# Transition to a new methodology for the production of mortality projections for national population projections

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## 1. Executive summary

University of Southampton (UoS) was commissioned by ONS in 2013/14 to develop a methodology to provide a set of future mortality rates fit for purpose using methodology that is current and relevant, that will improve the efficiency/accuracy of the national population projections. Specifically:

1. The model and the results should be stable over time, given further data and the publication of subsequent outputs.
2. The methodology should be transparent and defendable in the face of customer and stakeholder enquiries.
3. The projections must be plausible, for example in line with recent observed trends and events.
4. Implementation needs to be efficient in terms of staff and expert resources.
5. Outputs must be publicly acceptable, with discontinuities when compared against historic data explainable and justifiable.

2020-based interim national population projections (NPPs) (ONS, 2022) were published in January 2022. This was a principal projection only release. Since then, on 27th January 2023, a variant projection reflecting provisional estimates of international migration to year ending June 2022 has been released (ONS, 2023).

ONS produces NPPs on behalf of the National Statistician and the Registrars General for Scotland and Northern Ireland. We agree the underlying assumptions with the devolved administrations - Welsh Government, National Records of Scotland (NRS) and Northern Ireland Statistics and Research Agency (NISRA). They also provide final sign off for the assumptions and any changes to the methodology.

The prospective methodology for setting mortality assumptions developed in collaboration with the UoS is in the final stages of assurance with a user engagement (ONS, 2023) concluded recently and an independent ONS quality assurance internal review undertaken.

This paper outlines the work done to develop and assure the new methodology. This includes descriptions of the current and new methodology, conclusions from the user engagement's comparison of the two approaches, assumptions and adjustments to the new methodology, and an overview of the assurance carried out so far.

According to the Code of Practice for Statistics (UKSA, 2023), we aim to meet user needs by:

- Being transparent by sharing the new methodology in more detail
- Applying sound methods beyond the development of the model, in assessing the outputs and adjusting according to current trends
- Making content relevant and accessible on the uses and limitations of the mortality projections

We would like to ask the panel the following questions:

1. Are they satisfied that we have followed reasonable steps to quality assure the new mortality projection method, in line with the Code of Practice for Statistics?
2. Should a priority be to publish additional and tailored users' guidance to accompany the publication of the projections as recommended by the recent quality review?
3. Shall we work to make the new mortality projection system available on ONS GitHub (GitHub, 2023) to increase transparency/open scrutiny and public trust? Most of the input data is publicly available.

## 2. Background and motivations

The national population projections (NPPs) are published by age and sex for the UK and its constituent countries every two years, although release timescales have changed around Census 2021. The NPPs are based on the latest mid-year population estimates, which together with assumptions of future age- and sex-specific levels of fertility, mortality and migration, allow us to project the population size and structure up to 100 years from the base year. We aim to use the prospective method for mortality assumptions for the first time in the production of the next set of NPPs.

### 2.1 Current methodology

The future mortality trends are currently projected in the form of mortality improvements, which are assumed annual percentage changes in mortality rates by age and sex.

Our current standard mortality projections methodology is to derive age-specific mortality improvements for males and females in the base year of the projection and assume they will converge to target rates of improvement by the 25th year. All future years' mortality improvements by age beyond the 25th year of the projection are held constant at the target rate for that age until the end of the projections. Assumptions about the target rates of improvement and the speed of convergence to these target rates are determined in consultation with the NPP mortality expert advisory panel and actuarial advice from the Government Actuary's Department (GAD).

The current methodology has been consistently applied for many years and is flexible to manual adjustments, for example to adjust for the effects of coronavirus (Covid-19). However, it is a labour-intensive process that is generally very manual, which potentially creates opportunities to introduce error and means it is challenging to quality assure. The current approach is also particularly sensitive to recent mortality data which has led to quite large changes between projection rounds. The application of the method is reliant on the services of an actuary from GAD who combines the advice of the experts to determine the main assumptions and helps with producing the projections.

For the 2020-based interim NPPs, our current mortality projections methodology was used. The short-term mortality improvement rates were adjusted between 2019 and 2024 for people aged 30 years and over to account for the increased mortality recorded during the coronavirus (COVID-19) pandemic and the potential short-term effects on mortality.

For the UK, annual rates of mortality improvement were assumed to converge to 1.2% for ages 0 to 90 years by 2045. Annual improvement rates were set to decline linearly from 1.2% to 0% between ages 91 and 109 years. For ages above 110 years, a 0% improvement rate was assumed. Annual mortality improvements were assumed to remain constant by age and sex at the 2045 level for each year thereafter.

As in previous projections, mortality improvements for the UK for the base and subsequent years were adjusted for Scotland, while improvements for England, Wales and Northern Ireland were aligned to a set of improvements for the UK excluding Scotland. The same long-term rates of improvement were assumed for all constituent countries as for the UK.

This article (ONS, 2022) provides an overview of the assumptions developed for the 2020-based interim NPPs.

## 3. New methodology

### 3.1 Overview of approach

Development of the new methodology has involved collaboration between the Population Statistics Hub in MQD, the Demographic Analysis Unit (DAU) in Demography, the University of Southampton (UoS) and the University of Warwick. The development has resulted in the publication of two peer-reviewed papers by Dodd et al. (2021) and Hilton et al. (2019).

The proposed new mortality projection methodology uses an age-period-cohort (APC) model approach, which separates the contribution of age, period and cohort effects on mortality improvement and is commonly used to model demographic processes.

The model uses the same input data as the current method: UK mid-year population estimates and annual calendar year deaths from 1961 to the latest available year, by single year of age and sex. As with the current method, the new model should in future be able to use an equivalent population base such as that which the Dynamic Population Model (DPM) provides.

The method projects future mortality rates, by age and sex, based on the historical population and deaths data. This is done by fitting generalised linear models to mortality rates seen between 1961 and the base year, and then adjusting the model equations to project mortality rates up to 175 years into the future. The new methodology retains the input of expert opinion on long-term mortality improvement rates and the speed of convergence to these rates; these assumptions would be set based on an average of the responses provided by discussion with the NPP mortality expert advisory panel.

There are three different parts to the model, each tailored to specific age ranges.

1) The main APC model fits mortality improvement based on the age, period and cohort effects. It covers most ages, from age 1 year to $X$ years. In the examples provided here, $X$ is 90 years for females and 92 years for males; the specific values of $X$ are chosen to allow for a smooth change in the mortality rates from the main model to the old age model and will be reviewed regularly.
2) A separate model is fit for infants aged zero years. The infant model takes the same form as the main APC model, except that it does not include a period effect, and it uses estimates of the cohort effect from the main model.
3) The old age model is for ages $X+1$ years to 125 years. The old age model takes the form of a logistic model for which the dependent variable is mortality rates rather than improvement rates. The use of a logistic model is to ensure that mortality rates converge on a constant value as age increases.

Further functionality has been added to the model as a result of user acceptance testing either to retain useful elements of the existing approach (for example incorporating expert opinion into the projections), or to enhance the flexibility of the model (for example to adjust the projections in the

event of the 'mortality shock' or slowdown in observed mortality improvements). These adjustments are detailed in Section 4.

To align with the need for greater traceability and reproducibility of our statistical production systems, the new method has been implemented in an open-source language (R), and we are working towards the recommended Reproducible Analytical Pipelines (RAP) standards.

## 3.2    Comparability with the current method

The current method results have been compared to the prospective method in [Section 4 of the recent user engagement](#) (ONS, 2023) for the 2018- and 2020-based projections.

 The main findings are that the proposed model:

- Produces similar fitted mortality rates in the base year to those produced by the current method of smoothing mortality rates over time
- Projects lower mortality rates at ages 70 years and over compared with the current method; this results in slightly higher projections of life expectancy at birth and at age 65
- Produces projections that are more stable over time (in the absence of any mortality shocks), meaning there is likely to be a greater degree of similarity between consecutive projection rounds
- Produces projections that are less sensitive to the recent slowdown in mortality improvements; this can be mitigated to some extent by weighting up more recent input data
- Is sensitive to unusually high mortality rates in the base year of the projection; a period weighting adjustment can be applied to remove all, or some, of the period effect in the base year from subsequent years of the projection.

## 4. Assumptions and other adjustments

Adjustments have been made to a standard APC model, some of which aim to replicate desirable features from the current method, while others aim to increase the flexibility of the model so that we can account for external factors such as a mortality shock.

### Expert opinion

In the first few years of the projections, the projected improvement rates are determined almost entirely by the fitted age and cohort effects from the model (the period effect is assumed to be zero). As we progress over the 25 years of the projection, the modelled improvements are weighted down and the expert opinion is weighted up, so that by the 25th year (and all subsequent years) the projected mortality improvements are determined solely by expert opinion. The expert opinion values are determined based on responses to the questionnaire sent to the expert advisory panel (see Section 5.2) In the user engagement we presented results from the model which are based on a 1.2% long term improvement rate for most ages, reducing linearly to 0% between ages 91 and 110, which is the same assumption that was used in the 2020-based interim projections.

We can also adjust the speed of convergence between the base year and target improvement rates, for example to achieve a certain percentage of the convergence by a given year. This is currently set to achieve 50% of the convergence by the 11th year of the projection, which replicates the assumption used in the most recently published projections.

### Weighting

An advantage of the APC model is that it takes full account of the time series of input data, and each year is weighted equally. However, in the last decade, mortality improvements have slowed compared with previous decades. We have therefore added the flexibility to weight up more recent

data, and weight down more historical data, in order to account for this. Any weighting for future NPPs would be discussed with the NPP mortality expert advisory panel. For illustrative purposes in the user engagement article, the following weights were applied: $1/N$ for 1961, $2/N$ for 1962, and so on, up to $N/N$ for the latest year, where N is the number of years of data.

*Mortality shocks and recovery*

The coronavirus (Covid-19) pandemic led to much higher-than-average mortality rates for certain age groups in 2020 and 2021. We call this a "mortality shock" and need to make assumptions about the extent to which the shock will continue throughout the projection period. In the proposed model we have the flexibility to adjust for a mortality shock occurring in the base year of the projection by weighting down the period effect from that year so that it does not affect projected mortality rates beyond a specified number of years. For example, in the user engagement article (ONS, 2023) we showed results from applying a single scenario, where we projected the following recovery in mortality rates:

- 50% recovery by the first year of the projection
- 75% recovery by the second year
- 87.5% recovery by the third year
- 100% recovery by the fourth.

The above is just an example, and we would seek the advice of the NPP expert advisory panel on how to appropriately adjust for a mortality shock, and whether it is correct to remove all the shock, or alternatively, to allow a proportion of the shock to continue throughout the projection.

*Country disaggregation*

The underlying mortality assumptions described in this section are agreed with the devolved administrations on whose behalf ONS produces the NPPs for the UK and constituent countries.

To run data in the model, we need a relatively long time series of population and deaths data. We have data back to 1961 on a consistent basis for the UK, for England and Wales combined, and for Scotland. The population of Scotland is also large enough that we can run the Scottish data in the model directly. As we do not have separate data of sufficient quality for England, Wales and Northern Ireland going back far enough, we run data for the UK excluding Scotland directly in the model and then apply smoothed ratios derived from the National Life Tables to produce mortality rates for England, Wales and Northern Ireland. This is a similar approach to our current method so is not in our view a limitation of the new model.

*Variant projections*

We can run variant projections through the model by changing the long-term target mortality improvement rates and the speed of convergence between the base year and the target improvement rates. These would need to be determined through discussion with our NPP mortality expert advisory panel, whose conclusions will be published as part of the NPPs release.

## 5. Assurance

### 5.1 Methodology assurance

Since this project was initiated, the new methodology has gone through multiple stages of assurance. We are now looking to get final assurance to the approach and future development plans ahead of production of the mortality projections that will feed into the next set of NPPs. The

approach was taken to Methodology and Research Assurance Group (MaRAG) in June 2022. It has also been discussed in a dedicated expert advisory panel meeting (regular panel meeting is described in Section 5.2) and DAU have been in regular discussion with GAD to seek their views and feedback on adopting this approach.

The continued collaboration between ONS teams and the UoS has meant that the model-based approach has been developed whilst NPP publications continued and with the observation of a mortality "shock"; the Covid-19 pandemic. As mentioned earlier, the methodology has resulted in the publication of two peer-reviewed papers (Dodd et al., 2021; Hilton et al., 2019).

### *User acceptance testing*
The Population Statistics Hub in Methodology and Quality (MQD) have supported Demographic Analysis Unit (DAU) in Demography in carrying out the User Acceptance Testing (UAT) of the proposed mortality projection model and co-ordinated further development work on the UoS model.

The development of the model was done in between release cycles for the mortality projections resulting in incremental changes, over separate development phases. Specifically, three UATs have taken place over the years, often ahead of DAU's work on setting mortality assumptions which feed into NPPs. The purpose of the UATs has been to establish whether the mortality projections model developed by UoS can replace the current ONS mortality projections and develop the system and guidance accordingly, as well as resolve any issues with the model implementation found when running comparisons with the current approach.

The most recent UAT, completed in June 2022, covered:

- Further development of system and accompanying guidance by MQD including functionality to:
    - Change the year in which 50% convergence to expert opinion is achieved (i.e. speed of convergence)
    - Change the weighting of input data (for example to weight up more recent data)
- New functionality to allow us to remove, all or part of, the impact of a "mortality shock" such as the Coronavirus (Covid-19) pandemic in the base year over a specified number of future years
- Production of variant projections by changing the target improvement rates and the speed of convergence to these target rates

A table in the appendix provides and overview of the first two UATs.

### *User engagement*
A recent user engagement (ONS, 2023) has been carried out on the prospective methodology. Overall, there was support for the new model, particularly using an approach that combines both data-driven projections in the short-term phasing to expert opinion in the longer term.

A high-level summary of views suggested:

- More information would be useful on the specific detail of the methodology
- Some users valued the transparency and efficiency of using a model, while others were concerned about difficulty replicating a complex model for own use; request to publish the model code and data to aid users' understanding
- The input of expert opinion is valued especially for mortality shocks and the uncertainty of long-term improvements

- Support for the added flexibility of the model to weight up more recent data and weight down more historical data; the weighting applied will need to be continually reviewed
- Different views on treatment of old age mortality improvements, e.g long-term rate of mortality improvements of 1.2% to age 90, tapering to nil at age 110 but support the ONS method to treat separately
- It would be useful to test how the model would have performed in the past, to consider the accuracy of assumptions from expert opinion and potential for changing the weights and/or to publish results from past projections run using the new methodology
- Any assumptions need to be fully supported by data to show they are unbiased
- Need to present mortality variants and assign probabilities to them
- Requests for mortality projections for different subgroups, e.g. by ethnicity or by deprivation decile

*ONS internal review of methodology*

The Best Practice in Modelling team (Quality and Improvement, MQD) has recently reviewed the modelling approach for mortality and provided recommendations around the model assumptions and communication of the approach and outputs. The new modelling approach is dependent on several assumptions, detailed in the Section 4. The review has advised on providing improved supporting evidence for the decisions made around these, further sensitivity testing of the assumptions, a review of the input data to the models, and a review of how the mortality assumptions are disseminated.

The mortality projections are a key input to the national population projections and a detailed [article on the mortality assumptions](#) (ONS, 2022) was published alongside that release. However, ONS also released on the same day the past and [projected period and cohort life tables](#) (ONS, 2022) as a headline only bulletin. This release is also produced from the mortality assumptions and the review suggested that better links be made between these publications, with a high-level narrative to explain the use cases and limitations of the projections to prevent improper use of the outputs.

A final recommendation of the review was to ensure all information regarding the model, especially concerning the assumptions, is being made more easily accessible to informed users.

These recommendations will be taken forward alongside the work required for the publication of the projections later this year, to improve the quality of our statistical outputs.

## 1.1. Production assurance

*Expert advisory panel*

Prior to production of the mortality assumptions, as part of the assumption-setting process, a panel of mortality experts advises on:

- Annual mortality improvement in the short term by age and sex to account for the impact of the coronavirus (Covid-19)
- Target rates of mortality improvement by the 25th year by age and sex
- Method and speed of convergence of improvements between the base year and target year
- Mortality improvement at the oldest ages
- How mortality improvement for each country of the UK might differ
- Underlying factors that may influence future mortality

The panel are sent a questionnaire and supporting guidance prior to meeting, where the results are collated and discussed, minutes are taken for the meeting.

The assumptions are finalised by an actuary from the Government Actuary's Department (GAD) and are signed off by representatives of ONS, NRS, Welsh Government and NISRA who form the NPP Committee.

As an example, this article provides an overview of the assumptions developed for the 2020-based interim NPPs.

NPP accuracy reports, the last of which was published in 2016 (ONS, 2016), show how well NPPs (up to 2012-based) have performed compared to population estimates, births, deaths and estimated international migration.  The conclusion for mortality was that improvements in life expectancy tend to be under projected but that the quality of the mortality projections had improved over time. A new report is in progress to show how more recent projections have performed (publication date is to be confirmed).

## 6. Discussion

The main focus over the next few months ahead of publication is to make the system implementing the new method operational and reproducible, including addressing the recommendations from the review carried out by the Best Practice in Modelling team (Quality and Improvement, MQD), in terms of documentations of all assumptions made. This will include specifically:

- Automation of constituent country disaggregation;
- Finalising system and guidance in accordance with RAP principles;
- Review of the input data.

We will also review how the mortality projections are published and disseminated to ensure they are used appropriately, and informing this by taking on board the user feedback through the engagement. We will consider providing users with recommendations on how to use the projections, alongside strengths and limitations.

While the initial focus will be to ensure the first publication using the new method is of the highest quality, as part of a continuous improvement cycle, we will be commencing work on:

- Documentation and testing of assumptions through simulation studies, including inputs values used;
- Evaluating the impact of changes to the population statistics estimation systems (MYEs production, SPDs and DPM);
- Incorporating uncertainty into the mortality projections, including how to communicate it to users.

For both of these longer-term extensions, the intent is to ensure coherence of approaches across populations statistics outputs, and we will be working closely with our users in a collaborative fashion.

## 7. References

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## 8. Appendix: Overview of earlier UATs

| UAT 1 (2016/17) | UAT 2 (2018/19) |
|---|---|
| Evaluation of the original version of the model | Further testing (e.g. transition ages between models, Scotland) and development (e.g. cohort smoothing, convergence functions) of the model |
| Further development of the model and assurance of proposed changes (e.g. expert opinion and constraining of male-female mortality ratio, etc.) to it | Testing the plausibility of projections and checking the consistency between projections over time (current vs. proposed approach) |
| Testing of the model with mortality shocks | Development of more user-friendly system in R and user guidance |