

Planning to Make Healthcare More Sustainable

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Abstract: Annual expenditure on healthcare runs into trillions of dollars globally and varies enormously among countries. Healthcare systems also generate a significant proportion of the world's greenhouse gases (GHGs), linked to climatic change that in turn affect human health. As part of the attempts to mitigate climatic change, healthcare providers are seeking to reduce the GHGs they emit in treating patients. This article discusses attempts to quantify the cost and carbon footprint of healthcare services and a mathematical model is used to quantify how changes in healthcare delivery might contribute to meeting budgets and emissions reduction plans whilst maintaining public health.

Keywords: systems modeling, operations research, demand side dynamics, supply side dynamics

Introduction

The per capita expenditure by governments on healthcare varies enormously among countries, ranging from \$0.70 per person per year in Burundi to \$4,508 in the United States (US). Although it holds loosely that the health of a population improves with increased expenditure, the relationship between a health outcome, such as life expectancy and spending, is not linear (Wilkinson and Pickett 2010). Although this deviation from linearity may be partially accounted for by factors like environmental quality (Correia *et al.* 2013) and social factors, such as deprivation and inequality (Wilkinson and Pickett 2010), health outcomes are affected by the quality of service provided, which, inevitably is strongly influenced by the purchasing power. Whatever healthcare system is in place for a population, it needs to be efficacious and affordable.

In planning services for the long term, the term 'affordable' may also be interpreted as 'sustainable', especially in the current global economic circumstances as public purses have to cope with the most challenging affordability envelope

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in a generation. However, over the past couple of decades ‘sustainability’ has emerged as a measurable quantum, which includes not only economic cost, but also environmental and social costs. Concerns over sustainability have evolved as there is now data indicating that anthropogenic activity has contributed to the increasing temperature of the Earth, with potentially serious climatic consequences that can drastically change the quality of human existence.

The notion of climate change has built up around global temperatures driven up by a rise in carbon dioxide and other GHGs released into the atmosphere. The seriousness of climate change as an issue is exemplified by some authors suggesting that it is the greatest threat to human health in the 21st century (Costello et al. 2009), perhaps killing 150,000 humans per year (Schwartz *et al.* 2006) and causing wars and other forms of social unrest. Even with the prospect of horrendous consequences materializing, efforts to reduce GHG emissions and plans for adapting how we might live, have been emerging only slowly (Godlee 2011). For the global population to reduce its emissions to a level considered sustainable and abate global warming, an examination of how we conduct our daily lives is essential. This can only be achieved through inter-disciplinary research that identifies the source of our emissions and ways of curbing them (Cooney 2010). The development of conceptual and numerical models can help with this process through sensitivity analyses.

The particular elements of our living environment, which generate GHGs vary enormously in terms of their impact, yet all contribute to global emissions. They range in size from individual domestic units, which comprises 72 per cent of GHG emissions (Hertwich and Peters 2009), to large multi-site conglomerates and institutions, such as factories, government offices, airports, and healthcare facilities. Sizing emissions through development of a conceptual model for each arena is inevitably an onerous task. However, research is underway, which is starting to scope the GHG given off from treating illness and maintaining the health of the population in general. To understand the sources of emissions generated through healthcare and how different ways of working might reduce their quantity, assessment of healthcare impacts must include hospitals and other medical facilities due to their rates of energy consumption (Charlesworth *et al.* 2011).

In the UK, estimates suggest that emissions from healthcare form a significant fraction of those GHG emissions attributable to the public sector, which overall accounts for 10 per cent of the global total (Hertwich and Peters 2009). For example, the English National Health Service (NHS) is responsible for 30 per cent of all public sector carbon emissions (Gatenby 2011), or 19.7 million T CO₂ eq (GHG expressed in terms of tonnes of carbon dioxide equivalent) in 2010 (Naylor and Appleby 2012). The activities responsible for the emission of these GHGs in the NHS comprise almost two-thirds that are attributable to procurement and 19 per cent to energy use in its buildings (Sustainable Development Unit 2012).

To set the size of emissions from the NHS in context, the GHGs emitted by the English NHS is larger than those emitted by passenger aircrafts taking

off from London's Heathrow Airport annually (Naylor and Appleby 2012). As with spending, the proportion of emissions allotted to healthcare varies among countries. For example, in the US, 7 per cent of CO₂ emissions were linked to the health sector (Chung and Meltzer 2009) versus 4 per cent in England (Naylor and Appleby 2012).

If the NHS meets its self-imposed reduction in carbon footprint of 80 per cent by 2050 (Cole 2009), it will reduce the carbon footprint of England by approximately 2 per cent. Whether this is achievable or not can only be determined through careful consideration and modelling of how operational changes in the delivery of healthcare might manifest themselves in the delivery of this target. However, any reduction in emissions will realize additional health co-benefits associated with mitigation in the health sector (Costello 2009, The WHO 2011, Haines *et al.* 2009). Modelling the sources of carbon emissions can assist greatly in ensuring that these mitigation measures are effective and realistic.

While modelling has been frequently undertaken to estimate the carbon footprint of individual areas of care; e.g., renal care (Connor *et al.* 2010; James 2007), reflux control (Gatenby 2011), dentistry (Duane *et al.* 2012), and the energy used in emergency care (Blanchard 2009), the carbon expended by wider healthcare systems has received much less attention (Zander *et al.* 2011). One of the rare attempts was undertaken by Pollard *et al.* (2013) in which over a quarter of the carbon footprint of delivering secondary healthcare to a region of the UK was simulated on a 'bottom-up' basis. Pollard's approach has since been tested in dentistry in Scotland (2013). Pollard's methodology involves piecing together systems that give rise to larger, more complex systems, as has been used to assess carbon mitigation in energy policy development (e.g., the MARKAL model) (Loulou 2004). It is the first attempt to apply such a model to the health sector. When applied, it can aid in the examination of the broader implications of policy and service reconfiguration on carbon emissions set against current practice.

Healthcare resources are finite and inevitably restrain what can otherwise be delivered. For a healthcare service to be sustainable as well as effective, it needs to be affordable. The same conceptual model, with which emissions of GHGs are calculated, can be employed to estimate the costs incurred of delivering healthcare, thereby permitting the possibility of gauging affordability. Here we discuss whether Pollard's model, having been proven adept at quantifying the GHG emitted from secondary healthcare and at estimating the dual cost-carbon savings achievable in dentistry, is fit for purpose in seeking a better, if not optimum, balance between cost effectiveness and emissions minimization in the delivery of healthcare.

Healthcare delivery within a challenging affordability envelope with high patient expectations and aspirations to minimize adverse impacts on the climate and our ecosystems requires very careful planning. There is a need to create time, to innovate when planning healthcare resources, and potentially do things differently. These actions could take the form of building teams within healthcare

organizations that will be able to take on the construction of complex models and their use and calibration, or possibly to use a tool that has been designed to aid the reconfiguration of healthcare services.

In addition to being made fit for the purpose through modelling the consequences of redesigning healthcare, use of the Pollard Model facilitates demonstration of how small operational changes can link together to create a more streamlined healthcare delivery system. Through publication, the science underpinning its methodology has been validated leaving its developers with the ambition of readying it for widespread use with universally available healthcare datasets. The model removes the need to assemble expensive teams of experts charged with conceptualizing and studying how best to reconfigure local healthcare services.

Because the model is fed with generic healthcare datasets, its application transcends geographical boundaries. Its modular construction enables sensitivity analysis through model runs. For example, the model architecture could easily incorporate concepts, such as using electronic gadgetry to empower patients to monitor themselves within their own homes as well as supplying biochemical, physiological, and behavioural data to healthcare professionals. Other uses for which the model could be developed include the construction of facilities that would, for example, allow healthcare systems to discharge patients more quickly from its more expensive facilities. Current plans for the development of large care homes in China (Jhan 2013) could be readily quantified using the model with their running costs and carbon footprint determined straightforwardly.

To date, talk of sustainability in healthcare is typically focused on the need to control the emissions generated from treating patients. However, it is difficult to argue that any 'green' system for treating patients that is not affordable is sustainable. The model presented here calculates both the cost and the carbon footprint of the way in which a healthcare system operates, thereby enabling a judgement to be made around its sustainability in the truest sense of the word.

The versatility of the bottom-up approach stems from the simplicity of the conceptual model. It facilitates a demonstration of how healthcare is delivered across patient-carer interfaces and is able to aggregate a number of quanta utilized in delivering care; whether they are carbon, cost, or water use. With regard to water, it provides an interesting perspective. It must be noted that the NHS in England consumes enough water and generates enough sewerage to fill London's Wembley Stadium every 16 days (Naylor and Appleby 2012).

The modelling approach described here is very much a work in progress, but can already help manage the consumption of precious resources needed to deliver healthcare whilst, at the same time, ensure that the quality of care and patient expectations are not compromised. Being constructed bottom-up from a low level, the model allows a demonstration of how the current cost base and carbon footprint may be derived for an organization that meets these expectations and needs. The model's architecture lies at the individual component level, whether that denotes an individual heater, light bulb, or mode of transport.

Thereon, the emissions given off by these processes are aggregated at a level against which comparison with measured consumption may be made. Not only does this provide assurance that the carbon footprint or cost of a clinical area or pathway may be appraised, it also allows for demonstration of how changes in clinical practice and internal processes in individual areas contribute to a reduction in cost or emissions within the healthcare system.

Modelling Philosophy

In developing a mathematical model to improve the provision of healthcare, a decision was taken to separate the model's dynamics into demand and supply side.

It was assumed that patients should be treated at the closest site at which the treatment required was available, or, at the site at which the patient wished to be treated. A core philosophy underpinning the model was that patient demand should not be constrained by capacity availability. Where demand outstripped capacity, it was expressed as a 'capacity gap' to be remedied by undertaking changes in the manner in which healthcare services were delivered. Consequently, evaluation of the demand at each site was more straightforward in that it could be driven by the geographic distribution of a local population, the rate at which those members of the population needed healthcare and the sites at which healthcare services were offered.

On the supply side, the model strives to be as simple as possible as it quantifies the resources required to treat the population. It does this through consideration of elements that constitute a patient's treatment (care pathway). Against each of these component parts a cost, a set of resources, and a quantity of greenhouse gas emissions is allocated. As mentioned previously, the simplicity of the supply-side conceptual model allows any quantum to be output from the supply-side model so long as the quantum is consumed at the point of care. Consequently, the model is able to calculate the number of patients that require treatment at a given site and work out the cost and carbon footprint of treating this number of people and crucially, whether or not there is sufficient capacity to treat this number of patients. Key to the demonstration of how feasible the delivery of each configuration is, the model is designed to be populated by those managing and delivering services. In this regard, staff appreciate how changing the way they run services manifests itself in the delivery of targets and savings at the very top level. In other words, the staff can gauge the significance of changing how they operate with respect to 'the bigger picture' by using the model.

The aim of the model is to help those healthcare services to identify the optimum balance in service provision such that carbon emissions are kept as low as possible whilst maintaining affordability and maximizing patient access to services. Different configurations of services are compared and the configuration

which satisfies the most metrics in terms of cost, carbon, and patient access can be readily identified. The tool helps to identify a manner in which care services are laid out whereby cost savings and carbon reduction may coincide and the point of care is available to meet needs in appropriate locations.

The Model Dynamics

In calculating the carbon footprint of large proportions of secondary healthcare in Cornwall, Pollard *et al.* (2013) used data, which outlined the concepts defined in Figure 1. The provision of care, whether it be secondary healthcare, social care, or dentistry, is influenced by a number of factors, including demographic and related to service delivery. Factors relating to deliverability include finance and the availability of resources, which were included in a later study run using the Pollard model to evaluate impacts of dentistry in Fife, Scotland. This latter study is currently being prepared for publication.

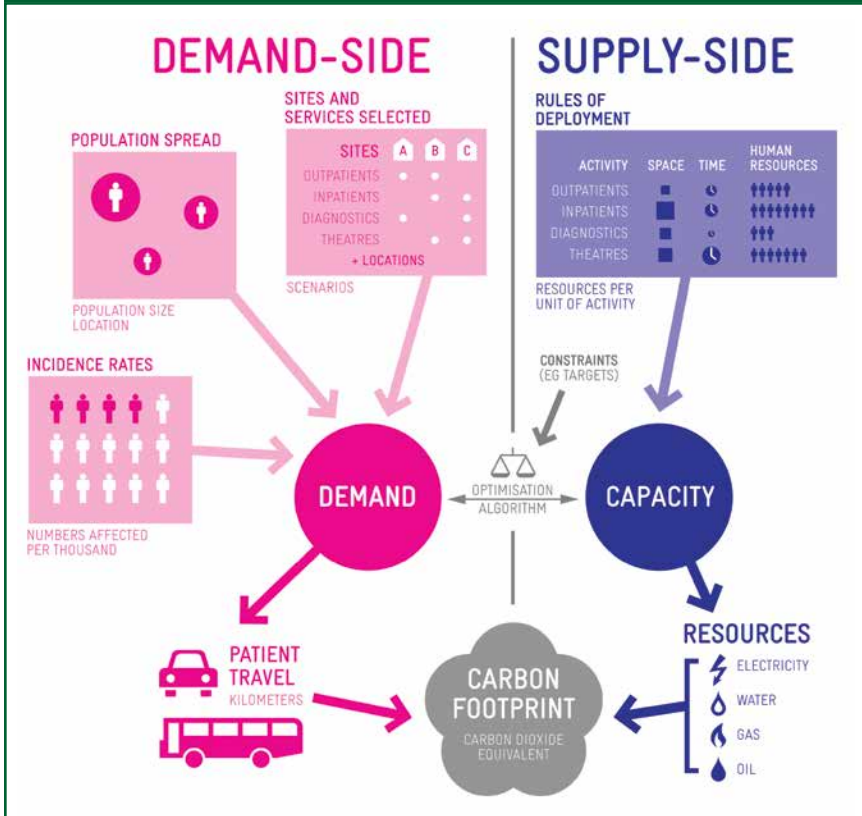
The broad mechanics within the model are as follows. Widely available healthcare data is used to determine the demand for services at sites considered for provision of clinical facilities. Initially, this demand is converted into a currency into which it may be compared against the capacity available on site assuming services are run in ‘business as usual’ manner. Any capacity gap (in terms of physical space, resources, and staff) is then addressed through conversation with hospital management and clinicians, and iteratively remodelling with the tool to determine a ‘best fit’ solution which satisfies issues around carbon reduction, patient care, maximum utilization of resources, and affordability. Consequently, demand-side and supply-side elements of the model are run independently.

The data types used by the carbon foot printing capability of the model were outlined by Pollard *et al.* (2013). However, in simulating the cost base of healthcare provision, additional data regarding the origin of these costs, (for example the rules by which human resources are deployed) must be considered. Where possible the model utilizes datasets which are generally available. However, values unique to a locality ideally need to be used although they can be initially estimated using national averages. The model is not unlike any other in that for its output to be sensible and useful, the input data needs to be realistic and accurate.

In more detail

Healthcare is delivered within a variety of arenas each having a unique complexity with regard to the conceptual and numerical models required to replicate them. With regard to secondary healthcare in the NHS, which was the subject of the study by Pollard *et al.* (2013), these arenas comprise outpatients, diagnostic tests, therapeutic interventions, operating theatres, and inpatient wards. As a patient enters secondary healthcare, he or she will access one or more of these arenas per episode of care. Because secondary healthcare is commonly regarded as one of the more resource-intensive domains of the NHS, significant investment

Figure 1: Conceptual Diagram of the Solution Used within the Carbon Model



Source: Pollard (et al.) 2013

has been made in recent times to facilitate management of patients outside of secondary healthcare, whether through schemes designed to avoid admission to hospitals or to bring on earlier discharge of patients from them. Consequently, the scope of Pollard's secondary care model includes community hospitals which, in some areas of the UK, can treat the less complex conditions and house patients towards the end of their recovery from surgery or from medical admission, but are not in a condition in which they can return safely to their normal place of residence.

In order to determine the workload of each site earmarked for the provision of healthcare, whether in a community hospital, acute hospital, or GP surgery, the distribution of the local population must be considered. Without this, it is not possible to model the emissions generated by patient transport. Build on the conceptualization of demographic spread, the model calculates the distance from each potential patient to each site at which services might be located. As

scenarios are built up of differing combinations of sites, there expected travel time and distance can be aggregated accordingly. The model also allows for the provision of selected services at certain sites, which may be driven by services consuming expensive resources for small numbers of patients. Consequently, the balance between the centralization of such services and the burden to patients can be assessed using the model.

To calculate the patient transport needs for each service reconfiguration, the model converts demand for services at each site into the resources required at each site. The work areas modelled in the secondary care model include clinics (for outpatients), theatres and recovery bays (for procedures), beds (inwards), and diagnostic machines and rooms for diagnostic tests. A similar framework has been constructed for the geographical provision of dentistry, which has been piloted in Scotland using dental surgeries as the work area unit.

To ascertain whether the capacity at each site is sufficient to serve the demand likely to alight at each location, units must be chosen which are common to both measures. For example, outpatient demand can be converted to time by using the anticipated duration of each appointment type. If a site's outpatient capacity is expressed in terms of the same unit of time, an assessment can then be made as to whether a configuration of outpatient services per site is sufficient to serve anticipated patient demand.

The current or baseline capacity per service per site, $C0_{ij}$, can be calculated at each site by using inputs from those delivering the service, whether they be clinicians or managers. The baseline capacity can be expressed as:

$$C0_{ij} = W_{ij} X_{ij} Y_{ij}$$

where,

W_{ij} is the days per year that service 'i' is offered at site 'j'

X_{ij} is the time that service 'i' is offered at site 'j' per day

Z_{ij} is the number of units (clinic rooms, bed, theatres, diagnostic testing machines) available to service 'i' at site 'j'

Each of the variables defined above can be changed if the capacity at each site is insufficient to meet the demand anticipated, or, if it is likely that too much capacity is programmed to materialize, resulting in waste and unnecessary cost. Iterative use of the model is recommended for 'stepping through' scenarios which have different ways of working, each of which will be analysed for cost, their anticipated emissions, and their expected impact on patient access and outcomes.

With each element of capacity there is a need for resources — in terms of staff, capacity, and equipment. This enables an estimation of the cost, staffing requirement, and carbon footprint of delivering services for each scenario tested. Sites at which services are held may be varied as per the scheduling rules and

manner in which the staff is deployed at each site, leading to variations in capacity at each site assessed for cost and carbon output. A sensitivity analysis then materializes from the output that the model generates for each service configuration, enabling a judgement to be made on which service configurations would enable a healthcare provider best deliver on cost, emissions reduction, and patient access.

Although the model presents expected levels of need and the capacity required to deal with local demand, its modular nature allows for the periodic variability in need to be accounted for, which is vital for planning services. Predicted capacity requirements may then be adjusted to tolerate unseasonal variation. Although it is impossible to ensure sufficient capacity with total certainty, it is possible to make inferences on the capacity needed with a high level of confidence, for example, for 98 per cent of the time using historical data. Such adjustments in the model's predictions will minimize treatment delays within the redesigned system caused by variation in the need for treatment.

The findings to date

Given that the testing grounds have been in rural or semirural geographic regions within the UK, early indications suggest that geographical service reconfiguration has and will continue to have a larger effect on the sustainability of healthcare than undertaking less radical measures, such as gradual switching to low energy light bulbs. As the NHS drives to reduce its carbon footprint by 80 per cent by 2050, the case for radical redesign may be strong. However, radical redesign is likely to incur significant capital outlay. The key strength of the Pollard Model is that it allows those delivering and planning healthcare services to demonstrate how working differently contributes to the aggregated performance of an organization with respect to meeting its targets, whether financial or environmental. The Pollard Model makes clear to those who “do their bit”, how their work contributes to the wider organizational picture and to the net rate of return on any capital investment.

The inclusion of greenhouse gases emitted from patient transport included in the carbon footprint of healthcare organizations invites consideration of the boundaries inside which the carbon footprint of healthcare should be calculated. Questions around model scope could be extended to examining whether the complete life-cycle of goods procured by the healthcare system for the treatment of its patients should be in the carbon footprint of healthcare organizations. In the study of Pollard *et al.* (2013), which considered the delivery of secondary healthcare in Cornwall around outpatients, diagnostics, theatres, and inpatient wards, it was found that per patient treated, patient transport comprised the most significant proportion of carbon footprint despite outpatient services being the most decentralized. This was due to the utilities consumed in the delivery of the remaining modalities of care. Even so the Cornish study encompassed approximately 30 per cent of the carbon footprint of delivering secondary healthcare in Cornwall.

Expansion of the model to include the procurement of goods used by a healthcare organization is possible, but is difficult to achieve using the bottom-up principles. Healthcare is thought to be interconnected with eight broad sectors either upstream or downstream (Huang *et al.* 2009), each of which would have to be modelled 'bottom-up' if the complete life-cycle of supplies were to be included in the model's scope. Patient transport, on the other hand, is less difficult to include due to finite number of residents within each geography and a simple relationship between the distance travelled between each patient and facility and the time it takes each patient to travel for the treatment.

Whereas the baseline condition in the original study by Pollard *et al.* (2013) assumes that patients were treated at their closest point of healthcare delivery, use of the Pollard model in quantifying possible savings in delivering dental care within Fife, Scotland assumed a different baseline for patient travel (Duane and Pollard 2013). Results from a patient travel survey were used, which illustrated the impact of patient choice versus the scenario where patients were treated at the site closest to their domicile. In effect, actual patient journeys aggregated to approximately double the case if patients were treated at the site closest to their domicile.

With regard to the cost savings possible through reconfiguration, the Fife study demonstrated that through increasing the utilization rate of dental surgeries it was possible to rationalize the number of sites at which dental surgeries were located. Interestingly, any increase in patient travel incurred through reducing sites from 22 to 13 was less than the savings expected through redirecting patients to their nearest site for treatment.

In the case of patient travel, the Fife study quantified the electricity required for delivering dental services to Fife's residents. As the number of dental surgeries was increased or decreased, the electricity which was proportionate to the number of patients treated remained constant between each scenario, whereas fixed power per site varied with the number of sites modelled.

The Fife study also looked at the clinical staff required for each service reconfiguration. Given that in theory, significant human resource savings could be possible through rearranging services, whilst maintaining patient safety and standards of care. A question must be asked whether a study might be worthwhile, which quantifies the long-term effect on healthcare, if services are geographically reconfigured with resulting savings recycled into preventative medicine.

To realize the significant gains in terms of cost and carbon reduction that service redesign might bring, it is likely that capital investment would be necessary. A key feature of the Pollard model is that it allows those providing healthcare services to demonstrate the effect that operational changes might have on the 'triple bottom line'. As a consequence, the Pollard model acts as a vehicle by which the net rate of return of investment may be calculated and adjusted as different ways of working are considered.

Conclusions and Future Directions

The Pollard model has been validated as being fit for the purpose of simulating how the cost and carbon footprint of healthcare delivery might vary with different ways of working. As part of this capability, it demonstrates the degree to which the burden shifts between patient and healthcare organization as services are redesigned geographically. It represents a unique opportunity for those delivering and commissioning health care services to show whether or not aspirational changes in cost base or emissions are achievable and what changes at the point of care will be necessary to make aspirational targets.

The Pollard Model is able to identify the resources required at specific geographical locations to meet the care needs of the population. This need can be partitioned by the urgency at which it is required resulting in health and social care, comprising a multi-faceted, complex system. To avoid system bottlenecks and capacity shortfalls, the rate at which these resources are deployed for the less-urgent care can be scheduled around the need for immediate and more pressing treatment. In addition, simulations depicting alternative care practises; e.g., domiciliary care and empowering patients to self-monitor their conditions, could be deployed in ascertaining the best use from geographical configurations once they are discovered. Moreover, this exercise may involve iterative simulations ‘homing in’ on what will be best practice within and across a number of inter-linking care sectors. To facilitate this, a suite of software packages will be constructed around the Pollard Model.

Finally, it is important to note that the approach described here is not limited to reducing the carbon footprint or increasing the sustainability of healthcare systems in high-income countries alone. The model can be used to improve other environmentally damaging and inefficient public services and business operations, and is also suitable for deployment in lower-and middle-income countries, providing reliable data can be gathered. The Pollard model therefore represents an additional highly versatile tool to aid in the construction of a more sustainable world.

Acknowledgements and Funding

Dr Paul Upton, Medical Director, Royal Cornwall Hospitals NHS Trust; Mark Summers, Head of Low Carbon Unit, NHS Cornwall and Isles of Scilly; Stephen Sherratt, Chief Executive, Pollard Systems, Ltd and Director, SoupDragon Resources Ltd.

The European Centre for Environment and Human Health (part of the University of Exeter Medical School) is supported by investment from the European Regional Development Fund and European Social Fund Convergence Programme for Cornwall and the Isles of Scilly.

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