historical data and collection of multiple models which forecasts the future patient's demand and workforce availability for each Health and Social Care Partnership (HSCP) and it optimizes the workforce, re-distributing the doctors as per the projected requirements. This study focuses on Glasgow as a sample. However, this system should be applied throughout NHS Scotland.

2. Context

2.1. General Practice Services

In the UK and more specifically in Scotland, a local GP practice team is the prime NHS department to be approached for general healthcare assistance.

These practices are made up of integrative teams which generally include General practitioners (GPs), advanced nurse practitioners, general practice nurses, practice managers, receptionists and physiotherapists.

2.2. Health and Social Care Partnership

Health and Social Care Partnership (HSCP) in the NHS is a collaborative effort to integrate healthcare and social services within specific geographic areas. It coordinates and streamlines service, ensuring holistic and patient-centered care. It often involves multi-agency collaboration and are responsible for resource allocation, preventive services, and quality improvement. HSCPs aim to meet the diverse needs of the local community efficiently.

2.3. NHS Workforce

NHS Education for Scotland NES releases an annual report with a set of key performance indicators including staff employed and vacancies.

“On 31 March 2022, NHS Scotland had a total headcount of 181,723 staff, the highest reported to date and a 2.3% increase in the past year” (NHS Education for Scotland- NES, 2022).

The employment demand and supply in NHS Scotland can be understood from the vacancy rates. High vacancy rate may indicate larger assigned responsibilities over current staff coping with staff shortage. The cause can vary from recruitment challenges to low employee retention levels which at the same time could be triggered by wage competition.

NHS Education for Scotland -NES (2022) discuss this further:

> The vacancy rate of allied health professions increased from 6.2% to 8.2% from March 2021 to 31 March 2022 *(Figure 1).* Similarly, the number of nursing and midwifery vacancies has increased over the past year from 6.6% to 8.7% over the same period.

2.4. Workload of GPs in Scotland

In recent years, a crescent capacity/demand imbalance has been observed resulting in a general practice sustainability crisis. This is mainly caused because many GP practices cannot meet the demand of their patients due to clinicians' shortages. This situation impacts directly on patient’s waiting times for scheduling appointments, follow-up appointments and planned surgeries. Also, it affects the workload of doctors and nurses.

2.5. Waiting times in Scotland

Patients consider waiting times to be a significant indicator as they offer valuable insights into how NHS Scotland is addressing the service demand. Waiting times are consistently measured and reported, highlighting systemic inefficiencies and enabling monitoring of NHS Scotland's performance across the country.

2.6. Health Inequalities in Scotland

Health services quality and efficiency can affect patients' health directly. Also, it can affect them indirectly when impacting socio-economic factors. The Scottish people perception of public health services relies on NHS responsiveness and availability.

From year 2010 to 2020, Scottish Government spending on health was increased only by one per cent per annum. Despite the prior decade, the spent increased by 5 per annum. In recent years increase is well below the requirements for maintaining service quality (Figure 2). The health funding constraints faced by the Scottish Government were a result of the UK Government’s austerity programme.

2.7. Learning-based dynamic scheduling

With the profound utilization of the Internet, big data and cloud platforms, manufacturing job structure has developed from simple job shops to complex connected shared and smart manufacturing systems.

Zhou, Zhang and Horn (2023) discuss this further:

> Scheduling problems are a classic type of optimization problems in the manufacturing domain, such as job shop scheduling, flexible job shop scheduling, and distributed job shop scheduling problems. Especially, the dynamic task scheduling problem is closer to the requirements of real manufacturing systems than the static scheduling problem. Smart manufacturing scheduling has some characteristics compared with job shop scheduling not only because of the larger number of tasks and services, but also because of the dynamic state of services and uncertainties.

2.8. Autoregression Integrated Moving Average

Autoregression Integrated Moving Average (ARIMA) is a powerful time series analysis technique used for modelling and forecasting sequential data. It consists of 3 main components: Autoregressive (AR) for capturing data dependencies, integrated (I) for differencing to achieve stationarity, and Moving Average (MA) for modelling random fluctuations. This technique is widely used to understand and predict time-dependent data, making it valuable for research publishers.

3. Action plan

To understand NHS Scotland increasing waiting time problem, scrutinized research has been conducted. The solution has been designed to tackle this pertinent problem.

Fundamentally, the solution offered is the creation of a learning-based dynamic scheduling system which will have three positive outcomes. Firstly, the design purpose, which is to optimize the workforce throughout each city. This means that the tool will be able to identify understaffed and overstaffed HSCPs and consequently, be able to suggest a possible workforce interchange within the same city. Secondly, the system will identify the real workforce vacancies, guaranteeing the number is not under or overestimated. And lastly, finding the ideal location and quantity of new GPs infrastructure required. Additionally, *Table 2* includes the detailed budget for setting of a new GP; the budget includes workforce wages from multiple bands, office equipment, medical insurance for staff and others.

4. Methodology

Data analysis and modelling are required to estimate the demand and GP availability for healthcare resource optimisation. This procedure is described in detail in this section.

4.1. Data Gathering and Integration

Patient's population data from the last 3 years in Scotland (2021-2023) have been collected and analysed to understand the patient inflow pattern for various time intervals (yearly, quarterly). Data has been collected from various sources and combined to conduct thorough research and get to a meaningful conclusion to predict the demand. The dataset sources are cited in the references section of this document.

To gain a deeper understanding on how NHS Scotland is currently facing its service demand, it was compared to the distribution of ongoing waits quarterly for the last 3 years. The data in 2023 is only available until the end of June 2023.

4.2. Exploratory Data Analysis (EDA)

Upon the analysis after last three years data for Scotland we were able to identify the demand in different time intervals from 2021 to 2023. From the captured information we can estimate the future demand for each HSCP, GP linked to a location. To gain a deeper understanding of the demand per HSCP, GP we have taken one single HSCP which contains several GPs. For this instance, we have taken Glasgow city as a sample. Further details can be found in the research, findings, and analysis section.

4.3.Feature Engineering

Created relevant features that can help in predicting demand and GP availability. Some feature ideas are described further below.

4.3.1. Demand Prediction

Based on the analysis, it was possible to come to the quarterly demand from 2021 to 2023. Taking the past three year's demand as an input, it has been feasible to anticipate the future's demand, employing the time series forecasting technique to predict future patient demand.

4.3.2. GP Availability Prediction

Predicting GP availability is a bit more complex due to various factors affecting their schedules and on-call status. Here's how it was approached:

An analysis was performed to determine the GP doctor's count according to per HSCP patient's demand.

4.4. Model Evaluation

The model was assessed using metrics like MSE and suggested for the development of the accuracy.

4.5. Implementation, integration, and continuous improvement

The study does not include the implementation process; however, this stage of the project is of high relevance. Previously, it is recommended trial sample implementation test and evaluate model performance with sample real-time data integration. Within this stage, comes to life the integration of the demand and GP availability predictions into the healthcare scheduling system to support real-time decision-making.
Lastly, it is worth adopting continuous improvement measures like monitor systems that find the accuracy of your predictions in real-time, KPIs tracking, and gather feedback.

5. Research, Findings and Analysis

Regarding waiting times in Scotland, there is a significant increase in the number of patients waiting between 2021 and 2022 (*Figure 3* and *Figure 4*). The line chart in *Figure 5* represents a sharp increase of the number of patients waiting for treatment from Jan 2021 to June 2023. It can be clearly seen that the number of patients waiting increased at a rapid pace from 5.18 million to 7.87 million between Jan 2021 and June 2023.

The number of patients in each year by HSCP from 2021 to 2023 can be seen in *Figure 6.* From the graph, Glasgow has a significantly higher number of patients among other HSCPs in Scotland. Additionally, an outstanding increase in patient count has been observed in Glasgow over a 3-year period, with increasing patient figures from 2.9 million in 2021 to 3.1 million in 2023 (Figure 7). This data can also be observed in *Figure 8* on a quarterly basis. From *Figure 9*, it is observed that NHS Greater Glasgow and Clyde has a notably higher number of patients, approximately 5.3 million patients each year, compared to other health boards in Scotland.

When it comes to workforce, it has been identified a declining trend in number of doctors in Scotland from year 2021 to 2023 (*Figure 12*). *Figure 13* shows that Scotland's big cities such as Glasgow and Edinburgh have the highest number of doctors. *Figure 17* showcases a predicted increase in the number of patients in 2024, indicating a growing future demand.

The prediction models of the study are the most complex and time-consuming elements. The demand prediction model design was quite complex, it went through test and trials from different statistical approaches trying to find the best possible fit for the dataset. The ARIMA model was found to be the best statistical approach for the demand prediction as there was no seasonality component present. Once the model was ready, the prediction for both, demand and availability were set for the trial projection on Glasgow for year 2024. *Table 1* describes the study results outlining current and expected workforce and workforce differences among Glasgow HSCPs. Highlighted in yellow are Argyll and Bute and Orkney Islands HSCPs which denote a negative workforce difference of (-6) and (-12) workforce correspondingly. This means there are 18 doctors available to give services in other HSCPs within Glasgow to cover projected demand.

6. Conclusion

As a solution to the current NHS Scotland waiting times increment, it is pertinent to use the information advantage to deliver efficient and smarter solutions. Fundamentally, the proposal is the development of a learning-based dynamic scheduling system. The model's primary goal is to optimize the workforce in the cities of Scotland, as for an organization of this magnitude, cost reduction is essential. The learning- based dynamic scheduling system detects understaffed and overstaffed HSCPs, as well as recommend potential workforce swaps within the same city and pinpoint the opportunity staff swaps among HSCPs. In future, an additional feature may be added which can identify location and amount of new GPs infrastructure needed across the country.

The input of the model is patient inflow and workforce available per HSCP for Scotland from 2021 to 2023. The output of the model is the future quarterly demand of patient count and workforce per HSCP for Scotland year 2024.

During the data gathering process, there was no dataset available containing all the required data. Therefore, the dataset utilized for this study was created by a collection of multiple sources listed in the reference section. Each GP within an HSCP has a unique combined identifier (practice code and HSCP code). This unique identifier acted as a mapping factor to join various datasets to prepare a master dataset.

Scheduling appointments and managing doctors' availability across several HSCPs is a complex procedure that has significant effects on the healthcare sector. Optimising health systems requires the combination of technology, patient-centered treatment, and efficient resource allocation. Furthermore, ongoing, data-driven evaluations and a dedication to patient satisfaction are necessary for these techniques to be implemented successfully. In order to provide all patients with high-quality care while striking a delicate balance between doctor availability and appointment scheduling, it will be essential to adopt new technology and approaches as the healthcare landscape changes.

All the necessary assumptions of time-series models were satisfied. For advance application, the model can be applied for every General Practice centers.

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7.1. Data sources

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8. Appendix

Table 1. *Workforce projected values, Glasgow 2024*

**Workforce denotes quantity of doctors.*

HSCP	Current workforce	Expected workforce	Workforce difference
Aberdeen City	228	363	135
Aberdeenshire	211	353	142
Angus	92	169	77
Argyll and Bute	131	125	-6
Clackmannanshire and Stirling	148	244	96
Dumfries and Galloway	130	217	87
Dundee City	153	227	74
East Ayrshire	108	185	77
East Dunbartonshire	102	154	52
East Lothian	125	163	38
East Renfrewshire	85	159	74
Edinburgh	614	845	231
Falkirk	137	210	73
Fife	290	545	255
Glasgow City	622	1062	440
Highland	323	341	18
Inverclyde	62	111	49
Midlothian	110	142	32
Moray	93	132	39
North Ayrshire	132	193	61
North Lanarkshire	216	491	275
Orkney Islands	43	31	-12
Perth and Kinross	160	214	54
Renfrewshire	152	262	110
Scottish Borders	120	168	48
Shetland Islands	30	32	2
South Ayrshire	108	160	52
South Lanarkshire	234	481	247
West Dunbartonshire	102	133	31
West Lothian	170	267	97
Western Isles	31	38	7

Table 2. *The detailed budget of setting of a new General Practice*

Category	Estimated Cost
Practising Privileges and Insurer Recognition	
Data Protection Fee	£40 per year
Disclosure and Barring Service (DBS) Check	£53-£73 (depending on the type of check)
Medical Billing	
Billing and Collection Setup Fee	Up to £250
Ongoing Billing Services Cost	3-5% of fees collected
Office Equipment	
Office and Business Equipment (internet, computer, phone system, desk, chair)	Approximately £2,500
Accounting and Finance	
Business Bank Account Charges	£90 per year + transaction costs
Accounting Software	£20-£35 per month
Total Estimated Cost (Excluding Indemnity Insurance)	
Initial Setup Costs	Approximately £3,000
Annual Running Costs	Approximately £33,000+
Indemnity Insurance	
Medical Indemnity Insurance (Annual)	£372 per year
Medical Indemnity Insurance (Monthly)	£31 per month
Total Estimated Cost (Including Indemnity Insurance)	
With Medical Indemnity Insurance (Annual)	£3,372 per year
With Medical Indemnity Insurance (Monthly)	£3,031 per month

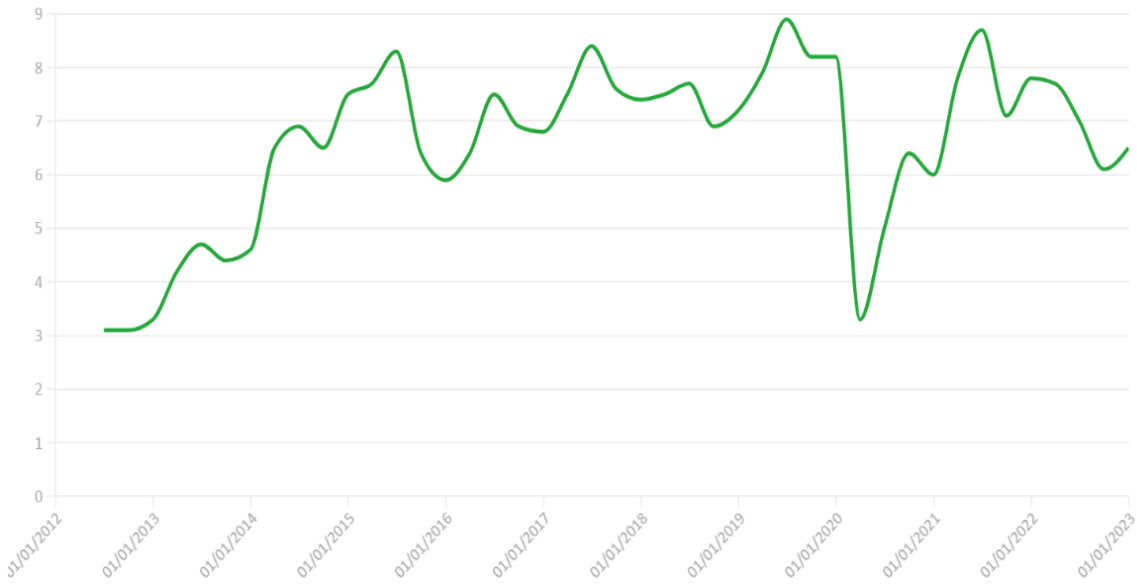

Figure 1. *NHS Scotland vacancy rates (Sep 2012 – Dec 2022)*

Source: TURAS. NHS Education for Scotland, 2023

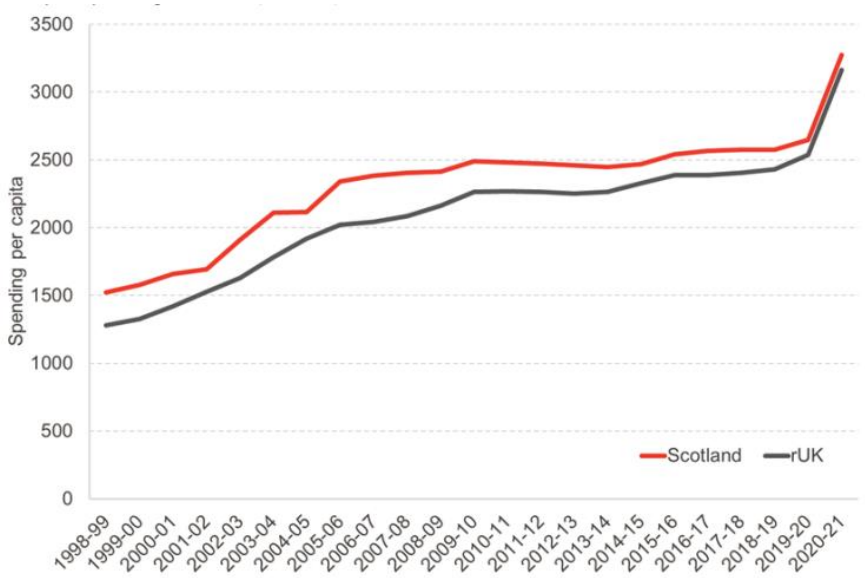

Figure 2. *Per capita spending (£million) after the financial crisis- Scotland and UK*

Source: FAI analysis of Government Expenditure and Revenue Scotland (Scottish Government,2021).

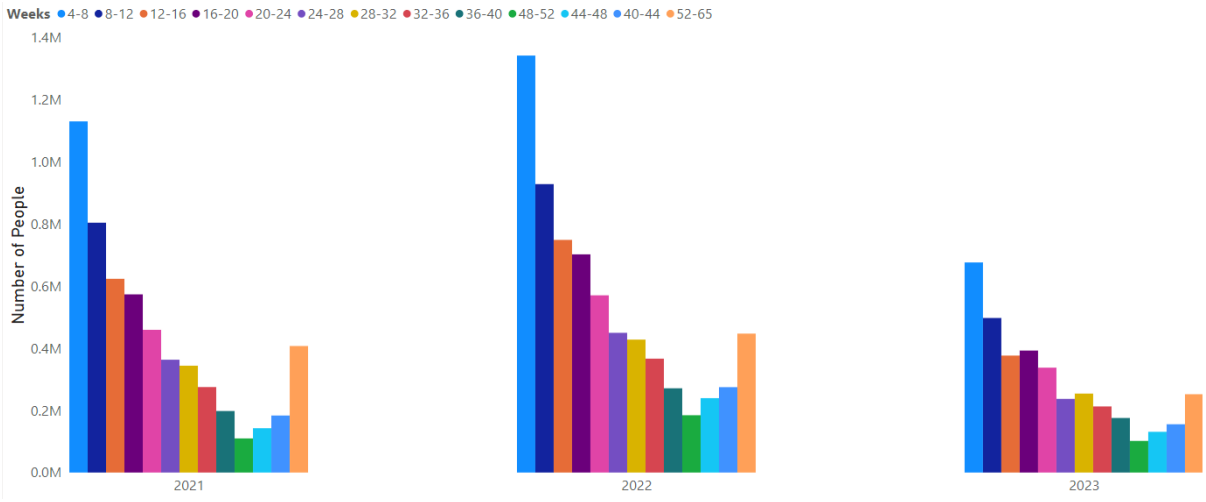

Figure 3. *Distribution of ongoing waits in Scotland by year (Jan 2021 – Jun 2023)*

Source: Stage of Treatment Waiting Times (PHS Primary Care Team, 2023)

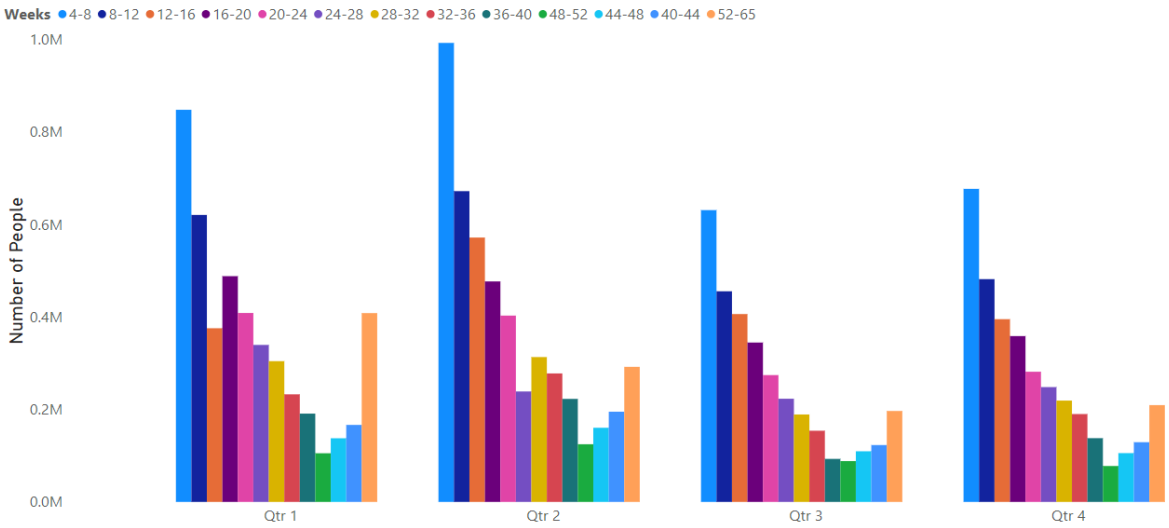

Figure 4. *Distribution of ongoing waits in Scotland by quarter (Jan 2021 – Jun 2023)*

Source: Stage of Treatment Waiting Times (PHS Primary Care Team, 2023)

Figure 5*. Number of ongoing waits in Scotland (Jan 2021 – Jun 2023)*

Source: Stage of Treatment Waiting Times (PHS Primary Care Team, 2023)

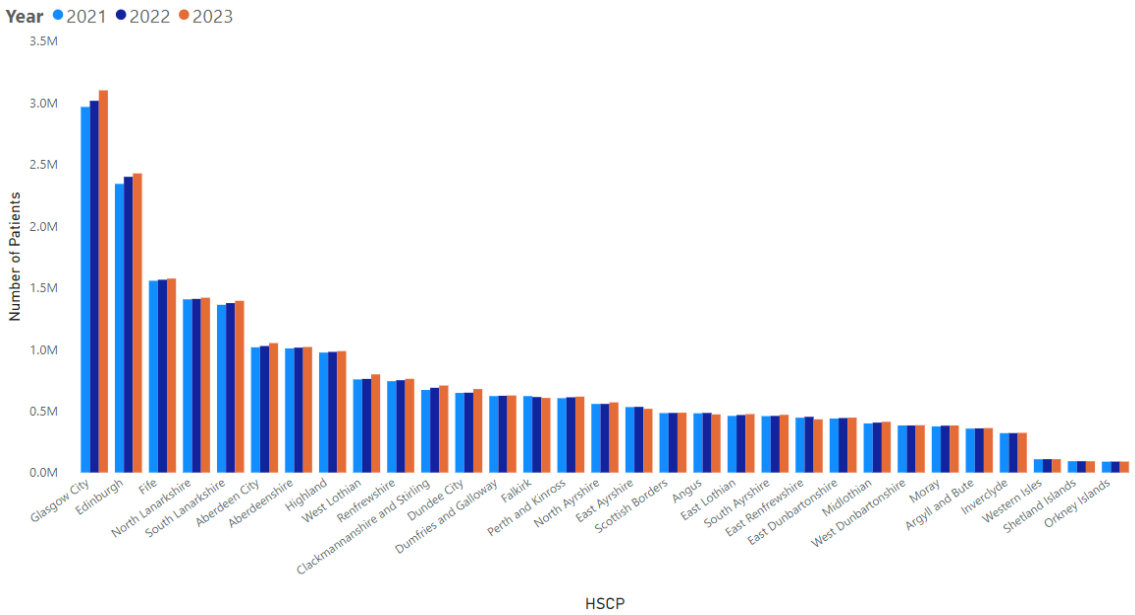

Figure 6. *Number of patients by HSCP (2021 – 2023)*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)

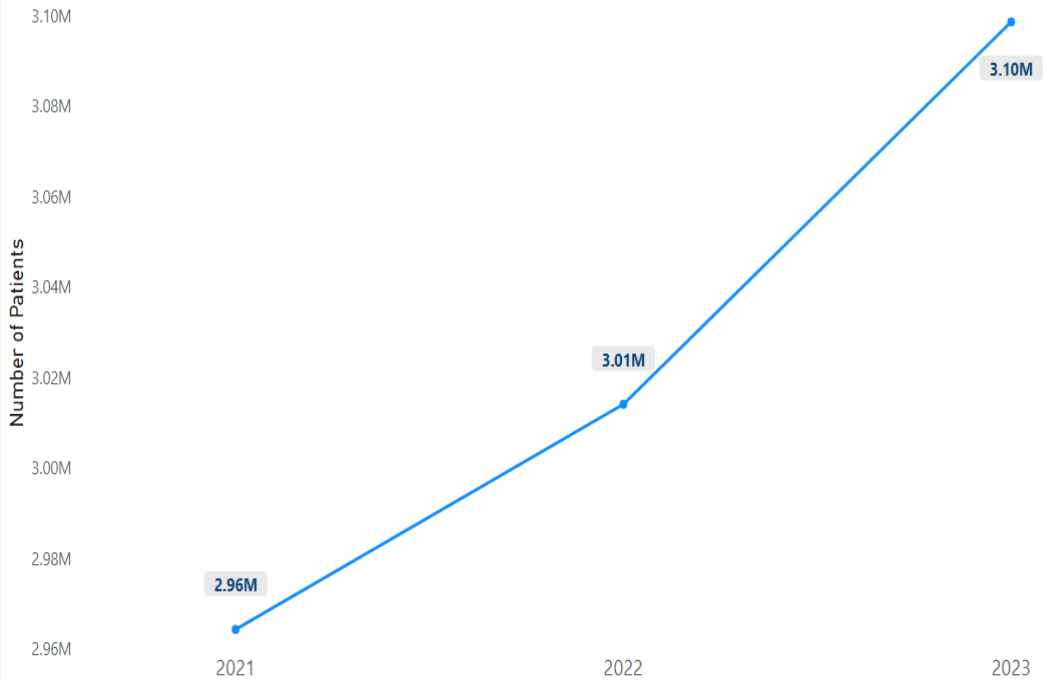

Figure 7. *Number of patients in Glasgow (2021 – 2023)*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)

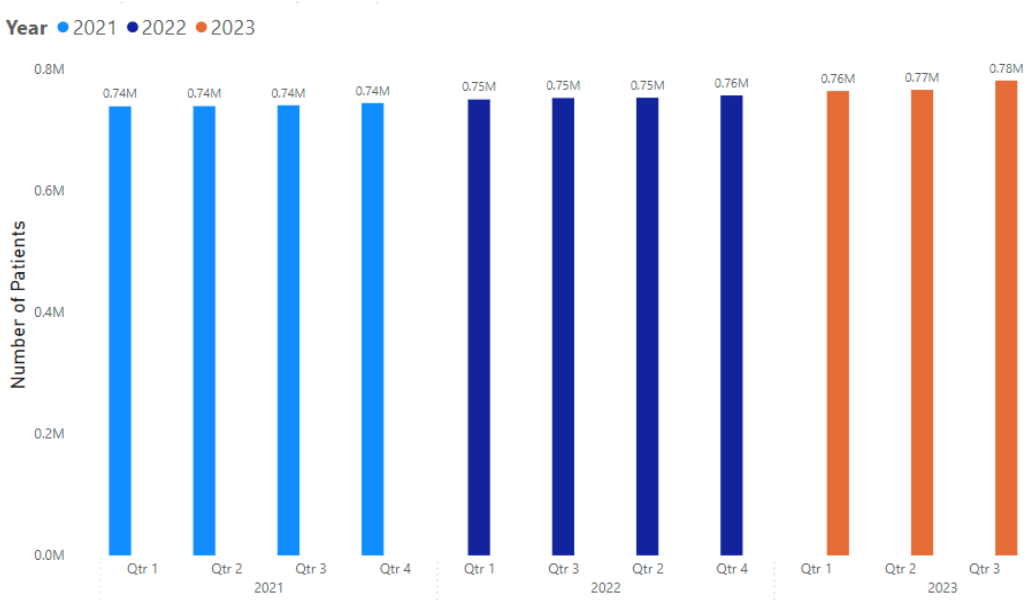

Figure 8. *Patients' population in Glasgow (2021 – 2023)*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)

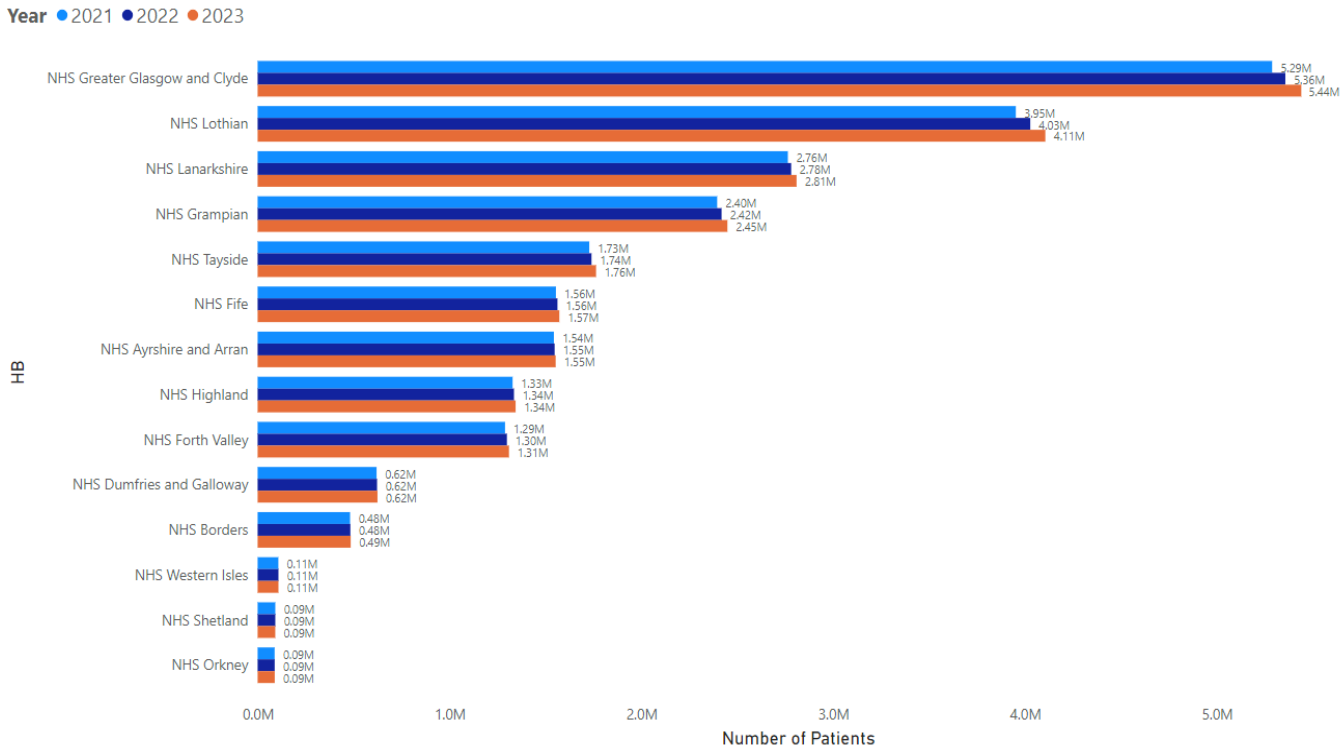

Figure 9. *Number of patients by HB (2021-2023)*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)

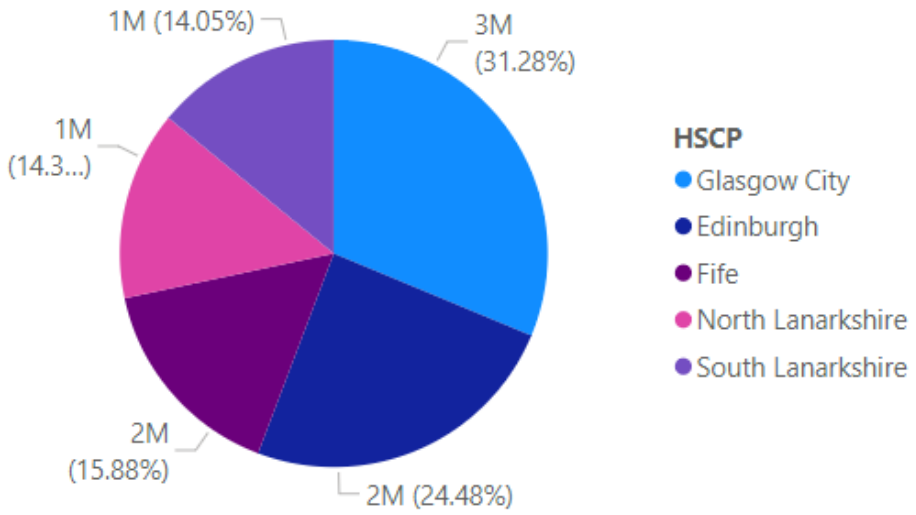

Figure 10. *Highest number of patients by HSCP, 2023*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)

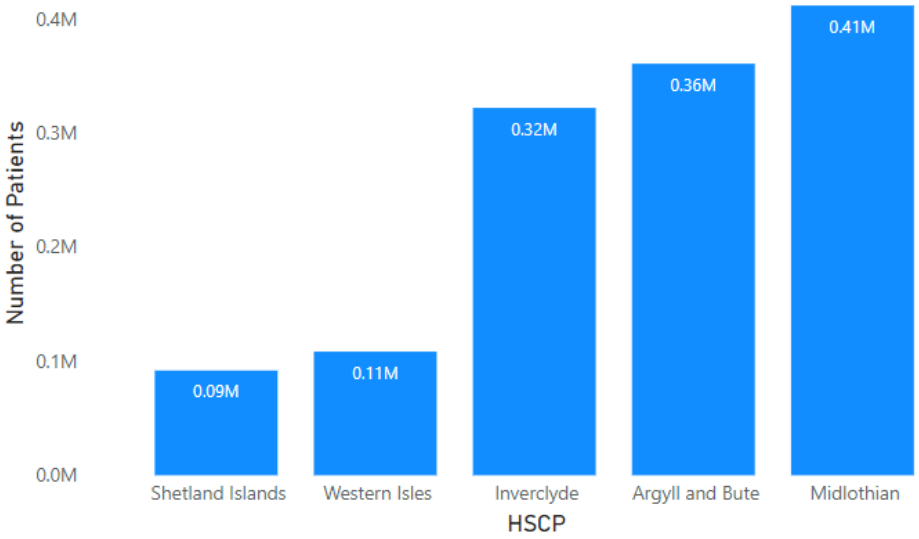

Figure 11. *Lowest number of patients by HSCP, 2023*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)

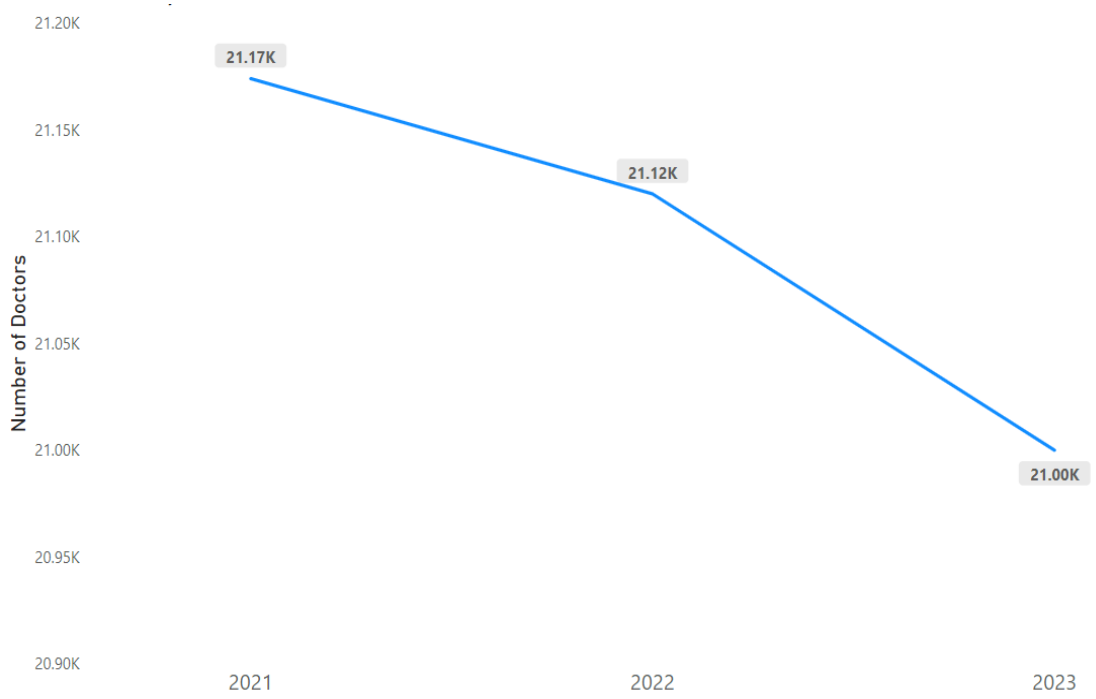

Figure 12. *Number of doctors in Scotland (2021-2023)*

Source: GP Practice Contact Details and List Sizes (PHS Primary Care Team, 2023)

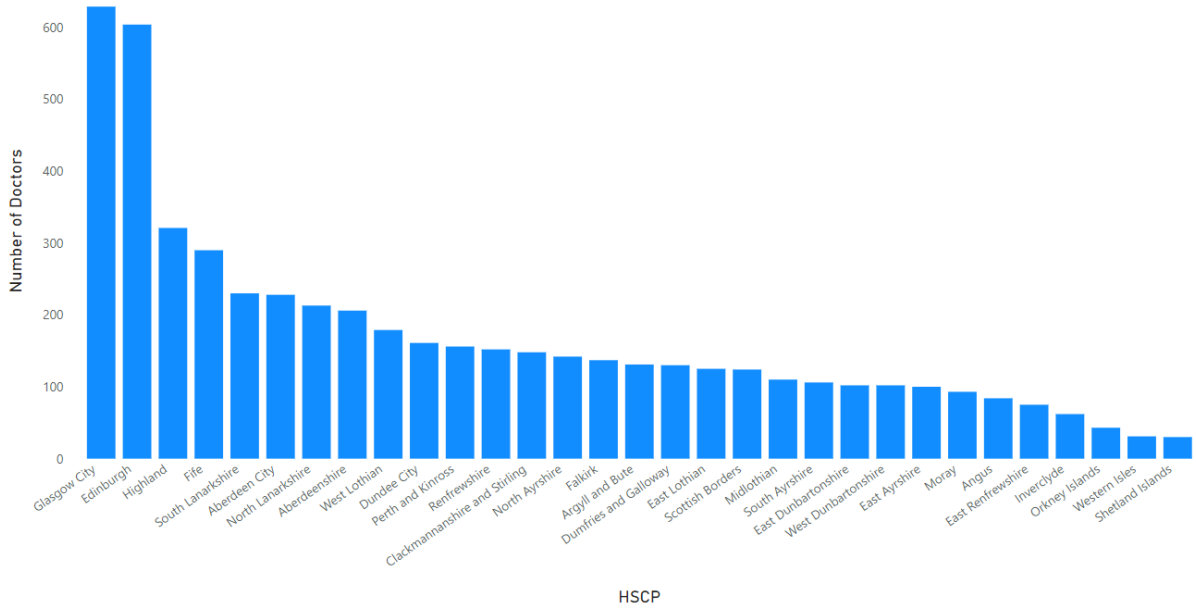

Figure 13. *Number of doctors by HSCP in Scotland (2023 Quarter 3)*

Source: GP Practice Contact Details and List Sizes (PHS Primary Care Team, 2023)

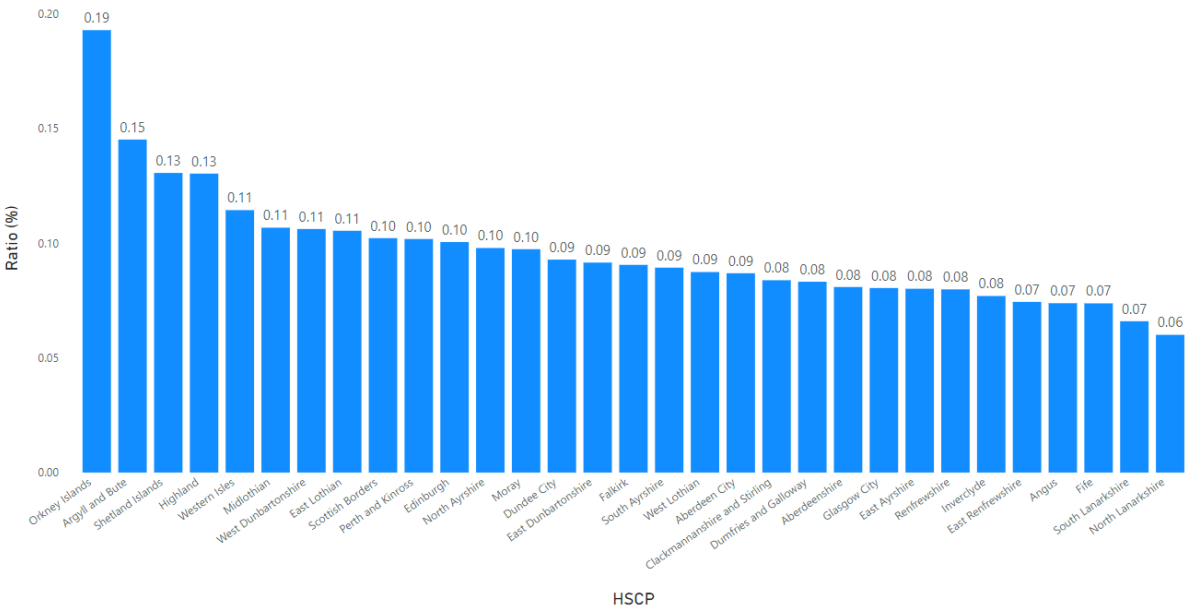

Figure 14. *The percentage of ratio between number of doctors and number of patients by HSCP, Scotland (quarter 3, 2023)*

Source: GP Practice Contact Details and List Sizes (PHS Primary Care Team, 2023)

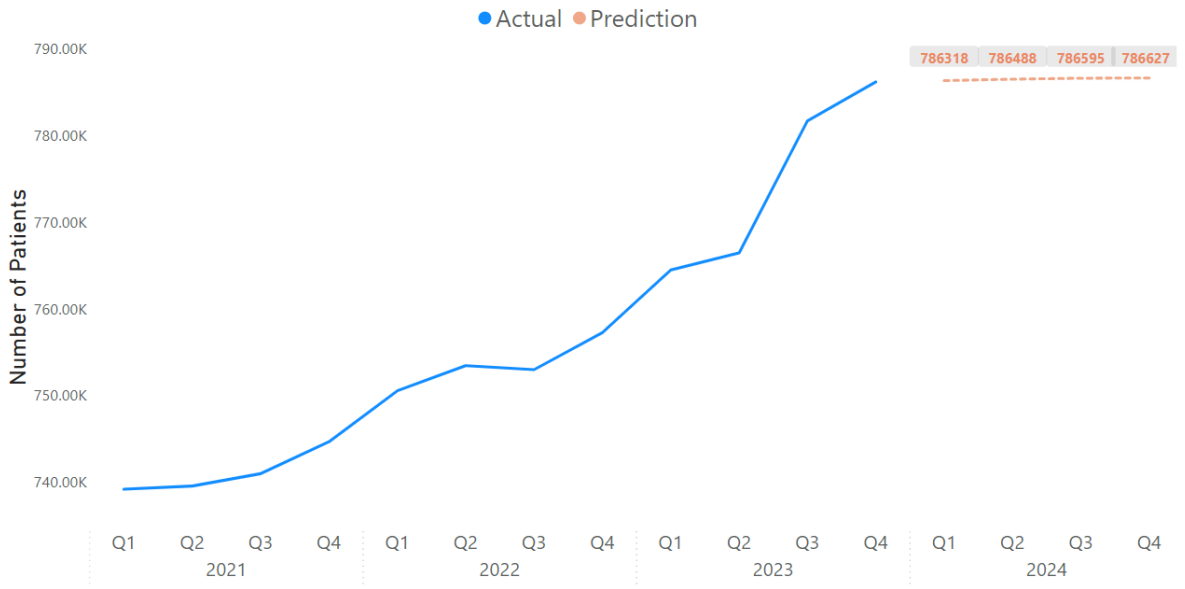

Figure 15. *The prediction number of patients using time series forecasting techniques in year 2024 Glasgow, Scotland*

Source: GP Practice Population Demographics (PHS Primary Care Team, 2023)