Assessing the future workforce supply for the UK Nuclear sector

Authors: Siôn Cave[*], Steve Bennett [**], Rebecca Pleasant [***] & Emma Woodham[*]

* Decision Analysis Services Ltd
** Cogent Skills
*** Nuclear Decommissioning Authority

Abstract

A highly skilled workforce of approximately 80,000 full time equivalents is currently employed within the UK nuclear sector in a range of occupations that includes scientists, engineers, project managers and other technical and executive staff. Projections of workforce demand are comparatively accessible since major projects are well defined and planned many years in advance. In the UK there is expected to be a rapid upturn in demand over the next decade, primarily driven by the plan to build five new power stations, with an estimated peak of around 100,000 in 2022. The future workforce supply is more difficult to determine as a result of the multiple workforce entry points (e.g. through apprenticeships and from other sectors), and the many attributes that define the workforce such as, occupation, training background, time to competence, and so forth. In order to handle this large parameter space and support the development of better supply projections, the UK Nuclear Skills Strategy Group (NSSG), which is accountable for developing a skills strategy to secure the supply of qualified and competent staff, has commissioned a System Dynamics based workforce model. The NSSG consists of key employers and government representatives, for both the civil and defence nuclear sectors. This paper describes the model and modelling process that has been developed for UK nuclear industry on their behalf.

Key Words: System dynamics, workforce planning, nuclear, strategy, apprenticeships

1 Introduction

This paper describes a major project to model the supply of skills for the UK nuclear industry. The project was commissioned by the Nuclear Skills Strategy group (NSSG), which consists of key employers and government representatives across the civil and defence nuclear sectors. Its primary role is to develop a nuclear skills strategy to secure the required supply of qualified and competent personnel, for which a reliable source of Labour Market Intelligence (LMI) is essential. While demand data is comparatively accessible, since major projects are well defined and planned many years in advance, the matching supply side is formed from a number potential routes whose contributions vary with time, geography, occupation and training background.

The work was carried out by Cogent Skills with support from Decision Analysis Services Ltd (DAS). Cogent is a not-for-profit organisation working with strategically important science-based industries in the UK to develop their existing workforces and ensure a pipeline of new talent. Specifically here, it works in partnership with other skills bodies and government, under the auspices of the NSSG, to examine the current and future needs of the nuclear industry. Cogent Skills is supported by DAS who provide specialist system dynamics consultancy. DAS deliver effective solutions to the challenging issues facing government and industry in highly regulated sectors using systems modelling and simulation methods.

This paper describes the work undertaken to model skills supply at a time of renaissance of nuclear power generation in the UK alongside an on-going programme of submarine construction. As a pioneering nation in nuclear power generation the UK also has a large decommissioning programme that will operate for decades to come.

For many years the workforce and skills requirements have remained long-term and reasonably stable. As proposals for new generating capability have evolved, and new technological opportunities identified, the dynamics of the supply and demand have become less intuitive. Strategic planning now requires a transparent, flexible and dynamic model of the workforce.

1.1 Contents

Section 2 describes the challenge of workforce planning for the UK nuclear sector. **Section 3** describes the systems dynamics model that has been developed to provide projections of future workforce supply. **Section 4** describes how the model is being used and provides some emerging results from the workforce modelling. Finally, **Section 5** provides some initial conclusions and provides potential next steps for the modelling work.

2 The challenge – Workforce planning for the UK nuclear sector

2.1 The UK's nuclear sector workforce

The UK's nuclear workforce (civil, defence and supply chain) comprises around 80,000 full time equivalents, but is expected to require expansion to a peak in the region of 100,000 as a result of a programme to build a fleet of new generating stations. Although the vast majority of the workforce requires some nuclear training to ensure safety, more than 80% of skills are characterised as generic, in the sense that the core disciplines are the technical, scientific and engineering skills employed elsewhere, and particularly other safety critical industries.

While nuclear specific skills do not dominate, the workforce is a highly technically skilled one. At the same time, nuclear policy over the last twenty years or so has resulted in a workforce older than the national average for the employed population.

In the short and medium term the proposal for new civil nuclear generating capacity, the first in the UK since the commissioning of Sizewell B in 1995, will cause a rapid up-turn in workforce demand. Five new power stations are planned, each taking between 5 and 9 years to build, with a sixth currently undergoing assessment. The projects are private enterprises drawing on skills from the same pool as parts of the defence programme.

In the longer term the possibility has been noted for the development of future technologies, for example small modular reactors, or Generation IV reactors, to make use of an enhanced skill base while further adding to the supply of low carbon electricity.

Across the nuclear industry, the necessary experience to achieve competence varies hugely between occupations, from a few weeks for basic training for access to a construction site with no nuclear fuel, to 10 to 15 years to develop subject matter experts. This in particular makes the modelling of the skills supply difficult without the sophistication of a system dynamics model.

However, with the right model structure in place, broader issues can also be addressed, for example the balance of between apprenticeships and higher education degrees, driven by government priorities, or the influence of workers migrating from other sectors as the economy changes.

Cogent Skills' role is in collating workforce data from a variety of sources and providing analysed LMI to inform skills policy for the NSSG, Government, Training Providers and others.

Over the last 4 years a comprehensive demand side picture has been built, but with a limited supply side component based principally on projections of the current workforce. Although this is useful in predicting likely required recruitment rates to meet expansion and replacement demand, it fails to reflect the complexity of the supply routes that are critical in determining the delays in supply. The model described here, marks an important, and much sought improvement in developing robust projections.

2.2 System Dynamics and workforce planning

System Dynamics is a modelling approach that enables complex systems to be better understood, and their behaviour over time to be projected using computer simulation. System Dynamics was first developed in the 1960's by Jay Forrester (Forester, 1961) with many more important texts produced in the subsequent years (for example see Sterman, 2000; Warren 2007 and Morecroft 2007). The System Dynamics approach has been successfully used across many different sectors.

The approach is composed of two key components; the first is mapping the system to better understand it, and the second is using computer simulation to calculate system behaviour over time.

2.2.1 Mapping the system to understand behaviour

The first stage of a System Dynamics based project involves mapping the cause and effect relationships that drive system behaviour. System Dynamics uses specific diagramming notation such as stock and flow diagrams or causal loop diagrams to map the system.

A Causal Loop Diagram (CLD) is used to capture major feedback mechanisms. The diagram includes variables and arrows (causal links) linking these variables together. A Stock and Flow Diagram (SFD) captures the main stocks in the system, and the flows that act to increase and decrease the size of the stocks.

Figure 1 illustrates the differences between CLDs and SFDs, based on the same simplified workforce supply system. In both diagrams the number in training is increased by *start training* and reduced by *complete training*. They then move into the *workforce size* stock, where they leave as a result of the *attrition rate*. The rate people start training is based on the difference between the *desired workforce size* and the actual *workforce size*:

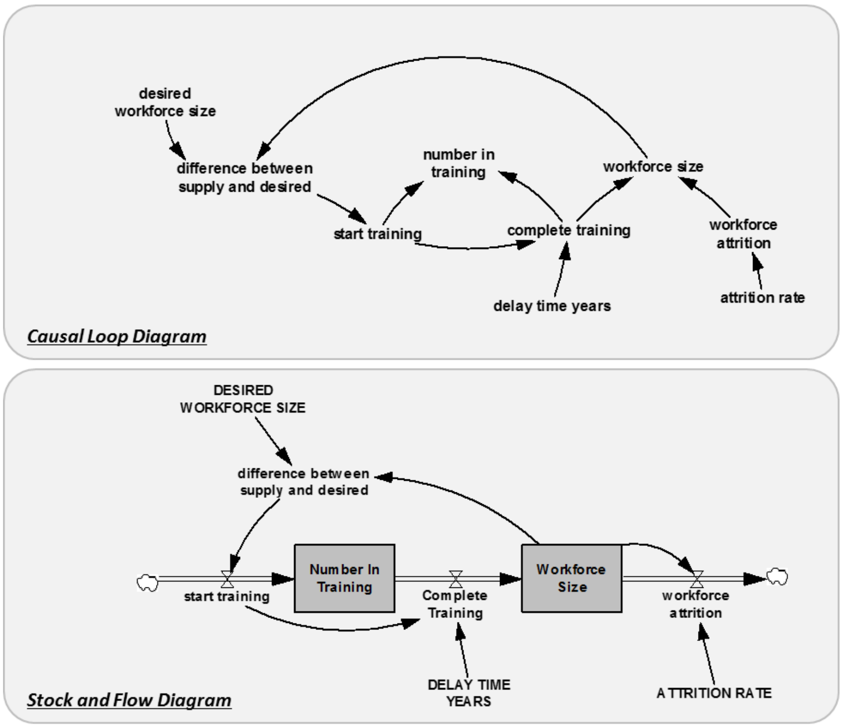

***Figure 1:** Example Causal Loop Diagram and Stock and Flow diagram for a simplified workforce system*

The diagrams are created with the system stakeholders, who best understand how the system of interest works. The completed diagrams represent a shared understanding of the system, which can then be used in many ways, for example to investigate points where interventions could be made.

2.2.2 Simulating the system to quantify behaviour

Once an agreed diagrammatic representation of the system has been created, specialist software can be used to quantify the relationships. The completed simulation model is then available to rapidly test system interventions in a risk free environment.

The simulation model provides a means to calculate change over time depending on the underlying assumptions and proposed interventions. System Dynamics models simulate rapidly using management information data sources. The models can be developed to produce outputs using desired performance measures, and validated against historical data.

A number of authors have produced guidance on producing robust SD models, for example see Sterman (2000), Keating (1999), Randers (1980) and Cave (2014).

2.2.3 Application of System Dynamics to workforce planning

System Dynamics has been applied a number of times in support of strategic workforce planning, across a variety of different sectors such as:

- Health and social care (for example see Brailsford and De Silva (2015); Barber and López-Valcárcel (2010), Masnick and McDonnell (2010) and Cave, Willis and Woodward (2016)).
- Defence (for example see Armenia et al (2012); Bakken, Østbye and Røksund (2005))
- Logistics (for example see Größler and Zock (2010)
- Agriculture (for example see Nanda, Rama and Vizayakumar (2005))
- Professional services (for example see Kunc, 2008)
- Information Technology (see McLucas and Lewis (2008), Collofello et al (1998) and Cave et al (2011))

There is no evidence in the literature of SD having been used for strategic workforce planning for those workforces operating within the nuclear sector.

3 Nuclear Workforce Supply Side Model (NWSSM)

This Section provides a description of the System Dynamics model and the development approach that was adopted.

3.1 High-level model requirement

The high-level model requirement bounded the model scope, and was agreed prior to commencing model development. This was agreed to be:

> *This model is to be developed in response to a Nuclear Strategy Skills Group (NSSG) requirement to describe the supply of skills to the nuclear industry, in a way that complements an already developed demand side picture. It will allow scenarios to be designed that in turn inform policy decisions on the level and timing of training and recruitment to meet the UK nuclear programme. The model is required to represent a common source of university graduates and apprenticeships feeding up to 20 different high level resource codes[1] (HLRC). The model is required to project the workforce supply over a 20 year time horizon.*

The model requirement was referred to throughout the development process to ensure that the model was going to meet the fundamental objectives the model was being developed to meet.

3.2 Model development approach

The model was developed from October 2016 to January 2017. A typical approach for model development, as shown in Figure 2, was followed during the project:

[1] A High Level Resource Code is part of the taxonomy agreed within the industry around a common definition of 20 or so key occupations. Examples are Quality Assurance, Project Management and Design.

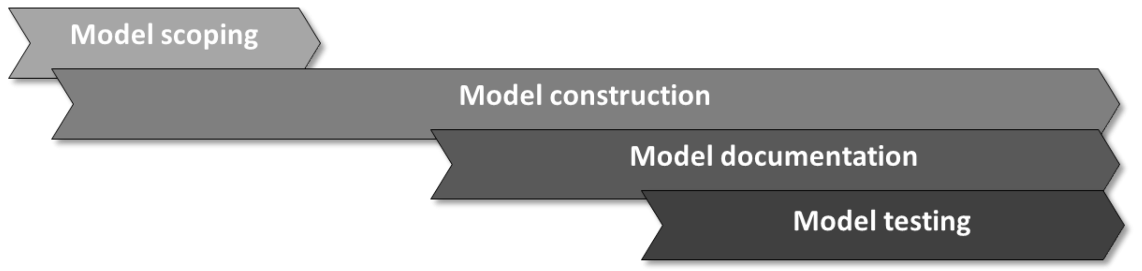

Figure 2: High level approach for developing a System Dynamics model (adapted from Cave (2014))

During the model scoping stage a formal model specification for the model was created based on input from the relevant stakeholders. The specification defined the scope and purpose of the model. The model specification also captured the structural assumptions that the model would be based upon. The specification was kept up to date as model assumptions were updated during the construction process, and was the starting point for the formal model description.

During the model construction stage the model was built using Vensim DSS[2] and MS Excel (the architecture is described in more detail in Section 3.4). The model was built iteratively so that the structures could be reviewed by the Cogent project lead and refined as appropriate. This stage also included data acquisition to enable the model to be reviewed based on realistic input data.

The model was then then formally documented and tested. The model documentation included information of the model purpose, the assumptions the model was based upon and instructions on how to use the model. Formal model testing was carried out by an independent SD modeller against a formal test specification which was developed based on checklists given in Cave (2014). Cogent also carried out user acceptance testing.

Stakeholders were involved throughout the process, for example to get agreement on the model representation and to "sanity check" model results.

3.3 Conceptual basis for the model

A key output of the model scoping stage was to derive the underlying conceptual model for the SD model which was agreed upon by the stakeholder group. This was created in workshops using Stock and Flow notation, and defined not only the supply stages that the model would represent, but also the model boundary.

Figure 3 below provides a high level view of the conceptual basis of the model:

[2] www.Vensim.com

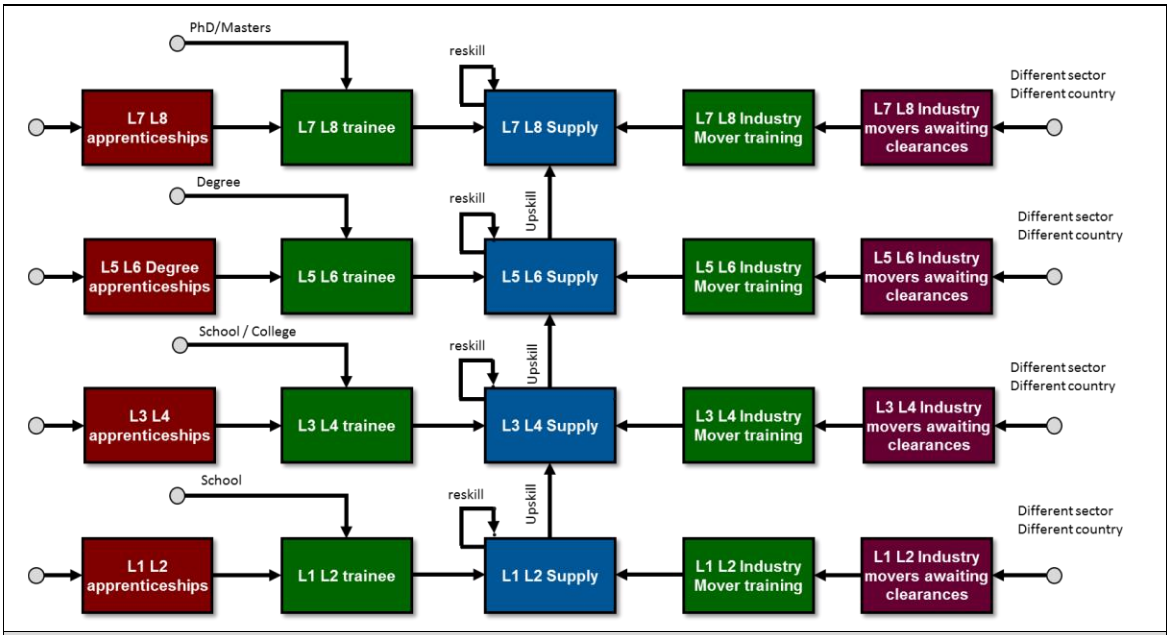

Figure 3: High level conceptual basis for the model

Figure 3 illustrates the key stocks that would be required for the model, along with the main flows. For simplicity, flows like attritions from the stocks are not shown, but would need to be represented in the quantitative model.

Each of the rectangles in the diagram represents a number of people at various stages of training or within the workforce itself. In addition, each rectangle represents different high level resource codes.

Four different role levels are considered, representing a combination of qualification, knowledge and experience, and referenced to the UK Regulated Qualification Framework (RQF)[3] levels 1 to 8. In broad terms these correspond to:

- **Level 1 Level 2 (L1 L2)** – Semi or unskilled occupations with qualifications typically at basic secondary school level. Sometimes including lower level vocational training at level 2

- **Level 3 Level 4 (L3 L4)** – Skilled occupations with qualifications at higher secondary school level or following vocational training with a sponsoring employer.

- **Level 5 Level 6 (L5 L6)** – Higher technical and professional roles often, although not uniquely, combined with a university first degree.

[3] The RQF systemises qualifications in England and Northern Ireland and maps to the European Qualifications Framework. https://ofqual.blog.gov.uk/2015/10/01/explaining-the-rqf/

- **Level 7 Level 8 (L7 L8)** – Higher technical and professional roles with some technical specialism and/or a long period of experience gained within the industry. This might include higher degrees (MSc and PhD).

The **blue rectangles** in the central column of the diagram represent the supply of competent workers capable of meeting demand at the four different skill level groups for the different high level resource codes. It is possible for people to reskill from one high level resource code to another, and also to upskill from one skill level group to another. Reskilling occurs through formal training/apprenticeship and upskilling through formal training or through experience.

There are two routes through to the supply stocks. The first is through apprenticeships and following formal education. This route is shown to the left of the supply stocks. The **brown rectangles** represent the different apprenticeships that could feed into the nuclear sector. Following an apprenticeship a period of job specific training is required, shown in the subsequent **green rectangles** in order to achieve competence prior to moving into the supply stocks. Direct entry to these stocks is possible, for example someone completing a degree can proceed to the L5 L6 trainee stock.

The second route to the supply stocks is for people coming to the UK nuclear sector from another sector or country. This route is shown to the right of the supply stocks. The **purple rectangles** represent experienced hires awaiting security clearances and/or foreign qualification validation. Following clearances being received, a period of job specific training is required, shown in the subsequent **green rectangles** in order to achieve competence prior to moving into the supply stocks.

This conceptual basis for the UK nuclear system formed the basis of the quantitative model development.

3.4 Model architecture

The quantitative model was developed using an Excel and Vensim model architecture, as illustrated in Figure 4 below:

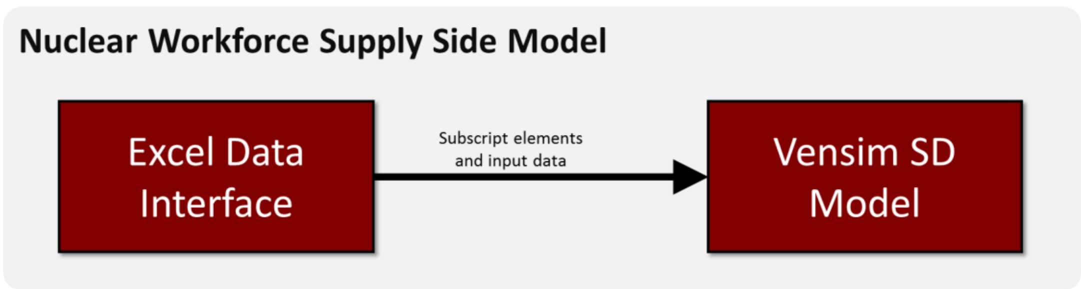

Figure 4: Model architecture

The Excel data interface contained all the data input into the model, and the definition of the model segmentation.

The Vensim model calculated the supply projections based upon the model input data, over a time horizon of 20 years. A single run took approximately 5 seconds to simulate. Analysis of the results was carried out using Vensim's native analytical tools.

3.5 System Dynamics model

The System Dynamics model was developed based on the conceptual model described in Section 3.3. In addition to the key flows shown in the Figure 3, the model also contains additional flows in order to represent:

- Attrition from the stocks
- Flows of people leaving the system following the completion of apprenticeships, training and the clearance processes

Each of the stocks in the model are heavily segmented. In order to make the model as flexible as possible the majority of the subscripts are defined within the Excel data interface, and the model segmentation updates each time the model is simulated. Model segmentation includes:

- **Apprentices** – Apprentices follow a programme of vocational training with a sponsoring employer at RQF Levels 2, 3 or 4. The model is currently defined with 72 different apprenticeship standards.
- **Degree Apprenticeship**– Degree Apprenticeships have been designed and promoted to combine higher education and with the industry focus of apprenticeships. The model is currently defined with 9 different types of degree apprenticeship.
- **Graduate** – Degree and higher level degree courses. The model is currently defined with 15 different types of graduate degree.
- **High Level Resource Code (HLRC)** – A wide range of role descriptors is used across the industry by different employers. A taxonomy based on some 100 agreed resource codes has been devised by the industry and skills bodies to allow workforce data to be compared. These have been further grouped into HLRCs to manage the presentation of workforce data in a reasonable number of occupations. The model is currently defined with 20 different HLRCs.
- **Region**– Geographical location. The model is currently defined with 8 different regions.

The excel spreadsheet also contains all the data required to initialise the model, including all of the delays associated with the apprenticeship/training and clearance processes.

Each of the training and supply stocks have units of people, and represent a head count. Actual supply is calculated in terms of Full Time Equivalents (FTE), which is calculated from the supply stocks multiplied by the appropriate participation rate[4]. The projections are heavily segmented and can be presented by the following dimensions:

- High Level Resource Code
- Skill Level
- Region

The model projects supply forward over twenty years, using a one month time step, and takes approximately 5 seconds to run a single simulation. The System Dynamics model also includes the demand calculated from Cogent's nuclear sector demand model to enable comparison between supply and demand within Vensim.

Finally, the model includes a mass balance to test for the conservation of material within the system, all variables have their units defined, and all variables include an expected range to alert the user to deviations from normal behaviour.

3.6 Data sources

The Excel spreadsheet contains all the input data used by the Vensim model, including all data references and a complete data audit trail.

Cogent has a history of working with the major operators and other interested skills bodies in the nuclear industry over a decade. Both raw data and industry insight has been provided by the Human Resources departments of the site operators, new site developers and the Construction and Engineering Construction Industry Training Boards (CITB and ECITB). The use of the data and the results and conclusions are reviewed by the NSSG which includes senior Human Resources staff from across the industry.

4 Using the model and emerging results

Early use of the model has been to adjust input stocks and flows to achieve a supply profile that matches demand as closely as possible. In general, more than one combination of apprenticeship and industry mover stocks will be available, although timing considerations often constrain the range of options. Where there is latitude, alternative balances in the supply pathways represent policy options. For example, government focus on apprentice programmes, with a strong financial driver through the apprenticeship levy, may encourage plans based on maximizing the apprentice workforce stock offset by decreases elsewhere.

Initial results have emphasized the crucial role played by the phasing contribution introduced by the delays arising from classroom and practical training. Long lead-time

[4] The extent to which the workforce work full or part time.

routes are limited not only in the short term, but also later when more responsive sources (experienced personal from analogous industries or reskilling from within the industry, for example) are already in position. The result is a sensitive trade-off between the rate of change of demand, supply phasing and pipeline attrition rates.

An example of supply side fitting, based on test data, is shown in figure 5 below. Each line of charts shows in turn: the effect of a new cohort of apprentices; the effect of an intake of experienced workers from analogous industries; and finally the two supply routes combined. The demand (stepped) and supply curves appear in the right hand column, while the dotted curve in the top right chart shows the projection of the current workforce with natural attrition.

In the first row, the long lead time to train apprentices means that the increased supply only appears after the demand curve has further diverged from the projection of the existing workforce.

In the second row experienced workers make a more rapid impact on supply but, in this case, the supply is allowed to decay before reaching the peak in demand.

In the third row the two supply routes are combined to produce a supply curve that forms a reasonable fit to demand.

This is a possible, but not unique, scenario for illustration based on a limited set of input data. Nevertheless it does show some of the considerations in analysing the supply.

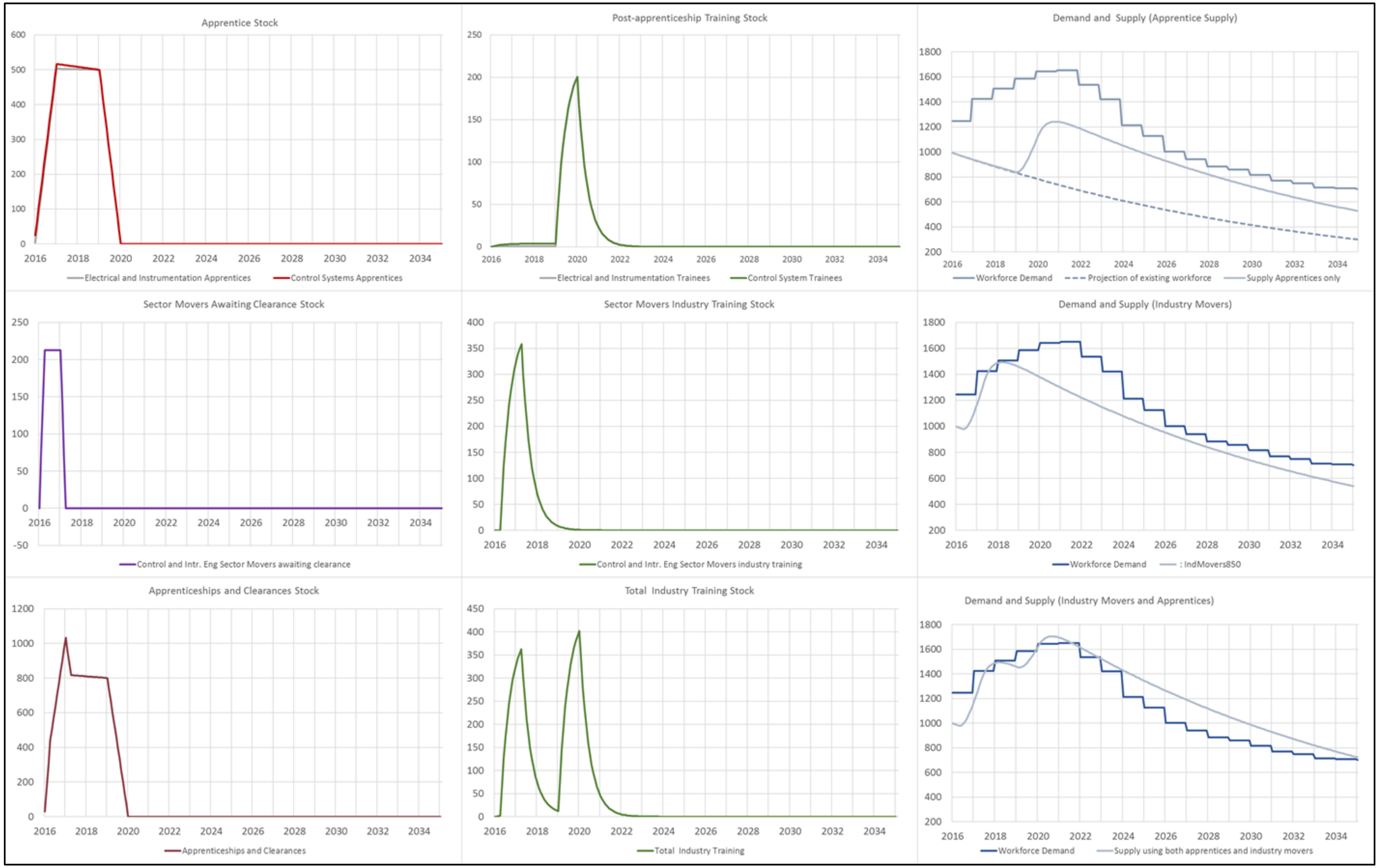

Figure 5: Sample illustrative results

5 Conclusions and Next Steps

The structure of the model has been designed, implemented and tested. Work is now underway to introduce properly representative data to fully exploit its capabilities and streamline the optimization processes.

The benefits of using the System Dynamics approach for modelling the future supply of the nuclear sector workforce have included:

- The process of developing a model in collaboration with stakeholders from the workforce helped all parties to understand the complex nature of the nuclear workforce system, and identify the key variables that influence it.
- The visual representation of the model structure using Stock and Flow diagrams made it easier to share and explain to people.
- The formalised approach to model development described in Section 3.2 and the associated documentation, such as the model test specification, built confidence in the model.
- Validation of the SD model was made easier as the model links were explicit within the stock and flow diagrams. This is a clear advantage over Excel where the links between variables can often be opaque.
- It was much easier to interrogate the models at a variable level, which aided debugging and carrying out model behavior analysis.
- The analytical tools within the Vensim environment made it easier to explore the dynamics associate with all the model variables.

Finally, there is scope for the following improvements to be made to the model: :

- Improved policy development interface.
- Sub-sector representation (for example an explicit defence sub-sector of the overall UK nuclear sector).
- Using Monte Carlo capabilities to make an assessment of the uncertainty associated with the projections.

6 Abbreviations

CLD	Causal Loop Diagram
DAS	Decision Analysis Service Ltd
FTE	Full Time Equivalents
HLRC	High Level Resource Codes
LMI	Labour Market Intelligence
NDA	Nuclear Decommissioning Authority
NSSG	Nuclear Skills Strategy Group
NWSSM	Nuclear Workforce Supply Side Model

SD System Dynamics
SFD Stock and Flow diagram

7 References

Armenia S., Centra A., Cesarotti V., De Angelis A., and Retrosi C. (2012) Military Workforce Dynamics and Planning in the Italian AirForce, ISDC 2012, At St. Gallen, Switzerland

Bakken B.E., Østby P.R., Røksund A ., Transforming a military personnel policy –learning from a model supported intervention, 23rd International conference of the system dynamics society, Boston, USA, 2005

Barber P and López-Valcárcel B G (2010) Forecasting the need for medical special-ists in Spain: application of a system dynamics model, Human Resources for Health 2010, 8:24

Brailsford., S and De Silva., D (2015) How many dentists does Sri Lanka need? Modelling to inform policy decisions., Journal of the Operational Research Society 66, 1566–1577

Cave S, Gliniecki M, Johnson S Nemesszeghy G (2011) Application of System Dynamics Modelling in support of Microsoft’s Automation Strategy, Proc: International System Dynamics Conference, System Dynamics Society, 2011 International Conference of the System Dynamics Society

Cave, S (2014). CfWI technical paper series no. 0008, Developing robust system-dynamics-based workforce models: A best-practice approach, London: CfWI Publications. Available at: http://www.cfwi.org.uk/publications/developing-robust-system-dynamics-based-workforce-models-a-best-practice-guide

Cave, S. Willis, G. and Woodward, A (2016). A retrospective of System Dynamics based workforce modelling at the Centre for Workforce Intelligence. The 34th Inter-national Conference of the System Dynamics Society, Delft, The Netherlands

Collofello J., Rus I., Houston., D Sycamore D. & Smith-Daniels D (1998) A System Dynamics Software Process Simulator for Staffing Policies Decision Support, Pro-ceedings of the Thirty-First Hawaii International Conference on System Sciences

Forrester J. W. 1961. Industrial Dynamics. The MIT Press, Cambridge, Massachusetts, 1961.

Größler A and Zock A (2010). Supporting long-term workforce planning with a dy-namic aging chain model: A case study from the service industry. Human Resource Management 49(5): 829–848.

Keating E. K. (1999) Issues to consider while developing a System Dynamics model. Retrieved June, 2013, from http://blog.metasd.com/wp-content/uploads/2010/03/SDModelCritique.pdf.

Masnick, M & McDonnell, G (2010) A model linking clinical workforce skill mix planning to health and health care dynamics, Human Resources for Health, 8:11

McLucas A and Lewis E (2008) A multi-methodology approach to addressing ICT skill shortages in a government organisation: integration of system dynamics modelling and risk management in Proc: International System Dynamics Conference, System Dynamics Society, 2008 International Conference of the System Dynamics Society, Athens, Greece

Morecroft J. (2007) Strategic Modelling and Business Dynamics: A Feedback Systems Approach. John Wiley & Sons.

Nanda SK, Rama D, Vizayakumar K : Human resource development for agricultural sector in india: A dynamic Analysis. Conference Proceedings The 23rd International Conference of the System Dynamics Society: 17-21 July 2005; Boston

Randers J. 1980. Guidelines for Model Conceptualization. In Elements of the System Dynamics Method, ed. by J. Randers. Portland, OR: Productivity Press.

Sterman J. D. (2000) *Business Dynamics*. McGraw-Hill Higher Education.

Warren K. (2007) *Strategic Management Dynamics*. John Wiley & Sons.