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| Modelling CKD Progression with System Dynamics  Midlands Kidney Network/New Hospitals Programme | |
| 30 May 2025 | |
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Document control

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| --- | --- |
| Document Title | Midlands Kidney Network/New Hospitals Programme |
| Job No | Kantata: E001738-0012 |
| Prepared by | Sally Thompson |
| Checked by | [Checked by] |
| Date | 22 July 2025 |

Contents

1. Introduction 1

1.1 Background 1

2. Using the model on the isee exchange 2

2.1 Structure of the simulator 2

2.2 Running the simulator – Run Live versus ballistic mode 4

3. Documenting the SD model 6

3.1 Objectives 6

3.2 Logic 6

3.3 Data 12

3.4 Experimentation 14

3.5 Implementation 14

3.6 Code Access 15

1. Introduction
   1. Background

Dialysis centres are struggling with demand and there are concerns about capacity to meet future needs for renal services, particularly in-hospital. There is an expectation that need is going to grow, further challenging capacity through changes in population size and health profile.[[1]](#footnote-2)

The Midlands Renal Operational Delivery Network (MRODN) identified that centres in the region required advanced methods of estimating kidney replacement treatment needs in the future. There are options available to manage demand and capacity, but these require investment, and careful balancing of risk and reward. A model will facilitate better informed decisions about the future, facilitating "left shift" and ensuring future capacity and good patient outcomes whilst supporting positive change through evidence and analysis. The geographical scope of the model has expanded to include all NHS England regions.

Project objectives:

1. How might demand change over time?

2. What does that mean for capacity for ESRF services?

3. If future scenarios include changes to primary care identification and prescribing, what are the factors that impact on this and what support /interventions will be needed?

4. What might future workforce requirements be under these scenarios?

5. What is the cost/benefit equation for possible interventions that impact on future demand/capacity requirements? (how to achieve greater allocative efficiency)

* + 1. Modelling Workstreams

The long-term ambition of the modelling aspects of this project is to create an open-source hybrid model, that captures the population-level disease progression of CKD, modelled using system dynamics, which feeds into a more detailed discrete event simulation modelling KRT services. This document describes the system dynamics model, and has been written following STRESS guidelines[[2]](#footnote-3).

1. Using the model on the isee exchange

The simulator tool is freely and openly available on the [isee exchange](https://exchange.iseesystems.com/public/strategy-unit/chronic-kidney-disease-progression/index.html) (an open repository for the sharing of models built using Stella Architect). It has been designed to be used as a self-service tool, with guidance included on how to use the tool, and includes the ability to download the results of simulation runs.

* 1. Structure of the simulator
     1. Landing Page

The landing page gives a brief overview of the purpose of the tool and guidance on how to use the simulation buttons. Blue buttons link to:

* storyboard, where the model logic is explained
* A screenshot of a computer

  AI-generated content may be incorrect.simulator, where the impact of scenarios/interventions can be explored

Navigation bar

Simulation controllers

* + 1. Storyboard

Use the spacebar or the left and right arrows to navigate through the storyboard. Return to the landing page at any time by clicking on the ‘Home’ button at the bottom right of each page.

* + 1. Calibration

This page shows how well the model has been calibrated to known, historical data. CVD Prevent started reporting regional data quarterly in FY 2022/23, with an earlier report of prevalence to end September 2021. The last calibration point is 2024-Q2: in Q3 a change in laboratory methods caused a step change in the levels reported, which adversely affects the calibration.

Each chart shows the reported prevalence with a red dashed line, and the model fit is shown in blue. With the cursor over a chart, click and drag to ‘scrub’ and display values.

* + 1. More Info

This page gives more detail of the limitations and assumptions of the model, and includes links to data sources.

* + 1. Parameters

This page has an exportable table of the prevalence by diagnosis state and stage, mortality and costs (still in development). There is an additional table of incidence to KRT, for use in the linked KRT model.

* + 1. Simulator

There are three sections to this page – the input panel on the left-hand side, controls along the bottom, and outputs in the main area.

Outputs

Controls

Input panel

A screenshot of a computer

AI-generated content may be incorrect.

#### **Inputs**

Inputs are adjusted by turning the dial or moving sliders. These can be reset to the default value by clicking 

#### **Outputs**

The charts show the prevalence of each state and stage, with undiagnosed states in the top row (excluding the right-hand chart), and diagnosed in the bottom row. Stages progress from stage 3 on the left through to KRT on the right. For each chart, the yellow line shows the status-quo, and the blue line will display any changes made after the end of the time period of known data (2024 Q4 onwards).

The top-right charts display overall prevalence and mortality, and a sub-menu gives options for further break-down by diagnosis state.

#### **Controls**

#### **Clear Graphs**

This will clear the display of the latest run from the charts, but input values remain unchanged.

#### **Reset Inputs**

This resets all inputs to their default values, and clears the charts.

#### **Run Live**

This applies any changes to input values across the whole simulation period from 2022 onwards, and charts will update as and when input parameters are changed.

#### **Run/Pause/Stop**

A normal (as opposed to Live) simulation takes 5 seconds to run. Pausing a simulation mid-run allows you to make changes to parameters, whilst stopping a simulation will end it.

#### **Run stepwise: +1 Year, +5 Years, to End**

Running a simulation in ballistic mode will advance the simulation for the specified period, then pause – allowing you to make changes to parameters before continuing.

#### **Export Run**

The outputs of a run (modelled prevalence per year) can be exported to csv file. You will be prompted for a file name, and this will download to your Downloads folder.

* + 1. Costs

The ability to include costs of interventions has been included. The input bar of the Simulator page is repeated here, along with extra inputs for the cost of primary interventions, primary care costs, medications costs and an aggregate value for KRT.

Output charts display the cost implications of runs, and compare to the baseline.

A screenshot of a computer

AI-generated content may be incorrect.

* 1. Running the simulator – Run Live versus ballistic mode

Run Live is the default mode when the Simulator page is first loaded. This mode gives a good overview of the general behaviour of the system when changes are made, but is unrealistic in that those changes apply throughout the whole period from the end of 2024 onwards. Using the ballistic mode allows you to make changes for a specific period of time.

For example, consider a scenario where the status quo continues until 2028, at which point a diagnosis improvement strategy comes into effect. It aims to improve diagnosis by 15% in 2028, rising to 30% in 2029, then 50% from 2030 through to 2034, then 75%.

To simulate this:

* + - 1. Reset inputs & clear graphs
      2. Run stepwise +1 year until Year is 2027.
      3. Turn ‘increased diagnosis %’ to 15
      4. Run stepwise + 1 year
      5. Turn ‘increased diagnosis %’ to 30
      6. Run stepwise + 1 year
      7. Turn ‘increased diagnosis %’ to 50
      8. Run stepwise + 5 years
      9. Turn ‘increased diagnosis %’ to 75
      10. Run stepwise to End

The incremental changes will be reflected in the charts.

1. Documenting the SD model
   1. Objectives
      1. Purpose

This model focuses on the first project objective, ‘how will demand change over time?’, and aims to have a better understanding of the prevalence of people with advanced stage CKD (stages 3-5), taking into account changes in population and the effects of different interventions, with a specific aim to determine the incidence of people likely to require KRT in the long term (10-20 years).

* + 1. Model outputs

The main outputs of interest are the stock levels (prevalence) for each CKD stage and diagnosis state. The flow (incidence) to KRT will be of interest for use in the related discrete event simulation KRT model.

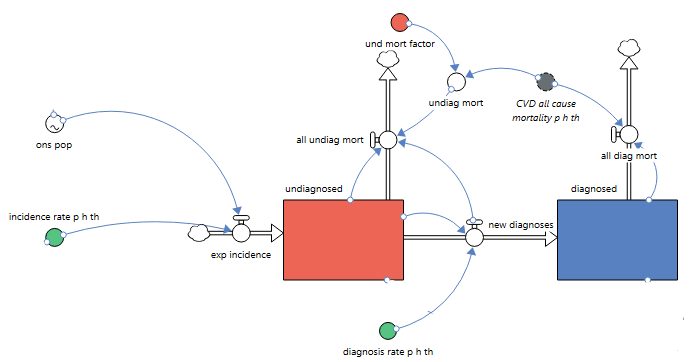
* + 1. Experimentation aims

Through workshops, three different interventions were identified, as detailed in the table below. The design of the interface allows for these interventions to be applied for the whole simulation period, or turned on/off at specific points in the future using the ballistic mode.

|  |  |  |
| --- | --- | --- |
| **Intervention** | **Quantify in the model** | **Notes** |
| Primary prevention strategies | Apply a percentage reduction (product of reach and effect) to the annual incidence | A ‘catch-all’ that could incorporate multiple strategies |
| Increase diagnosis to KDIGO guidelines | Apply a percentage increase to the number diagnosed | Value applied equally to all stages of diagnosis |
| Increase use of SGLT2 inhibitors and other medications | Apply a percentage reduction (product of reach and effect) to the maximum reduction (measured in people per hundred thousand) in progression and mortality | Applied differently to the undiagnosed and diagnosed populations.  Assumes effects are equal at all stages of the disease. |

* 1. Logic
     1. Base model overview diagram

There are two levels to the SD model – the top level is used to determine the annual incidence rate, taking into account changes in population.



A diagram of a computer flowchart

AI-generated content may be incorrect.The more detailed disease progression model uses the incidence rate derived from above, and differentiates between stages and diagnosis states.

* + 1. Base model logic

The overall logic of the model is that all new cases are initially undiagnosed, and in time they become diagnosed. Mortality can occur at any time, and in either diagnosis state. As CKD is a progressive disease it is assumed that there is no mechanism for recovery to a lesser stage.

The number of new cases are determined by the incidence rate being applied to the population projection. All new cases start as undiagnosed stage 3. From here, people can either be diagnosed, and flow down into the diagnosed stage 3 stock, or their disease can worsen to undiagnosed stage 4/5. From here, people can flow to diagnosed stage 4/5. Mortality can occur from any stock. Mortality is based on the ‘All cause CVD’ mortality rate, with an adjustment factor applied at different stages. For any given stage, there is no difference in mortality between diagnosed and undiagnosed.

Flows between stages and diagnosis states are rates per hundred thousand, with the denominator always being the upstream stock.

Costs were added to the model to allow the projections to be quantified in financial terms, with particular focus on the cost of medications and the cost of KRT. Costs for medications usage and KRT are applied as an annual cost per person to the relevant stocks.

* + 1. Intervention logic

In workshop 2, three interventions were agreed as being the most important and likely to influence future behaviour of CKD.

* + - 1. Primary prevention:

A figure for the reach (the percentage of the general 18+ population that are subject to the intervention) and effectiveness (of those people reached, what percentage do not develop CKD) produce the overall impact, which reduces the number of new cases compared to the baseline figure.

* + - 1. Improved adherence to NICE/KDIGO guidelines:

A percentage increase of the baseline diagnosis rate.

* + - 1. Improved disease management (use of SGLT2 inhibitors and other medications):

Applied separately to the undiagnosed and diagnosed populations, figures for the reach (percentage of the population of interest that are targeted), and adherence (of those reached, what percentage will adhere to correct usage) produce an overall impact, which reduces the progression rate and mortality rate. The effect of alternative and/or additional medications can be included, with a multiplier adjustment based on the SGLT2i reduction in rates.

* + 1. Algorithms

NA

* + 1. Components

The tables below detail the elements of an un-arrayed model; the working model is arrayed by NHS regions and an aggregate level for England. A full list of arrayed elements, and values where appropriate, are available on the [Github repository](https://github.com/The-Strategy-Unit/renal-services).

* + - 1. Stocks

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Equation** | **Initial Value** | **Comments** | **Units** |
| undiagnosed | undiagnosed(t - dt) + (exp\_incidence - new\_diagnoses - all\_undiag\_mort) \* dt | INIT("CVDP\_undiag\_S3-5") | Stock of people with undiagnosed CKD, used in the top level model | People |
| diagnosed | diagnosed(t - dt) + (new\_diagnoses - all\_diag\_mort) \* dt | INIT("CVDP\_diag\_S3-5") | Stock of people with diagnosed CKD, used in the top level model | People |
| und\_S3 | und\_S3(t - dt) + (und\_new\_cases - "und\_T3\_to\_4-5" - S3\_diag - und\_3\_mort) \* dt | INIT(CVDP\_und\_S3) | New cases start in this stock | People |
| und\_S4-5 | "und\_S4-5"(t - dt) + ("und\_T3\_to\_4-5" - "S4-5\_diag" - "und\_4-5\_mort" - "S-KRT\_diag") \* dt | INIT("CVDP\_und\_S4-5") |  | People |
| CKD\_3 | CKD\_3(t - dt) + (S3\_diag - "S3\_to\_4-5" - diag\_3\_mort) \* dt | INIT(CVDP\_diag\_S3) |  | People |
| CKD\_4-5\_not\_KRT | "CKD\_4-5\_not\_KRT"(t - dt) + ("S4-5\_diag" + "S3\_to\_4-5" - "diag\_4-5\_mort" - "S4-5\_to\_KRT") \* dt | INIT("CVDP\_diag\_S4-5") |  | People |
| KRT | KRT(t - dt) + ("S4-5\_to\_KRT" + "S-KRT\_diag" - diag\_KRT\_mort) \* dt | INIT(UKRR\_KRT) |  | People |

* + - 1. Flows

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Equation** | **Comments** | **Units** |
| ***Incidence & Diagnosis*** | |  |  |
| exp\_incidence | ons\_pop \* incidence\_rate\_p\_h\_th / 100000 | Top level incidence, derived from in-model calibration | People/Years |
| new\_diagnoses | undiagnosed \* diagnosis\_rate\_p\_h\_th/100000 | Top level incidence, derived from in-model calibration | People/Years |
| "CKD\_incidence" | new\_cases\_pa | New cases per year based on derived incidence and impact of primary preventions | People/Years |
| ***Flow between stages*** |  |  |  |
| "und\_S3\_to\_4-5" | (und\_S3 - (und\_3\_mort + S3\_diag) \* Yr) \* ("und\_r\_3\_to\_4-5" - und\_dm\_progress\_reduction\_p\_h\_th)/100000 | Flow from undiagnosed stage 3 to undiagnosed stage 4/5 | People/Years |
| "S3\_to\_4-5" | (CKD\_3 - diag\_3\_mort\*Yr) \* ("r3\_to\_4-5" - diag\_dm\_progress\_reduction\_p\_h\_th)/100000 | Flow from diagnosed stage 3 to 4/5 | People/Years |
| "S4-5\_to\_KRT" | ("CKD\_4-5\_not\_KRT"- "diag\_4-5\_mort"\*Yr) \* ("r4-5\_to\_KRT" - diag\_dm\_progress\_reduction\_p\_h\_th)/100000 | Flow from diagnosed stage 4/5 to KRT | People/Years |
| ***Diagnosis*** |  |  |  |
| S3\_diag | (und\_S3 \* r3\_diag / 100000) \* (1 + diagnosis\_improvement\_pc/100) | Diagnosed at stage 3 | People/Years |
| "S4-5\_diag" | ("und\_S4-5" \* "r4-5\_diag" / 100000) \* (1 + diagnosis\_improvement\_pc/100) | Diagnosed at stage 4.5 | People/Years |
| ***Mortality*** |  |  |  |
| all\_diag\_mort | diagnosed \* CVD\_all\_cause\_mortality\_p\_h\_th/100000 | Top-level mortality of diagnosed | People/Years |
| all\_undiag\_mort | (undiagnosed - new\_diagnoses\*Yr) \* undiag\_mort/100000 | Top-level mortality of undiagnosed | People/Years |
| und\_3\_mort | und\_S3 \* (und\_r\_S3\_mort - und\_dm\_mort\_reduction\_p\_h\_th)/100000 | Mortality of undiagnosed stage 3 | People/Years |
| "und\_4-5\_mort" | "und\_S4-5" \* ("und\_rS4-5\_mort" - und\_dm\_mort\_reduction\_p\_h\_th)/100000 | Mortality of undiagnosed stage 4/5 | People/Years |
| diag\_3\_mort | CKD\_3 \* (r\_S3\_mort - diag\_dm\_mort\_reduction\_p\_h\_th)/100000 | Mortality of diagnosed stage 3 | People/Years |
| "diag\_4-5\_mort" | "CKD\_4-5\_not\_KRT" \* ("r\_S4-5\_mort" - diag\_dm\_mort\_reduction\_p\_h\_th)/100000 | Mortality of diagnosed stage 4/5 | People/Years |
| diag\_KRT\_mort | (KRT \* r\_KRT\_mort/100000) | Mortality of KRT | People/Years |

* + - 1. Constants & Converters

|  |  |  |
| --- | --- | --- |
| **Name** | **Comments** | **Units** |
| ***Constants*** |  |  |
| incidence\_rate\_p\_h\_th | In-model calibration | Per Year |
| diagnosis\_rate\_p\_h\_th | In-model calibration | Per Year |
| "und\_r\_3\_to\_4-5" | In-model calibration | Per Year |
| "r3\_to\_4-5" | In-model calibration | Per Year |
| "r4-5\_to\_KRT" | In-model calibration | Per Year |
| r3\_diag | In-model calibration | Per Year |
| "r4-5\_diag" | In-model calibration | Per Year |
| CVD\_all\_cause\_mortality\_p\_h\_th | From CVD Prevent | Per Year |
| S3\_mort\_factor | In-model calibration | dmnl |
| "S4-5\_mort\_factor" | In-model calibration | dmnl |
| KRT\_mort\_factor | In-model calibration | dmnl |
| meds\_progress\_reduction\_p\_h\_th | Reduction in progression rate due to medication usage | Per Year |
| meds\_mort\_reduction\_p\_h\_th | Reduction in mortality rate due to medication usage | Per Year |
| costs pc stage 3 pp pa | Annual primary care costs per person with stage 3 CKD | £/person/year |
| costs pc stage 4-5 pp pa | Annual primary care costs per person with stage 4/5 CKD | £/person/year |
| cost\_meds\_pp\_pa | Annual cost of meds per person | £/person/year |
| cost\_KRT\_pp\_pa | Annual cost of KRT per person | £/person/year |

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Equation** | **Comments** | **Units** |
| ***Converters*** |  |  |  |
| baseline\_new\_cases\_pa | ons\_pop \* incidence\_rate\_p\_h\_th / 100000 | Status quo new cases per year | People/Years |
| new\_cases\_pa | baseline\_new\_cases\_pa \* (1-primary\_prevention\_impact) | Annual new cases when primary prevention applied | People/Years |
| primary\_prevention\_effectiveness\_pc | 0 | User input for scenarios | dmnl |
| primary\_prevention\_impact | IF TIME >lead\_time THEN primary\_prevention\_reach\_pc/100 \* primary\_prevention\_effectiveness\_pc/100 ELSE 0 | Applies primary prevention impact, after the lead-in time | dmnl |
| primary\_prevention\_reach\_pc | 0 | User input for scenarios | dmnl |
| KDIGO\_adherence\_improvement\_pc | 0 | User input for scenarios | dmnl |
| diagnosis\_improvement\_pc | IF TIME >lead\_time THEN KDIGO\_adherence\_improvement\_pc ELSE 0 | Calculated | dmnl |
| und\_disease\_management\_adherence | 0 | User input for scenarios | dmnl |
| und\_disease\_management\_reach | 0 | User input for scenarios | dmnl |
| und\_disease\_management\_impact | IF TIME >lead\_time THEN und\_disease\_management\_effectiveness/100 \* und\_disease\_management\_reach/100 ELSE 0 | Applies combined effect of reach and effectiveness on undiagnosed, after the lead-in time | dmnl |
| und\_dm\_progress\_reduction\_p\_h\_th | und\_disease\_management\_impact \* meds\_progress\_reduction\_p\_h\_th | Calculated reduction in progression | Per Year |
| und\_dm\_mort\_reduction\_p\_h\_th | und\_disease\_management\_impact \* meds\_mort\_reduction\_p\_h\_th | Calculated reduction in mortality | Per Year |
| disease\_management\_adherence | 0 | User input for scenarios | dmnl |
| disease\_management\_reach | 0 | User input for scenarios | dmnl |
| disease\_management\_impact | IF TIME >lead\_time THEN disease\_management\_effectiveness/100 \* disease\_management\_reach/100 ELSE 0 | Applies combined effect of reach and effectiveness on diagnosed, after the lead-in time | dmnl |
| diag\_dm\_progress\_reduction\_p\_h\_th | disease\_management\_impact \* meds\_progress\_reduction\_p\_h\_th | Calculated reduction in progression | Per Year |
| diag\_dm\_mort\_reduction\_p\_h\_th | disease\_management\_impact \* meds\_mort\_reduction\_p\_h\_th | Calculated reduction in mortality | Per Year |
| total\_prev\_pc | calib\_total\_prev/ons\_pop \*100 | Used for reporting | dmnl |
| r\_S3\_mort | CVD\_all\_cause\_mortality\_p\_h\_th \* S3\_mort\_factor | Mortality rate for stage 3, based on CVD all cause mortality | Per Year |
| "r\_S4-5\_mort" | "S4-5\_mort\_factor" \* CVD\_all\_cause\_mortality\_p\_h\_th | Mortality rate for stage 4-5, based on CVD all cause mortality | Per Year |
| r\_KRT\_mort | CVD\_all\_cause\_mortality\_p\_h\_th \* KRT\_mort\_factor | Mortality rate for those receiving KRT, based on CVD all cause mortality | Per Year |
| model\_diag\_prev\_rate | model\_diag/ons\_pop \*100 | Used for reporting | dmnl |
| pc\_diagnosed | diagnosed /(diagnosed+undiagnosed) \* 100 | Used for reporting | dmnl |
| model\_mortality\_p\_h\_th | model\_mort/model\_prev \* 100000 | Used for reporting | Per Year |
| adj\_incid | 100000 \* new\_cases\_pa/ons\_pop | Used to report rates by overall 18+ population | Per Year |
| "adj\_r\_undS3\_to\_4-5" | "und\_r\_3\_to\_4-5"-und\_dm\_progress\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| adj\_r3\_diag | r3\_diag\*(100+diagnosis\_improvement\_pc)/100 | Used to report rates by overall 18+ population | Per Year |
| "adj\_r4-5\_diag" | "r4-5\_diag"\*(100+diagnosis\_improvement\_pc)/100 | Used to report rates by overall 18+ population | Per Year |
| "adj\_r4-5\_to\_KRT" | "r4-5\_to\_KRT"-diag\_dm\_progress\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| adj\_rKRT\_mort | r\_KRT\_mort-diag\_dm\_mort\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| adj\_rS3\_mort | r\_S3\_mort-diag\_dm\_mort\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| "adj\_rS3\_to\_4-5" | "r3\_to\_4-5"-diag\_dm\_progress\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| "adj\_rS4-5\_mort" | "r\_S4-5\_mort"-diag\_dm\_mort\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| adj\_und\_rS3\_mort | r\_S3\_mort-und\_dm\_mort\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| "adj\_und\_rS4-5\_mort" | "r\_S4-5\_mort"-und\_dm\_mort\_reduction\_p\_h\_th | Used to report rates by overall 18+ population | Per Year |
| cost\_pc\_s3\_undiag | costs\_pc\_stage\_3\_pp\_pa \* und\_S3 | Total annual cost primary care undiagnosed stage 3 | £/year |
| "cost\_pc\_s4-5\_undiag" | "costs\_pc\_stage\_4-5\_pp\_pa" \* "und\_S4-5" | Total annual cost primary care undiagnosed stage 4/5 | £/year |
| cost\_pc\_stage\_3\_diag | costs\_pc\_stage\_3\_pp\_pa \* CKD\_3 | Total annual cost primary care diagnosed stage 3 | £/year |
| "cost\_pc\_stage\_4-5\_diag" | "costs\_pc\_stage\_4-5\_pp\_pa" \* "CKD\_4-5\_not\_KRT" | Total annual cost primary care diagnosed stage 4/5 | £/year |
| cost\_primary\_care | cost\_primary\_care\_undiag + cost\_primary\_care\_diag | Annual cost of primary care | £/year |
| cost\_primary\_care\_diag | cost\_pc\_stage\_3\_diag + "cost\_pc\_stage\_4-5\_diag" | Annual cost primary care in diagnosed stages 3-5 | £/year |
| cost\_primary\_care\_undiag | "cost\_pc\_s4-5\_undiag" + cost\_pc\_s3\_undiag | Annual cost primary care in undiagnosed stages 3-5 | £/year |
| cost\_meds | IF TIME > lead\_time THEN cost\_meds\_pp\_pa \* (num\_undiag\_on\_meds + num\_diag\_on\_meds) ELSE init\_cost\_meds\_pp\_pa \* (num\_undiag\_on\_meds + num\_diag\_on\_meds) | Total annual cost of meds | £/year |
| cost\_total\_KRT | KRT \*cost\_KRT\_pp\_pa | Total annual cost of KRT | £/year |
| cumulative\_intervention\_cost | RUNCUM(cost\_primary\_interventions\_targeted) | Total cost of primary interventions | £ |

* + - 1. Graphical functions

|  |  |  |
| --- | --- | --- |
| **Name** | **Comment** | **Units** |
| ons\_pop | Exogenous variable, population estimates and projections | People |
| "CVDP\_undiag\_S3-5" | Validation - known data | People |
| "CVDP\_diag\_S3-5" | Validation - known data | People |
| CVDP\_und\_S3 | Validation - known data | People |
| "CVDP\_und\_S4-5" | Validation - known data | People |
| CVDP\_diag\_S3 | Validation - known data | People |
| "CVDP\_diag\_S4-5" | Validation - known data | People |
| UKRR\_KRT | Validation - known data | People |
| UKRR\_KRT\_incid | Validation - known data | People/Year |
| cost\_primary\_interventions\_targeted | User input | £/year |

* + - 1. Sources & Sinks

The only exogenous source variable is the population estimates (2022 – 2023) and projections (2024 onwards)

The sink variables are mortality at each stage and diagnosis state.

* 1. Data
     1. Data sources

|  |  |  |
| --- | --- | --- |
| **Source name** | **Date range** | **Description** |
| Office of National Statistics | 2016-2040 | Population estimates and projections of ages 18+ for NHS regions and England |
| [Inside CKD](https://doi.org/10.1016/j.eclinm.2024.102614) | 2022 | Micro-simulation model projecting CKD 2022-2026, used to split prevalences into stage 3 and stage 4/5 |
| [CVD Prevent](https://data.cvdprevent.nhs.uk/data-extract?period=18&systemLevel=6&indicator=8) | 2020 onwards | CKD Prevalence: indicators CVDP001CKD, CVDP002CKD, CVDP003CKD indicator for NHS regions & England  CVD All-cause mortality rate |
| [UK Renal Registry](https://www.ukkidney.org/audit-research/annual-report/all) | 2021-2022 | Annual Reports - extract KRT incidence & prevalence, and CKD (not KRT) prevalence |
| [The Lancet](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(22)02074-8/fulltext) | NA | Reduction in progression and mortality rates with use of SGLT2 inhibitors, for those with and without T2D. |
| [Nature.com](https://www.nature.com/articles/s41598-020-63443-4) | NA | Split of CKD patients with/without T2D |

* + 1. Pre-processing

Data wrangling was carried out using R, and documented in Quarto (available on the Github repository).

|  |  |
| --- | --- |
| **Data** | **Wrangling** |
| ONS | Combine 18+ population estimates and projections to NHS regions |
| CVD Prevent | CVD Prevent reports diagnosed (coded), undiagnosed (sum of uncoded and high risk) |
| Inside CKD | Split diagnosed and undiagnosed prevalence into stages (stage 3 and stage 4/5 not KRT) |

Input parameters

Values for each arrayed dimension are available on the Github repository.

|  |  |
| --- | --- |
| **Name** | **Source** |
| incidence\_rate\_p\_h\_th | In-model calibration |
| diagnosis\_rate\_p\_h\_th | In-model calibration |
| "und\_r\_3\_to\_4-5" | In-model calibration |
| r3\_diag | In-model calibration |
| "r4-5\_diag" | In-model calibration |
| rKRT\_diag | In-model calibration |
| "r3\_to\_4-5" | In-model calibration |
| "r4-5\_to\_KRT" | In-model calibration |
| CVD\_all\_cause\_mortality\_p\_h\_th | CVD Prevent |
| und\_mort\_factor | In-model calibration |
| und\_S3\_mort\_factor | In-model calibration |
| "und\_S4-5\_mort\_factor" | In-model calibration |
| S3\_mort\_factor | In-model calibration |
| "S4-5\_mort\_factor" | In-model calibration |
| KRT\_mort\_factor | In-model calibration |
| sglt2\_progress\_reduct p h th | Reduction in progression with 100% SGLT2i usage |
| meds\_progress\_reduction\_p\_h\_th | Derived from Lancet paper |
| sglt2\_mort\_reduct p h th | Reduction in mortality with 100% SGLT2i usage |
| meds\_mort\_reduction\_p\_h\_th | Derived from Lancet paper |
| ons\_pop | ONS population estimates/projections |

All interventions are initialised with values of 0, to apply the baseline scenario as the default.

* + 1. Assumptions
* Inside CKD reports rates for diagnosis and CKD stage for the whole of the UK. It is assumed these rates apply equally to England and to each NHS region.
* Flow rates, per hundred thousand of the upstream stock, are fixed throughout the simulation period.
* Intervention effects are applied equally across the relevant states/stages.
* The overall reduction in progression and mortality with use of SGLT2 inhibitors (or equivalent) is a weighted average of the effects on people with and without Type 2 Diabetes[[3]](#footnote-4), and assumes 30% of those with CKD also have T2D[[4]](#footnote-5).
* The effect of additional medications is applied as a multiplier to the SGLT2i rates.
* Mortality at each stage/state is based on the ‘all-cause mortality rate’ of CVD Prevent. A scale factor is applied at each stage/state, the values of which are deemed either by expert judgment or by in-model calibration. Diagnosis does not have an effect on mortality at any given stage[[5]](#footnote-6).
  1. Experimentation
     1. Initialisation

All stocks are initialised with the initial value of their equivalent CVD Prevent/UKRR converter value.

* + 1. Run length
* Run length: 15
* DT: 0.125
* Time Units: Years
  + 1. Estimation approach

Two iterations of Powell optimisation used to calibrate:

* + - 1. incidence rate and diagnosis rate
      2. flows between stages/states and mortality

then manual adjustments for fine-tuning

* 1. Implementation
     1. Software

Stella Architect, version 3.8, build 3557 (likely to change as model is developed)

* + 1. Random sampling

NA

* + 1. Model execution
* Integration method: Euler
* Time step/DT: 0.125
  + 1. System specification
* Windows 10 Pro, version 22H2, OS Build: 19045.5247
* 11th Gen Intel(R) Core(TM) i7-11800H @ 2.30GHz 2.30 GHz, RAM 32.0GB
  1. Code Access
     1. Computer model sharing statement

The Stella Architect stmx model file and the values used to populate/initiate the model will be made available in a repository on the Strategy Unit’s [Github account](https://github.com/The-Strategy-Unit/renal-services). Ultimate ambition is for the model and interface to be converted to open source, but this will still read in and use the stmx model.

1. Kidney disease: A UK public health emergency. The health economics of kidney disease to 2033 published by Kidney Research UK (June 2023). [↑](#footnote-ref-2)
2. Monks, T., Currie, C. S. M., Onggo, B. S., Robinson, S., Kunc, M., & Taylor, S. J. E. (2018). Strengthening the reporting of empirical simulation studies: Introducing the STRESS guidelines. *Journal of Simulation*, *13*(1), 55–67. <https://doi.org/10.1080/17477778.2018.1442155> [↑](#footnote-ref-3)
3. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(22)02074-8/fulltext [↑](#footnote-ref-4)
4. https://www.nature.com/articles/s41598-020-63443-4 [↑](#footnote-ref-5)
5. https://bmjopen.bmj.com/content/12/10/e064513 [↑](#footnote-ref-6)