**Modelling national scale events: What lessons can we learn from the Covid-19 pandemic?**

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**Abstract**
This paper reviews the handling in the United Kingdom of the Covid-19 pandemic. It examines the daily official statistics that feature in news bulletins and considers how these relate to the spread of the virus in hospitals, care homes and the community. It considers the reporting of figures from computational models and how the aggregated statistics potentially present a misleading picture to the public about deaths, testing and infections. It identifies a number of significant weaknesses in the handling of information during the event and the need for improvement in information management and governance. A number of recommendations are presented for improvements in the handling of national scale high impact events.

**Introduction**
The spread of Covid-19 has presented serious challenges for national and regional governments when seeking to implement appropriate and proportionate policies to manage the spread and its impact. The approaches adopted have varied significantly between nations which raises the question of what the best strategy is to manage such incidents. In press briefings given by ministers and officials in the UK and elsewhere it has been said that the policies are based on following the science.

The UK Government apparently considers that the "science" of this epidemic is reflected in mathematical modelling undertaken by a team at Imperial College, London, whose forecast of 500,000 deaths is said to have prompted the adoption of a lockdown policy. At the same time the Swedish government based on scientific advice has pursued a public information and social responsibility approach, aiming to avoid the impact that lockdown has on individuals and the economy. These are two very different interpretations of epidemiology and the science behind the spread of Covid-19.

This paper is based on analysis of publicly available information [1, 2, 3] and explores the handling of the pandemic in the UK from a systems thinking perspective [4] and the application of a basic control systems approach to the problem. It then reviews what is known about the modelling undertaken by the Imperial College team. The paper then examines how the official statistics released on a daily basis relate to a simple ecosystem model of the country and spread of the virus in different environments. It discusses how changes to the management regime could improve our response to the spread of Covid-19.

**Applying control systems theory**
There is some ambiguity about when the spread of Covid-19 started. The narrative adopted by national governments is that the spread started in Wuhan and is associated with the Huanan seafood wholesale market [5]. However, a recent report from France [6] following retesting of a sample taken on 27$^{th}$ December 2019 suggests it may have been spreading for longer. This assertion is supported by an article in the South China Morning Post [7] and research findings that a number of strains exist [8] with varying symptoms and severity [9].

From a control perspective during the initial spread, the UK, USA and Europe comprised an open loop system as illustrated in Figure 1. Borders remained open and there was little or no quarantine or testing of travellers entering a western country. There was no effective restraint on the import of the virus by infected and infectious travellers. Detection of Covid-19 infections was through limited public health surveillance activities, medical practitioners identifying infected patients based on published symptoms and for hospital patients the laboratory testing and investigation of samples.

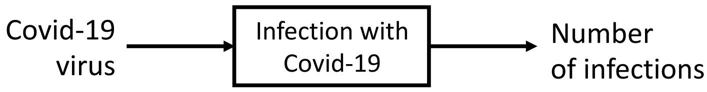


*Figure 1 - Open loop system, no controls*

As the level of infection and deaths increased in Wuhan, the Chinese authorities imposed strict control measures, including travel restrictions, track and trace of those potentially infected and lockdown of a number of cities [10]. Citizens in western nations became more aware of the potential spread as the media coverage increased [11]. Despite a worsening situation in China and evidence of international spread, the largely unrestricted global flow of travellers continued. On 22nd January 2020, Public Health England announced "enhanced monitoring" for all direct flights from Wuhan would be deployed, requiring arrivals to be checked for Covid-19 symptoms [12]. Airlines responded by suspending flights from mainland Chinese cities [13]. In addition to the above limited travel-related measures the UK government publishing hygiene advice on handwashing to limit virus spread, guidance for primary care [14] and on environmental cleaning following a possible case [15]. Effectively the open loop control continued (Figure 2) with infected travellers seeding the spread in the UK.

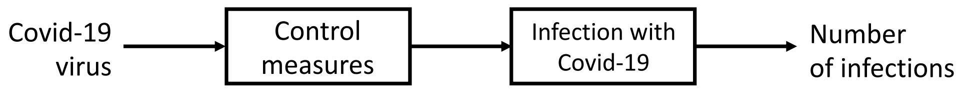


*Figure 2 - Open loop system, public hygiene advice*

On 31st January 2020 [16] there were the first reporting of two confirmed Covid-19 infections in the UK. The Chief Medical Officer for England is reported as saying: "*We are using tried and tested infection control procedures to prevent further spread of the virus. The NHS is extremely well-prepared and used to managing infections and we are already working rapidly to identify any contacts the patients had, to prevent further spread*." [17] The control metric was the number of infections, presumably based on patients presenting themselves for treatment by the health service and testing positive for Covid-19.

It is unknown at the end of January how many UK residents had been exposed to the virus, but the number of infections started to increase. Eight cases were identified by 10th February [18] and two medical practices closed in Brighton [19] one for cleaning and the other due to infection of medical staff. One of infected Brighton residents was diagnosed as contracting the virus in Singapore and was later linked to 11 other cases, five of which were in the UK [20]. Quarantine was employed as a control measure for 83 people repatriated from Wuhan, who were released when negative test results confirmed they were virus free [21].

The first UK Covid-19 related death was reported on 5th March [22], followed by a second on 7Th March [23]. The focus of the control metric appears to have shifted to deaths rather than infections. Both the deceased had apparently not recently travelled outside of the UK, indicating a spread of the virus in the community. The control approach moved to an embryonic close loop approach (Figure 3) where attempts were made to track and trace contacts, with testing to confirm whether they were infected. The Prime Minister's official spokesman stated that it was "*highly likely the virus is going to spread in a significant way*" [24]. Given the evidence from Asia of the infectious nature of the virus, this is indicative of an apparent lack of knowledge about the existing virus spread in the UK.

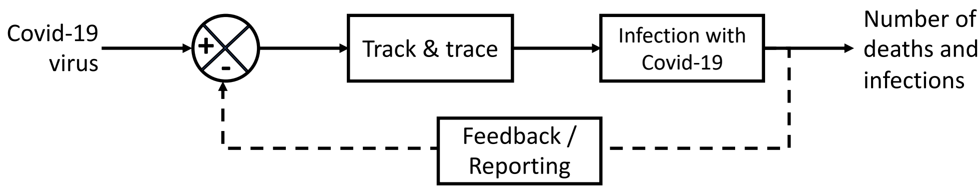


*Figure 3 - Initial "closed loop" model*

On 16th March the UK control model shifted towards isolation and social distancing as the control measures (Figure 4) with announcements that people should avoid all non-essential contact [25]. Then on 20th March, closure of all bars, pubs, cafes and restaurants [26] and the subsequent closure of schools [27] was announced. On 23rd March the Prime Minister announced that a lockdown would commence the following day; this unprecedented move was supported by emergency legislation [28].

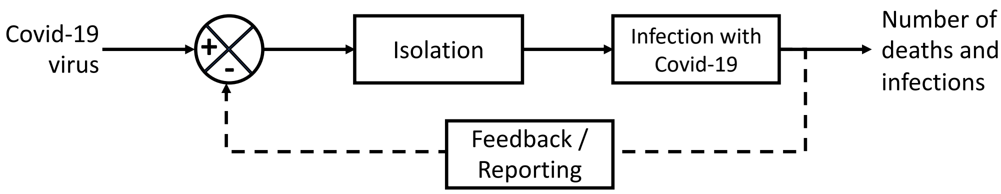


*Figure 4 - Modified "closed loop" model*

Although Figures 3 & 4 are referred to as closed loop, they are 'leaky' models, i.e. not all infections are detected and/or reported, so there are questions about how effective and timely the feedback was.

**Computer/Computational modelling and its role in the event**

The event has been accompanied by headlines reporting the projected number of deaths likely to occur from the spread of Covid-19. For example, The Sunday Times reported: "*It was team Ferguson's research paper of March 16 that prompted the lockdown, warning that without it more than 500,000 people could die. It also projected that a full lockdown of the kind now in force could reduce that to less than 20,000*" [29]. From a medical perspective, computer modelling and simulation refers to: "*the process of constructing and manipulating computer-based mathematical, graphical or algorithmic representations of real life systems or phenomena, for the purpose of conducting computer-based simulations to study, predict or optimise the behaviour of the system(s) / phenomena under consideration*" [30]. The model itself may be regarded as an abstract representation of the system(s) or phenomena, that has been created for a specific purpose. It is however only a projection or opinion based on assumptions about the virus, its spread and the impact on infected individuals.

When designing a computational model, the developer typically works through a series of steps:

> "*Step 1. Identify the problem.*
> *Step 2. Formulate the problem.*
> *Step 3. Collect and process real system data.*
> *Step 4. Formulate and develop a model.*
> *Step 5. Validate the model.*
> *Step 6. Document model for future use.*" [31]

Although this suggests that model development is a single series of steps, in practice it should be iterative, with the underlying hypothesis and assumptions tested against collected data and validation employed to assure the model as well as assess deviations between predicted and observed outcomes.

As part of the model definition, the developer will make a series of assumptions about how the system(s) or phenomena perform. These key design decisions may be reflected in specific aspects of the model software, e.g. the algorithms used, or as parameters that may varied during simulation experiments. The model documentation should provide: "*the developer's description of what the model or simulation will represent, the assumptions limiting those representations, and other capabilities needed to satisfy the user's requirements*" [32]. Whilst "*Step 5*" refers only to validation, best practice is the verification and validation, the former answering the question "*Have we built the model right?*" the latter answering the question "*Have we built the right model?*" [33].

The need for rigour in the design and assurance of computer models is recognised by the UK Department for Business, Energy & Industrial Strategy (BEIS). In its guidance on quality assurance for models [34] it sets out a development and assurance process "*to ensure that policy decisions are underpinned by a sound understanding of all relevant evidence, including associated risks and uncertainties*". In another official report on modelling produced by the UK Government Office for Science, it recommended that: "*Decision-makers need to be intelligent customers for models, and those that supply models should provide appropriate guidance to model users to support proper use and interpretation. This includes providing suitable model documentation detailing model purpose, assumptions, sensitivities, and limitations, and evidence of appropriate quality assurance*." [35]

Where computational modelling is used in engineering and scientific applications those that have been verified and validated can deliver results very close to practical measurements of the phenomena. This is achievable where the nature of the phenomena, be they physical, electrical, chemical, radiological, etc., are well understood and the models have been though a number of iterations to fine tune algorithms and parameters. This is not the case with Covid-19, which until a few months ago was an unknown agent and about which there are a number of uncertainties [36].

Given the BEIS guidance, where a model is to be used to influence UK policy and shape handling of the response to a national event, it would be reasonable to expect that the software: was developed using trustworthy software principles [37]: has been documented; was subject to verification and validation; and is available for review and/or audit by experts. This appears not to be true in this case as the model apparently "*consists of several thousand lines of dense computer code, with no description of which bits of code do what*". In agreeing with this statement its developer, Professor Neil Ferguson, stated in an interview: "*For me the code is not a mess, but it's all in my head, completely undocumented. Nobody would be able to use it . . . and I don't have the bandwidth to support individual users*" [38]. On Twitter, he posted the following: "*I'm conscious that lots of people would like to see and run the pandemic simulation code we are using to model control measures against COVID-19. To explain the background - I wrote the code (thousands of lines of undocumented C) 13+ years ago to model flu pandemics...*" [39].

Subsequently, when a refactored version of the code was made available online [40]. Typically refactoring is intended to improve readability, reuse and structure, without affecting the meaning or behaviour. It was revealed that the original code comprised a single file of 15,000 lines of code [41]. A review [42] of the repository and some of the issues being raised about the refactored code highlights software design and quality issues. For example, testing of this software by a team from Edinburgh University identified a bug [43], which yielded a variation of approximately 80,000 deaths over an 80-day period. This was dismissed as a known issue by one of the Imperial College team.

These short comings in the development and assurance of the model might be set aside if the modelling team had a history of producing reliable predictions. As highlighted in the press [44] and illustrated in Table 1 with supporting references, the track record of such modelling is poor with excessive gaps between the predictions and the actual deaths.

| Year | Disease | Predicted deaths | Actual deaths |
|---|---|---|---|
| 2005 | Bird Flu (H5N1) [45] | 200,000,000 (Global) | 374 [46] |
| 2009 | Swine Flu (H1N1) [47] | 65,000 (UK) | 457 [48] |
| 2000 | vCJD [49] | 136,000 (UK) | 178 [50] |
| 2002 | BSE [51] | 50,000 (UK) | |

*Table 1 – Epidemic/Pandemic Predictions*

**Understanding the Official Statistics**

UK public authorities are publishing a number of data sets relating to the deaths in the UK, Covid-19 related or not, infections, testing, and hospital bed occupancy. The relationship between the data sets is ambiguous as there are issues regarding the definitions employed for individual sets, the quality measure supporting their capture and the timeliness of reporting. A number of these issues are illustrated below.

<u>NHS Reporting</u>

NHS England release daily data on the Covid-19 daily deaths [1], which relates to: "*deaths of patients who have died in hospitals in England and had tested positive for COVID-19 or where COVID-19 was mentioned on the death certificate. All deaths are recorded against the date of death rather than the date the deaths were announced.*" The figures reported are a composite of deaths "*from the latest reporting period, 5pm 2 days prior to publication until 5pm the day before publication.*" This leads to a potentially confusing situation where the press is reporting the number of deaths "today" but the figure for deaths that actually occur on the reporting date will not be known for some time. This disparity is increased by the fact that the NHS England report only applies to deaths in hospital and excludes those in care homes or the community.

Examining the daily deaths in hospital data published by NHS England [52], the data as at 7th May reveals that in English hospitals the peak number of Covid-19 deaths was 874 on 8th April, which as shown in Table 2 is the aggregated deaths reported by NHS England over a 28 day period. On 9th April, the first day on which deaths the preceding day were reported, a total of 765 new deaths were reported, but of these only 140 occurred on 8th April. The differences between the number reported on a day and the latest outturn for that day are illustrated in Figure 6. This chart shows how the declining number of deaths in English hospitals is not reflected by the aggregate new deaths figures in the daily release. In practice the figures are potentially misleading if not appropriately interpreted, for example, in the period 21st – 25th April, media reporting could swing between extremes.

*Note: The data supporting Figures 5, 6 and 7 and listed in Table 2 were derived from the whole of England total on the COVID19 daily deaths by region tab of the Covid-19 daily announced deaths spreadsheets published by NHS England [1].*

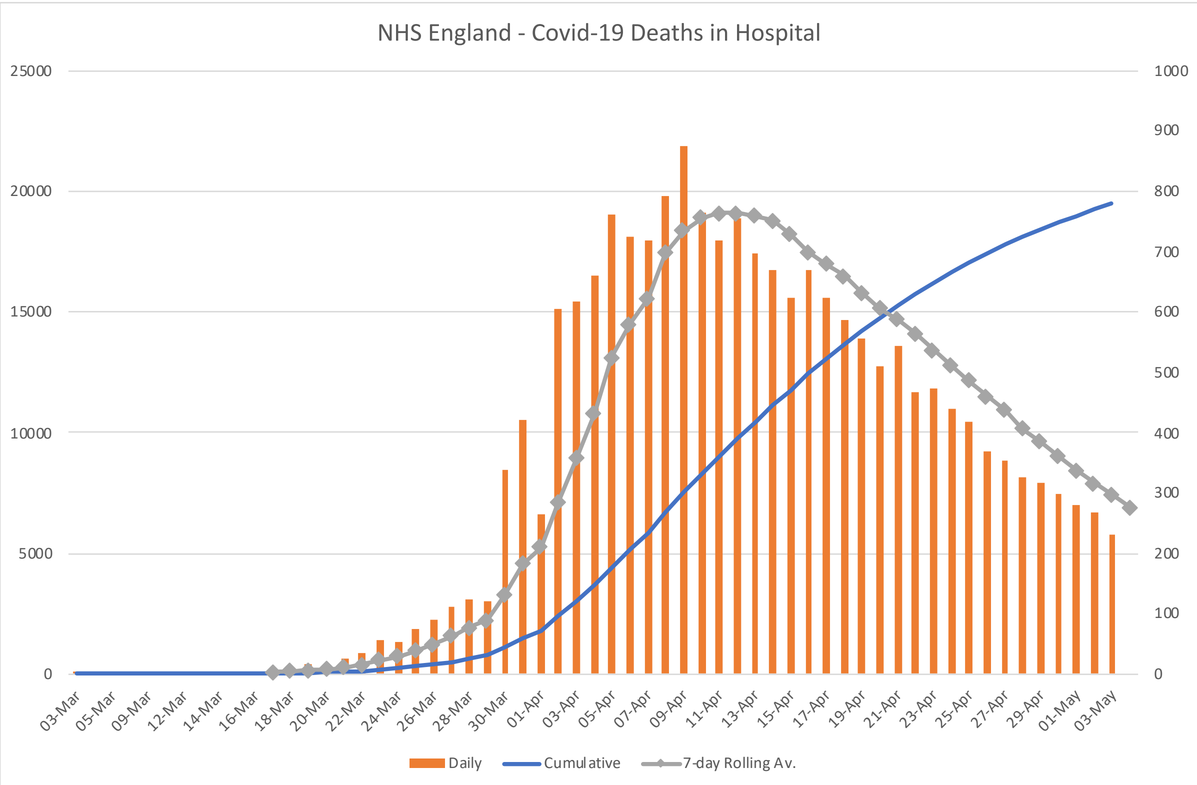


*Figure 5 - Daily deaths data - subject to further revision due to reporting lag*

| Date Reported | Deaths reported | Reporting Lag |
|---|---|---|
| 09/04/2020 | 140 | 1 |
| 10/04/2020 | 356 | 2 |
| 11/04/2020 | 161 | 3 |
| 12/04/2020 | 52 | 4 |
| 13/04/2020 | 28 | 5 |
| 14/04/2020 | 13 | 6 |
| 15/04/2020 | 21 | 7 |

| | | |
|---|---|---|
| 16/04/2020 | 11 | 8 |
| 17/04/2020 | 10 | 9 |
| 18/04/2020 | 7 | 10 |
| 19/04/2020 | 2 | 11 |
| 20/04/2020 | 2 | 12 |
| 21/04/2020 | 12 | 13 |
| 22/04/2020 | 13 | 14 |
| 23/04/2020 | 3 | 15 |
| 24/04/2020 | 10 | 16 |
| 25/04/2020 | 14 | 17 |
| 26/04/2020 | 2 | 18 |
| 29/04/2020 | 2 | 21 |
| 30/04/2020 | 4 | 22 |
| 02/05/2020 | 1 | 24 |
| 03/05/2020 | 3 | 25 |
| 05/05/2020 | 4 | 27 |
| 06/05/2020 | 3 | 28 |
| Total | 874 | |

*Table 2 – Breakdown of deaths on 8th April by date reported, as disclosed at 6th May*

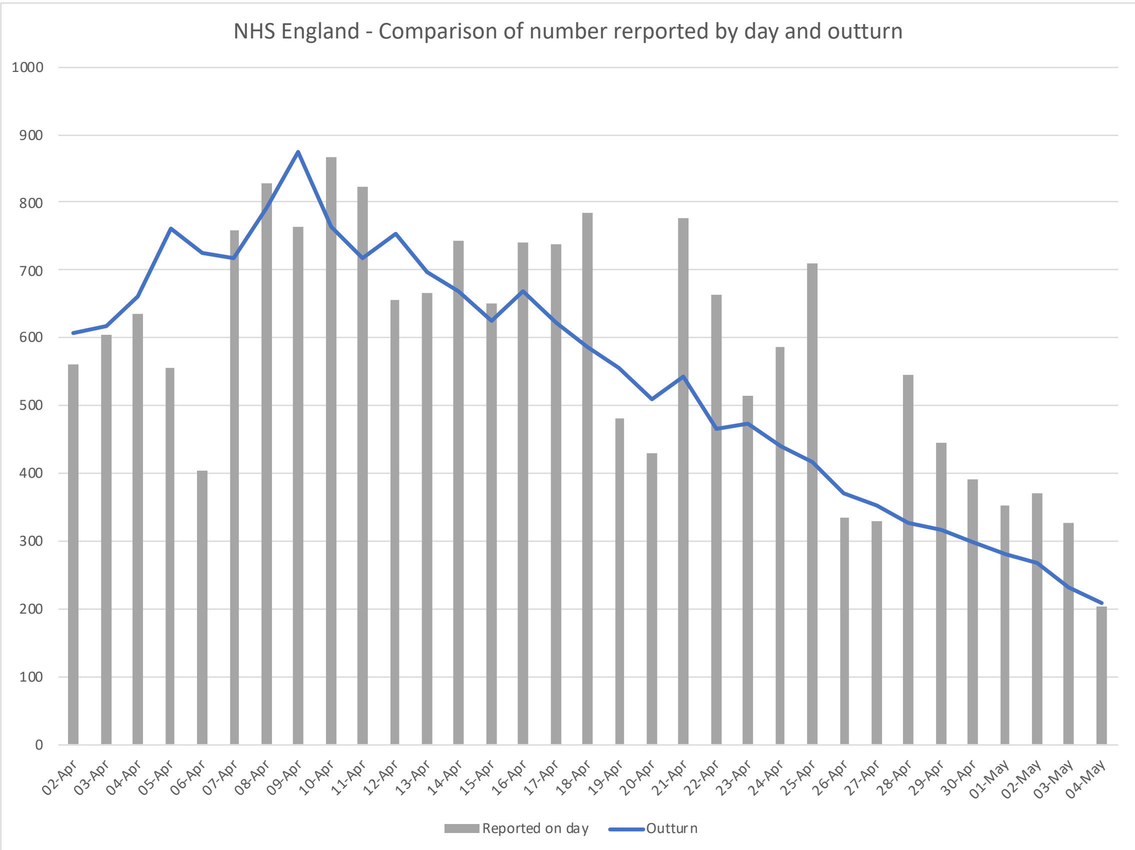


*Figure 6 - Reporting comparison*

The reporting lag has a significant effect on the totals reported. The number of "in hospital" deaths reported on a specific day is typically within 90% of the total outturn figure on the eighth day after the death occurred. As illustrated in Figure 7 there is a long tail on this reporting lag, with deaths being reported up to 54 days after they occurred.

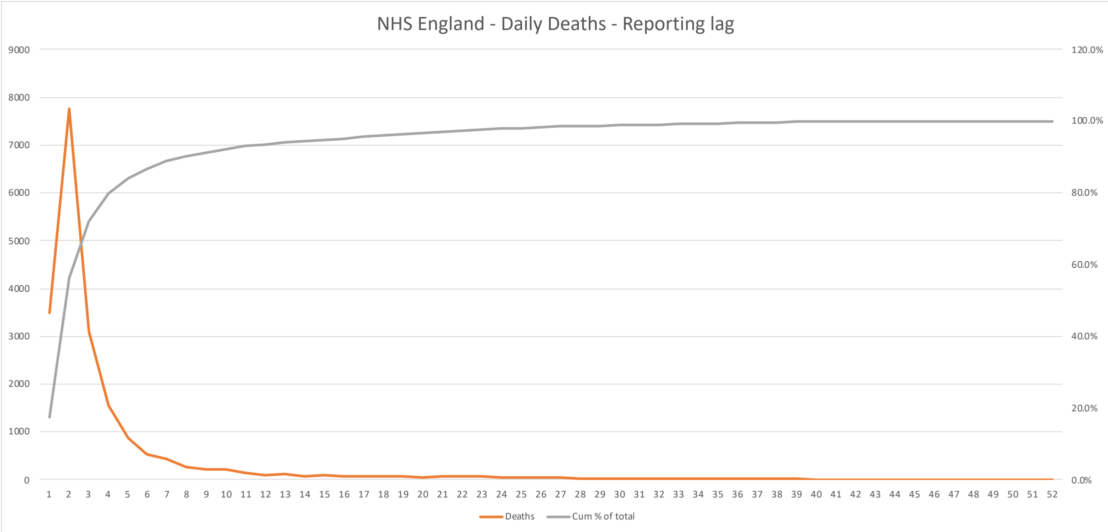


*Figure 7 - Reporting Lag - date of death to inclusion in daily figures*

<u>Cabinet Office</u>

The UK Government provides daily press briefings and releases a set of slides and supporting data for each briefing. The discussion below takes a snapshot of the data presented at the briefing on 6th May. The number of new Covid-19 cases is potentially a key factor in the policy regarding lockdown and the stated need to “save lives, protect the NHS”.

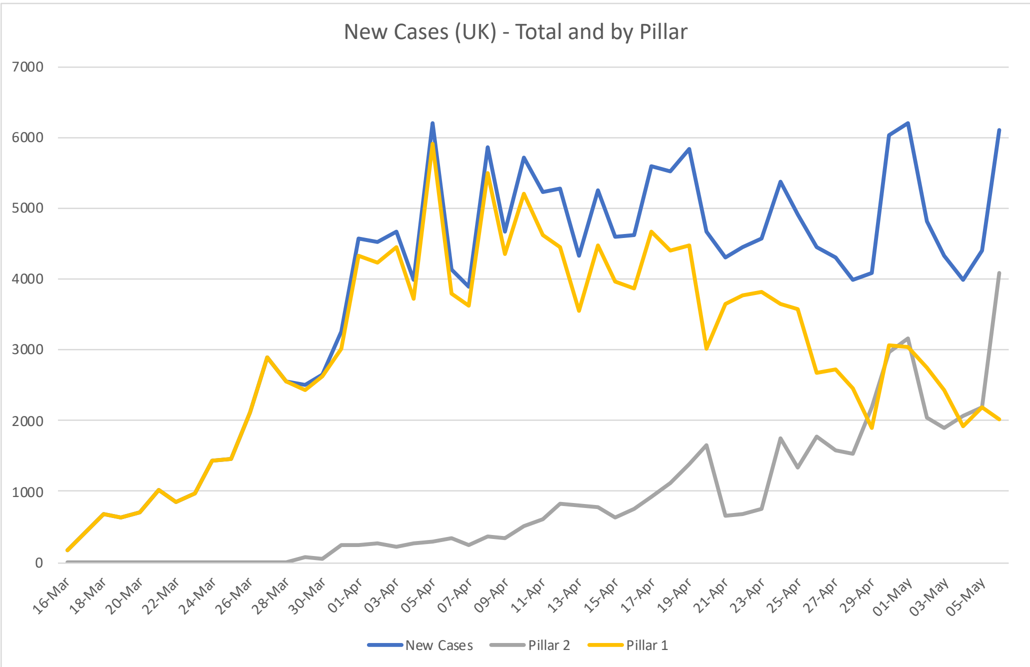


*Figure 8 - UK Government reporting of new Covid-19 cases*

The volume of new cases since 29th April could suggest that the virus spread continues unabated, but according to the slides [53] and data [54] released for the press briefing on 6th May, the number of Covid-19 related patients in UK hospitals has fallen from a peak of 20,686 on 12th April to 12,481 on 5th May. The data shows that in striving to reach the Health Secretary’s target of 100,000 tests per day [55], the increased testing for Covid-19 has identified more cases of infections, as illustrated in Figure 9.

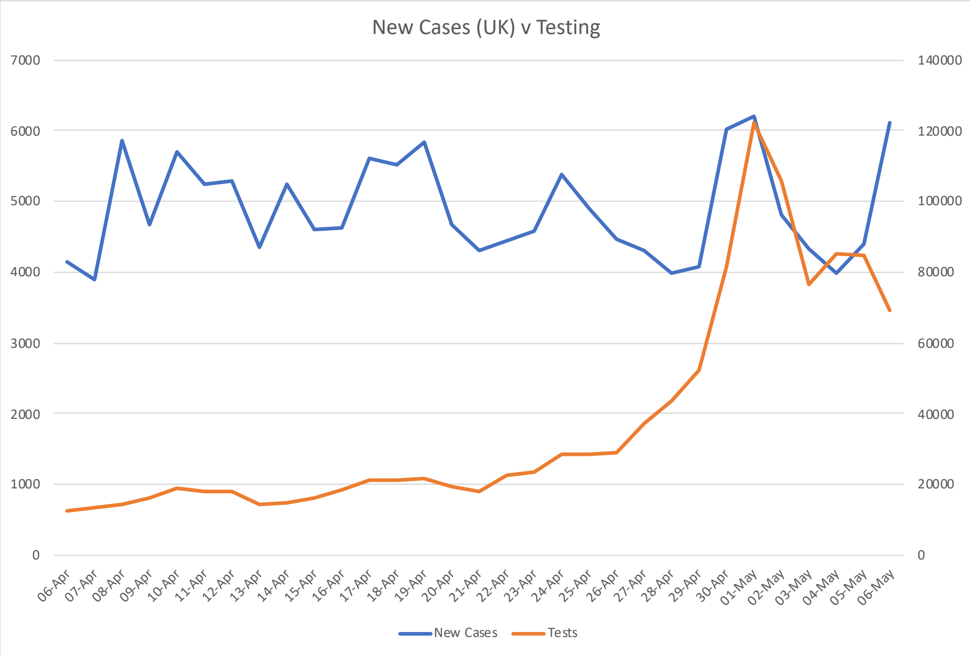


*Figure 9 - UK Government data on new cases and testing*

<u>UK Office for National Statistics (ONS)</u>

Compared to the NHS England Covid-19 deaths, the ONS publishes statistics for all deaths where Covid-19 was mentioned on the death certificate. The data published by ONS on 5$^{th}$ May [56] allows comparison of the NHS England data with the provisional total Covid-19 related deaths in England, this is illustrated in Figure 10. The provisional data shows that for deaths registered by 2$^{nd}$ May, 19,033 deaths had occurred in hospital and 28,272 occurred in total. Thus, a third of the deaths (9,239) occurred in care homes or the community. There are a number of supporting notes regarding the mortality statistics set out on the page from which the data set was downloaded [57].

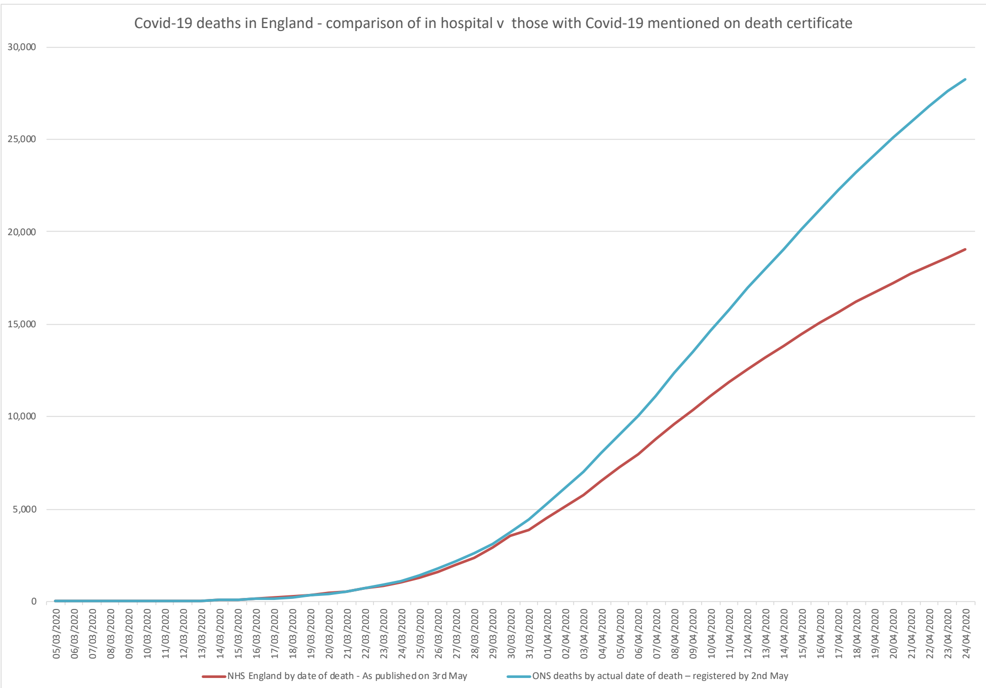


*Figure 10 - Comparison of total Covid-19 deaths reported in England with NHS England figures*

Excess Deaths

There are concerns that ONS figures may not fully represent the deaths associated with Covid-19, For example, an analysis [58] suggests that 11,277 excess deaths occurred in England and Wales during the period 21 March–24 April (35 days). The analysts suggest that such figures, whilst open to interpretation, may help us to understand the full impact of COVID-19 on mortality, including deaths indirectly related to COVID-19, for example those arising from delays in seeking medical care for other conditions. Other analysis by medical researchers demonstrates the rapid increase in deaths from all causes during April 2020 [59]

**Interpreting the relationship between Official Statistics and virus spread**

In viewing the various statistics identified in the preceding section, the complexity of the underlying physical 'system' is not evident. Figure 11 seeks to put the statistics in context by illustrating how individual statistics relate to the physical location of individuals in England. This Figure establishes a series of paths that an individual may follow having come into contact with the Covid-19 virus. It illustrates the serious information management challenge facing those trying to prevent further infection and/or manage those already infected.

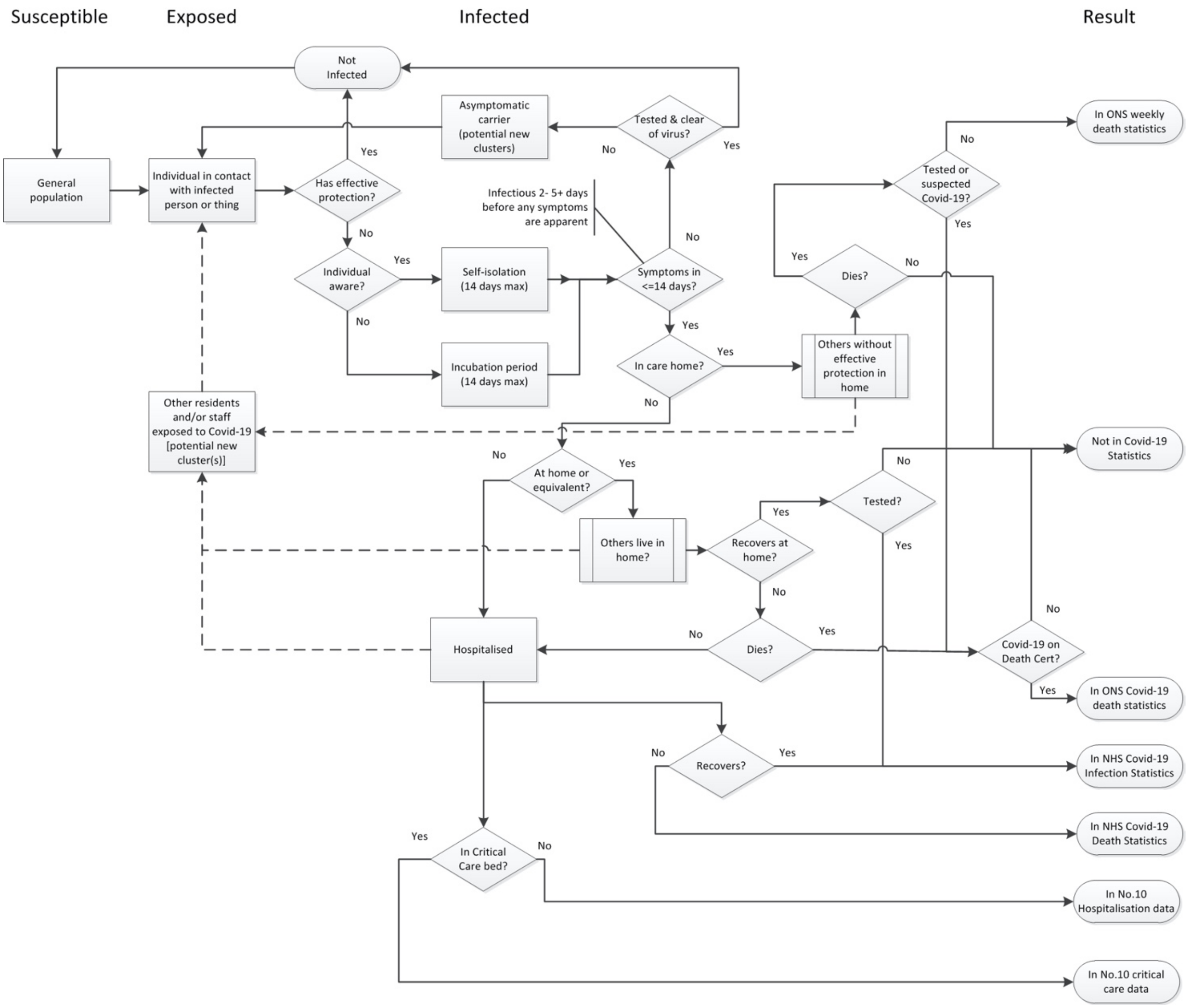


*Figure 11 - Flow chart modelling potential relationships between Official Statistics*

A complicating factor in seeking to control spread is the time interval between an individual being exposed to the virus and the emergence of symptoms. It has been stated that in the period 2 to 3 days [60] before appearance of first symptoms an individual may be spreading the virus to others, with infectiousness declining significantly 8 days after symptom onset. The research also indicates that if you cannot trace over 80% of the infected individual's contacts, you will lose control of the spread. If we examine the three dotted lines this implies that while asymptomatic:

a) in a care home setting a staff member or resident may be spreading infection to other residents and/or staff;
b) in a hospital setting, an individual whether a patient or not, may be spreading it to other hospital users and staff;
c) in both the above settings staff may carry the infection into their homes; and
d) in a domestic setting a family member or other resident may be spreading it to other occupants.

In these scenarios if testing only occurs when individuals report having symptoms then it is too late as they may have already infected a number of other people, i.e. pushing the reproduction rate ($R_e$) over 1.0 and sustaining the continued growth of community infection. The current English lockdown arrangements do not mitigate (a), (b), or (c) above as the contacts are not social contacts, they are a product of the medical or social care situation, or the individual's employment.

Another observation is that the various statistics do not identify the degree to which the population may have already been exposed to, caught and recovered from the virus without seeking medical attention or being tested. A research paper postulated [61] that a significant proportion of the population may fall into this category, which would be reflected in Figure 11 through the "Not in Covid-19 Statistics" outcome. There is some research now underway to explore this category [62, 63]

**Information Management and Governance**

As an island nation the UK has a complex management structure for health and social care, compounded by the responsibilities for reporting by Whitehall and the devolved administrations. The management of an event, like the spread of Covid-19, involves complex spatio-temporal information, with a need for an integration data model approach to support analysis of data supplied by national and local organisations. The latter is necessary to combine contextualised information from three distinct but interdependent environments: hospitals, care homes (and similar institutions) and the wider community. In reviewing the published data and accompanying notes, it appears that the different reporting chains at administration and national level leads to inconsistent infection, death and testing data sets.

In considering the data notes for the press conference held on 6$^{th}$ May, in respect of the "Daily tests (UK)" data [64], the notes state that:

a) "*For clinical reasons some people are tested more than once. Therefore the number of tests completed may be higher than the number of people tested.*"
b) "*For serology testing (Pillar 4), some protocols allow for samples to be tested repeatedly. Samples are anonymised prior to sending to the lab for testing, therefore*

*the identification of individuals tested is not possible in the current reporting process, and so the number of people tested is not reported.*"

c) "*Daily totals reflect actual counts reported for the previous day. Each day there may be corrections to previous reported figures. This means that previously published daily counts will not necessarily sum to the latest cumulative figure. It also means that today's cumulative count may not match the previous day's cumulative count plus today's daily count.*"
d) "*The number of tests includes; (i) tests processed through our labs, and (ii) tests sent to individuals at home or to satellite testing locations.*"

In view of the statements in (a) and (b) it is impossible from this data to ascertain how many individuals have actually been tested and whether an individual who tested negative in subsequent tests is found to be infected. This information would helpful to understand the efficacy of the testing, i.e. percentage of false negative results and the spread over time within health and other key workers. Given the anonymisation referred to in (b) it would suggest that the identity of the individuals is unknown, so they are untraceable. The statement in (c) means this data is of limited utility in conducting time series analysis, and the lack of geographical location for the tests limits our ability to assess whether tests are being targeted at areas where there are new outbreaks. The situation envisaged in (d) further undermines faith in the figures as a test sent to an individual's home does not represent a completed test until it has been processed.

In the same set of notes, in respect of the "People in hospital with COVID-19 (UK)" data [65], which is sourced from NHS England, Welsh Government, Scottish Government, Northern Ireland Executive, the following statements appear:

a) "*Fluctuations in the North West have been driven by data validation changes and missing trusts returning data (creating artificial spikes in reporting.)*"
b) "*Nine hospitals, including London Nightingale did not return data for April 9, resulting in a misrepresented drop in hospitalisations.*"
c) "*National data may not be directly comparable as data about COVID-19 patients in hospitals is collected differently across nations.*"
d) "*Community hospitals are included in figures for Wales from 23 April onwards.*"
e) "*Scottish data has been updated to only reflect 'confirmed' cases; with 'suspected' cases removed.*"

The statements in (a) and (b) represent poor collection and management of these statistics, and bring into question the governance arrangements, for example why were there missing trusts, what changes have been made to the data validation and how does this affect the results? The virus does not respect national or administrative boundaries, so variation in data definitions coupled with the notes (d) and (e) raise doubts about the consistency and accuracy of the dataset.

From this brief examination of two of the datasets used in the daily press briefings it appears that there is a significant information management issue regarding the Covid-19 statistics. The lack of consistent data definitions and information governance issues identified above suggest that the published figures fall short of the standards trustworthiness and quality set out in the UK Code of Practice for Statistics [66].

**Discussion**

The UK responded to the Covid-19 pandemic with a strategy that was based on an influenza virus rather than one designed to respond to a SARS-type virus [67, 68]. The lack of early engagement of public and environmental health teams to support tracking and tracing of infected individuals and their contacts allowed the virus to establish itself in the community. The situation may have been further exacerbated by the assumption, based on a plan to respond to an influenza pandemic, that the role of the health service was to hold the fort until a vaccine could be deployed – feasible for influenza and less so for Covid-19.

From a systems perspective the current management response to Covid-19 does not appear to address the interdependence of the three environments: hospitals, care homes and the wider community. Hospital and care home environments by their nature are not closed ecosystems, they are leaky due to the movement of people, particularly staff, between the environment and the wider community. Whilst good hygiene measures and social distancing may help, working in close proximity to infected individuals and the associated viral load may have contributed to the death of health workers [69] and presumably creates an increased risk of spreading infection back into the community as new clusters. It is interesting to note that in a hospital where higher levels of biosecurity were employed there have been no health workers infected [70]. Given the advice provided by PHE to primary care in January [71] it was apparently recognised at an early stage that the virus was highly infectious and additional biosecurity measures were required. Although lockdown can reduce the incidence in the community, these locations may act as reservoirs of infection that can be spread back into the community.

Figure 12 sets out a more sophisticated control systems approach that addresses the three environments. Given the infectious nature of the virus and the lack of a vaccine to slow or prevent its spread, there is a need for timely detection and intervention in respect of new infections and asymptomatic carriers. The use of routine rapid testing of staff, patients and residents could be deployed to detect and respond to new infections in these environments. There are a variety of tests available with varying degrees of maturity [72]. We should not be looking for 100% accuracy in the testing, as some errors will inevitably occur leading to false positives and negatives. The key objective is to be able to make quick, informed choices with a view to reducing spread whilst minimising the impact on people’s freedom and the economy.

An important criterion in setting up testing and the feedback/reporting process for care homes and hospitals is the need for rapid turnaround to ensure timely interventions can be made to limit further spread. The reporting process should proactively share information with community track/trace/testing teams so that appropriate health surveillance can be mobilised to monitor close contacts of those that are newly infected. These reporting and intervention processes need to be deployed at a local level to ensure timely action and to take advantage of local knowledge when tracking and tracing in the community. Looking at the response to Covid-19 of those countries affected by SARS and MERS, for example South Korea, based on their previous experience of this type of virus they have rigorously enforced this public health activity as a core part of their infection control [73].

In addition to the above public health measures there is a clear need to improve the information management and governance so as to provide reliable consistent information for policy makers and health service managers to use. The significant delays in reporting Covid-19 deaths and the complexity of the flows in Figure 11 make it difficult to develop a coherent picture of the virus's spread. This is probably compounded by the lack of information on how endemic its spread was in the community, although this is now belatedly being remedied.

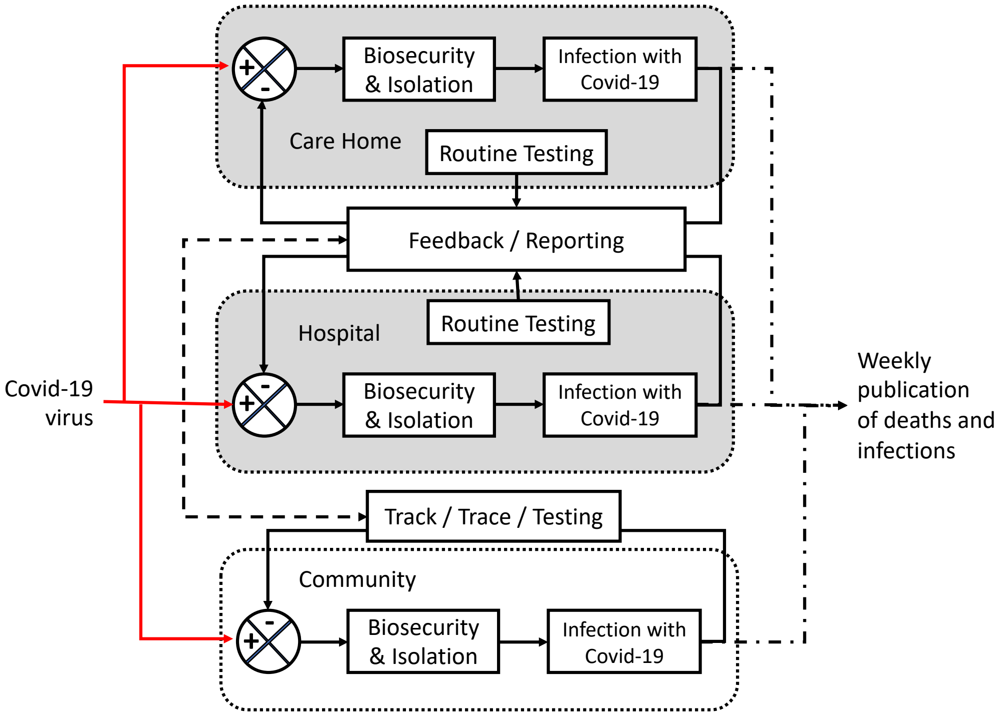


*Figure 12 - Addressing the system complexity to reduce spread of Covid-19*

**Recommendations**

The following recommendations from the analysis of the current published data collections related to the UK's response to the pandemic should be transferred into general preparedness and resilience planning. To improve the UK's response to similar events in future, it should:

1. Develop appropriate information management and governance practices, including standard data definitions, an integration data model and assurance process, so as to provide, with varying levels of granularity the government, responders and the public with a timely and accurate view of the situation;
2. Use of real time data and case studies of an incident collected from those engaged in the front-line response to inform and assist in the design of prevention and mitigation measures.
3. Where computational modelling is employed for scenario planning, institute publicly available checking of assumptions, verification of coding practices and the assurance and reproducibility of results.
4. Instigate an assurance process as soon as realistically possible in a crisis event to avoid incorrect analysis leading to policy decisions that are not going to achieve the goals set down by the public authorities.

5. Maintain awareness of the hazards of group thinking within scientific committees and advisory groups where these are likely to be influenced by the politics of research and the politicians.
6. In new or evolving situations, the science is rarely settled and is better exposed to review and challenge rather than assuming the advisors have the only or optimal solution. Conflict of interests can be avoided by creating a range of review and assurance mechanisms beyond the stakeholders at the heart of the event.
7. Application of models to the planning is acceptable, but where these models can be supported by results that accord with any other reasonable produced analysis and are updated with a feedback loop based on practical observations and analytical results during the event lifecycle.
8. Awareness and caution of applying models used in any discipline such as medical models where these have been developed on non-catastrophic events or single case outbreaks of a problem. The alternative which the Chinese used and which was applauded by the WHO was that China very early diverted from the WHO epidemic plans and established a set of systems based on observations of the event and its impact and an understanding of where to institute controls that would reduce infectivity and increase survival of victims.
9. Development of new models for resilience where control systems are designed for the systems involved in the event, taking into account capacity, staffing and other logistics that may affect the outcome and exercised to identify and remedy vulnerabilities in whatever controls or measures are proposed.
10. To avoid the publication of misleading information, whether in the form of headline-making predictions of deaths or casualties, or the reporting of metrics from the event.

**Conclusions**

Observing the UK's handling of the Covid-19 virus, despite pandemics appearing at the top of the national risk register for a number of years the planned response was for a different type of virus (influenza) where containment and vaccine development are relatively well understood. There are serious lessons from the UK's errors in using computational models that were not assured against epidemic data already available from China and Italy early in the New Year. The UK has based unprecedented key decisions on locking down the population and affecting the economy on unverified and unvalidated computation, which evidence from previous epidemic projections suggest generates publicity rather than delivering informed decision-making through good scientific practice. At the same time the UK has failed to institute key measures in infection control. The most severe consequences of employing non-assured models and failure to implement infection control based on real data about Covid-19 is that one of the world's financial centres, London now faces a complex challenge of an embedded virus and little or no gain in its control over a nine week shut-down.

The Figures 11 and 12 are generic tools to start to build a pathway out of this complex difficulty and to re-set the approach to virus suppression on the basis of real time data and controls that are in multiple vulnerable points for transmission. These Figures are suitable for addition of further layers of analysis to expand the process as information is gathered and an intelligence fusion occurs using clinical, social, security and statistical information.

The UK has apparently failed to lean lessons from its experience with the 2009 influenza pandemic, where the independent review observed - ”*modellers are not ‘court astrologers’. Time spent at SAGE and the CCC to discuss modelling produced using emerging data may have been better spent on other issues*” [74]. Perhaps if more time had been spent considering the handling of SARS-like infections by Asian countries, particularly South Korea whose population is comparable in size to the UK, more an earlier focus would have been placed on implementing a track, trace, test, quarantine approach thus limiting the spread in the community.

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