Distributed Test, Track and Trace System as a Contributor to Epidemic Containment Management

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***Abstract*—The outcome of the recent novel Coronavirus pandemic is profound and particularly poignant when countries like South Korea, who have learned from previous pandemics, appear to be better able to respond to the challenge. Since lock down due to the novel coronavirus of 2019, the Government of the United Kingdom has adopted retrospective testing and a smartphone application for contact tracing as part of its retroactive test, track and trace strategy. However, to thwart future epidemics, this paper proposes that a different approach should be adopted in preparation for the next epidemic. This consists of a distributed system solution comprising front-end testing nodes at the borders as well as test laboratories connected to a backend cloud-based data processing and data storage system. This core system can be used to test, track and trace infection hotspots at the start of an epidemic to avoid significant outbreaks in the United Kingdom. This hotspot data can be made available to local authorities so that more informed decisions can be made regarding approaches to contain any infectious viral spread. This would need to involve traditional epidemiological track and trace surveillance activities to understand the propagation effect; and therefore, understand the resultant disease coverage in the community so that mitigation measures can be successfully applied in a timelier fashion.**

Keywords—COVID-19, Cloud, Centralized Test Data, Distributed System, Lessons Learned, Propagation Tracking and Tracing.

I. Introduction

In 2015, the Philanthropist Bill Gates highlighted that the world was not ready for the next pandemic [1]. In the most part his warnings went unheeded because he was not a medical professional. In late 2019 Gate's premonition was realized when the Severe Acute Respiratory Syndrome (SARS) Coronavirus 2 (SARS-Cov-2) hit China and started propagating around the world by early-to-mid January 2020. The result has been the global pandemic of the 2019 novel coronavirus disease (COVID-19). There has been criticism regarding the alleged lack of preparedness for the viral onslaught that engulfed the United Kingdom (UK) and the rest of the world [2]. Countries like Taiwan and South Korea learned lessons from the SARS Coronavirus (SARS-Cov) and Middle East Respiratory System Coronavirus (MERS-Cov) outbreaks at the start of the first two decades in the new millennium respectively.

After it was established that SARS-Cov-2 was more easily spread than SARS-Cov and MERS-Cov [3], these Far Eastern countries applied a technical response to the 2020 pandemic; this included tracking and tracing infections based on test data collected by government sponsored bodies [4]. Jeremy Hunt, the Chair of the Health and Social Care Select Committee, believes in the main that the West saw COVID-19 as an influenza-like outbreak [5]. It has also been alleged that the UK's scientific modellers were dissuaded from prioritizing test kits because their predictions were based on influenzas [6]. The majority of the West should learn from the 2020 pandemic crisis in order to be more prepared for the next pandemic. The motivation of this paper is to highlight lessons to be learned regarding test, track and trace. A conceptual model is proposed that could be adopted by the UK and other countries in the World as part of a strategy to defeat any future pandemic.

II. Background to the Problem

The UK's approach originally appeared to be based around uninoculated 'herd immunity' after considering the initial scientific modelling outcomes, maintaining a focus on the economy as well as public health. However, as the pandemic took hold in early March this approach changed dramatically after advice from academia [7, 8, 9]. At the time scientists in the UK were keen to highlight that temperature screening would not be effective at transport hubs because people could at that point be asymptomatic and incubating SARS-Cov-2 [10]. Astonishingly, it transpires that 20,000 infected people entered the UK before lockdown by 23 March, but only approximately 300 were quarantined [11]. Apparently, the testing of people at transport hubs was discounted at the time because it was surmised that it would only delay the pandemic by 5 days [12]. On the other hand, Andreas Michaelis, State Secretary of the German Foreign Office, has stated Germany had significant test capacity from the start of the pandemic that enabled testing to be carried out at scale very early during the pandemic [13]. Academics are now convinced that the transition of the UK's response from 'contain' to 'delay' phases on 12 March abandoned containment, which meant that community monitoring was also dropped due to the lack of testing capacity [14, 15]. Professor Lee, a prominent scientist from South Korea has stated that testing, contact tracing and epidemiological surveillance are all interrelated, and the UK should have implemented such an approach [6]. It has been revealed that the lack of testing from the start has subsequently been a regret of the UK's incumbent Chief Scientific Adviser [16].

Professor Sridhar from the University of Edinburgh has stated from the outset that aggressive test, trace and isolate measures were needed to avoid thousands of further deaths and protracted damage to the economy which could be inflicted by future waves of infections; but she has also said that formal contact tracing using specialist surveillance staff tailed off as infections exponentially increased [17]. It has also been stated that adequate testing and containment should have been in place from the start of the national emergency [18]. The UK Government's retrospective response to the pandemic is now promoting a version of test, track and trace using retrograde measures now that test capacity has increased; and this has been declared as being pivotal once the contagion is under control and infections are falling [19]. Professor Newton, an eminent epidemiologist, has stated that the introduction of smartphone applications is only part of the response to the crisis. South Korea has proven the value of front-line epidemiologists to test people so that outbreaks can be contained [20]. The 2020 experience cannot be repeated and globally we must learn lessons from outbreaks of modern virologic pathogens such as SARS-Cov-2 [21].

III. Lessons Learned

In the event a considerable number of infected people were uncontrollably allowed to mingle with the population when arriving in the UK from abroad. Subsequently, testing has been difficult to scale up to hundreds of thousands; enabling SARS-Cov-2 to spread freely with minimal mitigation until lockdown was introduced. Consequently, the UK has had to retrospectively increase test laboratory capacity as well as scale and mobilize tests for many thousands of people [22, 23].

A. Viral Spread

The interim findings from a European academic study provides evidence that social distancing within a 2 meter radius whilst taking exercise is not enough. The recommendation is five meters or more for walkers and up to at least 20 meters for cyclists travelling at speed. The Massachusetts Institute of Technology went one step further and stated that the minimum 2-meter gaps may not be enough because coughing and sneezing can spread considerably further [24, 25, 26]. A study in the United States (US) indicates that SARS-Cov-2 could be spread through standard human respiratory processes, such as breathing, and also talking [27]. Therefore, these findings reinforce the perspective that SARS-Cov-2 is highly infectious.

Quarantine measures have been used to isolate some passengers arriving back from 'red areas' such as Wuhan in China [28]. This approach is similar to the approaches taken by Taiwan and South Korea to limit the spread; moreover, they progressed further by halting many international flights all together. During the peak of the pandemic approximately 15,000 passengers each day were still entering the UK from airports and joining the general populace without any quarantine measures; however, the expectation by the UK Government is that people should dutifully and responsibly self-isolate. Jeremy Hunt categorically stated that we need to quarantine and test passengers at international arrivals before allowing them into the country [29].

Differently to the UK, the Chinese had a pandemic monitoring and reporting system in place; but it was found to be ineffective because reporting by the authorities was not timely enough [30]. Three years ago, Operation Cygnus was conducted to test the UK's epidemic preparedness, but the findings outlined that national capabilities were found to be wanting [31]. That said, Public Health England did setup a COVID-19 epidemiological surveillance regime in February 2020 to detect new cases of the disease [32] but by March it had all but been scaled back in the face of exponential viral propagation. Consequently, we now know that the UK's suspected Patient Zero arrived back in the country from the Alps at least one month earlier [33].

B. Reactionary Response

The Tech Industry has risen to the challenge to help defeat COVID-19 [34]. For example, the NHSX – the UK's National Health Service's (NHS) technological innovation arm – has turned to cloud computing to track healthcare supplies and to boost productivity during the crisis [35]. A similar approach has occurred in the US – highlighting that the power of cloud computing is seen as being pivotal in the fight against COVID-19 [36]. Albeit the surge in demand for cloud capacity in some cases is outstripping pre-pandemic provisioning capacity [37].

Governments, as well as leading smartphone operating system corporations, are developing contact tracing applications that cache Bluetooth media access control addresses of other devices in the proximity. If the owner of the device shows symptoms then an anonymous alert is used to notify other people who have come into Bluetooth range that they have come in contact with a suspected SARS-Cov-2 or COVID-19 infectious person – instructing them to self-isolate. South Korea's variant tracks geolocation, whilst the versions being developed by the NHSX, Apple, Google and Singapore do not. However, there are concerns that too many opt-ins may make such technology ineffective [38, 39, 40]. The UK's application will require people to voluntarily raise an alert if they think they have symptoms [41] and unlike Apple and Google variants enable centralised tracking once an alert is raised. There is also a concern that anonymous data may not stay anonymous without robust legislation and regulation [42]. Some epidemiologists are sceptical saying that this form of contact tracing will not be effective with feared false positives [43]. Users' of the NHSX application can also use it to order a test once they raise an alert [44]. But a significant problem with this approach is the older generation may not even own a smartphone.

Professor Woodward, a cybersecurity researcher, has stated that time stamping will be an absolute requirement for the accuracy of associative presence with other people [45]. The latest generation of Bluetooth enables beaconing that can be used to anonymize peoples' identities; a flaw however with this approach is that it is a form of crowdsourcing; relying on consumers to voluntarily input positive diagnoses or suspected symptoms in the first place for it to work. This would make it more unreliable than formal epidemiological surveillance measures. Professor Christophe Fraser from Oxford University has an opposing view stating that contact tracing is needed because traditional surveillance techniques are too slow [46].

A package of interventions is important to combat a pandemic including reduced social gatherings, but testing is particularly crucial. During the COVID-19 national emergency the tests - known as Polymerase Chain Reaction (PCR) or swab tests of the pharynx – are deemed the most reliable test to achieve a reasonably accurate antigen detection outcome. The PCR tests can also provide indicators of what treatment intervention may be required for the patient. However, a negative result may not necessarily mean an individual is virus free [47]. Admittedly there are now antibody tests coming on stream [48], but it is expected that derivations of the PCR test will be the mainstay for future pandemics. The South Africans have mobilized a wide-spread SARS-Cov-2 surveillance regime comprising house-to-house monitoring. This response has been honed from their experience of HIV monitoring and is reportedly providing them with the ability to control SARS-Cov-2 hotspots [49]. Unfortunately, the rapid spread of the SARS-Cov-2 in the UK overwhelmed the county's testing capability and allegedly swamped the surveillance community [50]. Dr Lee from the University of Sheffield has stated that the UK does have a good pedigree of contact tracing in other examples of health cases, but future crises of similar proportion could require elevated public health powers as a matter of necessity [51].

IV. DISCUSSION

There are lessons that can be learned by drawing upon experiences from the cyber domain [52]. Table 1 draws a comparison between approaches used by cyber and medical domains. In both cases passive and active measures are required to achieve the best results; not just in a reactive manner but using proactive approaches too.

TABLE I. COMPARISION OF APPROACHES

Context	Activity	Scenario
Cyber Domain	Active Defense	Pre-emptively reduce the attack landscape by patching and monitoring hosts, and network traffic, with active network defense mechanisms and tools to detect suspicious activity or incursions. Reducing opportunities for attackers to gain a foot hold, persist and achieve their objectives.
	Protective Monitoring	After a security breach, compromise, or malware infection has been detected by passive defense systems, teams reactively mitigate by applying technical controls, processes/procedures to minimize impact and reoccurance. This is a reactive response to defeat the attackers in which time is of the essence.
Medical Domain	Proactive Testing	Test at key border control points, taking details of the test subjects' domicity, followed by track and trace using epidemiological surveillance. Pre-emptive testing measures and collation of positive results would identify hotspots as focii of interest for further monitoring. This could be used to lessen the impact of any surge in viral transmission and mitigate the depletion of NHS resources.
	Epidemio-logical Surveillance & Monitoring	Monitoring of positive infection rates in the community from reliable data coupled with statistical analysis facilitates proactive mitigation measures. By understanding where the infectious people reside at the beginning of an epidemic enables a better response to curb the spread and reduce infections more efficiently. Breaking chains of transmission by tracking hotspots and tracing infections could potentially negate testing of the wider populace at larger critical mass and scale.

In response to the SARS-Cov-2 dilemma this paper proposes a system concept for the UK use-case that perhaps with hindsight could have been in place from the outset. Learning the lessons from this pandemic, a system of this type could be used to coordinate testing at transport hubs at UK borders in the national interest. Testing provides an informed basis for track and trace activities in a controlled manner using trained epidemiological surveillance teams. During the 'containment phase' a system of this kind could have been used to test, track and trace infections of people who entered the country based on definitive data. The Distributed Test, Track and Trace System (DTTTS) approach encompasses system of nodes that collect definitive data and this collated information could be used to informedly monitor infection hot spots across society.

V. CONCEPT

From a medical standpoint the COVID-19 national emergency has been a missed opportunity to test people arriving from overseas during the pre-pandemic period. Based on the evidence from recent history aperiodic infections at epidemic scale can occur; examples are the SARS-Cov in 2002, and the MERS-Cov in 2012 [53]. Therefore, there is a probability that another strain of air transmitted novel coronavirus could occur within the next decade. By implementing a DTTTS capability it would enable the medical profession to: (1) Test at Borders, (2) Distribute Results, (3) Process/Store Informative Data, (4) Track Hotspots, (5) Trace Transmission in the Community.

To achieve this definitive testing will be needed to provide a categorical record of where contaminated pockets of infected people reside (whether it be UK citizens or foreign visitors) in a computerized database. Therefore, like Germany [13], the UK Health Authority could notify regional authorities to undertake surveillance measures in order to contain the spread of the virus from known hotspots; thereby enabling our society to track and trace any transmission and hopefully take action to limit its spread.

In addition, it would also provide an ability to monitor pockets of people in the community who have tested positive and alleviate the problems experienced through people who have been asymptomatic. This data could then potentially influence decision making about monitoring UK citizens or existing residents who are instructed to implement self-isolation measures in the community or enforce and monitor travelers who are instructed to quarantine themselves at declared addresses [54].

It would also alleviate the longer term-imposed burden on 14 day or longer quarantine durations being held *en masse* in special quarantine facilities. Thus, enabling better management of isolation/quarantine efforts on a case-by-case basis and in a controlled and managed manner (e.g. by delegating to devolved and local authorities). Such a system might avoid circumstances like the total country-wide lockdown that has been the case in 2020; minimizing damage to the economy, personal anxiety and mental anguish.

Building upon the collaborative capabilities of the Tech Industry and academia, a DTTTS concept could be realized as shown in Fig. 1. This approach would enable the medical profession to:

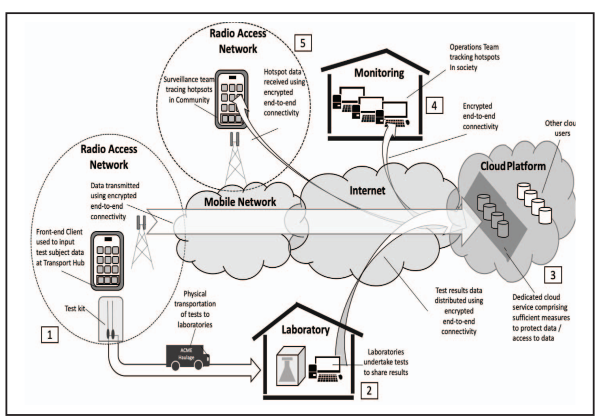

Fig. 1. High-level DTTTS ecosystem.

(1) Test at borders; (2) Distribute results; (3) Process/store definitive data; (4) Track hotspots, and (5) Trace transmission in the community. This fulfils the requirement to prepare, monitor, contain, and respond to the next virologic event. Such a model would enable the Department of Health to be in a position to take informed containment actions based on the data processed and held by the DTTTS.

VI. System approach

The Cloud element of the DTTTS could operate as an Infrastructure-as-a-Service (IaaS) implementation that could be hosted on a true cloud platform. An infrastructure as code approach would enable the system infrastructure to be templated and rapidly deployed when required from a cold-standby position; inversely, once operational it could also be torn down more conveniently when no longer required. In addition to the DTTTS, front-end PCR testers would be required with an adequate supply of test kits at transport hubs. Subsequently, since COVID-19 there are now more laboratories in place that could be used to input data into the system. These are crucial dependencies that are needed for such a system to be successful.

A. System Overview

- A hot-standby system would accumulate costs whilst not in direct use. Whereas a cold standby system could be spun-up at almost immediate notice by a trained team. It could be used to: (a) correlate test data; (b) identify where infected/socially isolated people reside; (c) monitor and track any expanded outbreaks from the hotspot locales, and (d) enable epidemiological surveillance teams to deploy to areas of outbreak to trace any ensuing wider expansion. This type of operational function can be achieved using cloud technology.

B. System Design

- Data input nodes would be required at airports, ferry ports and Eurotunnel stations amongst others. These endpoints would need to connect to the centralized cloud-back end. To facilitate this a client application would reside on multiple front-end devices and communicate with the backend. This could be achieved using 4^{th} or 5^{th} Generation cellular bearers, benefiting from the mobile telecommunications core network services that interoperate with the Internet. End-to-end communication would need to use encryption technology such as transport layer security. The front-end application can be sandboxed on the smart device applying data-at-rest encryption to protect any cached data. Interaction with the cloud could be conducted using a security tested and verified application programming interface that can validate traffic. User access to the application can be administered and controlled using a two-factor authentication mechanism.
- The identities of test subjects can be pseudo anonymized. Any attribution of personal data linking to medical data by association can be protected using cryptographic mechanisms; such as object encryption in databases, as well as virtual instance volume and storage volume/file-based storage encryption for data-at-rest protection where applicable.
- Internode encryption can be applied at various stages both externally and internally to the cloud to protect data confidentiality and integrity in transit.
- Data ingress and egress can be controlled in various ways in the cloud and be limited to trusted endpoint connections.
- Labs would require access to update test results against the case identities of test subjects in order to provide a reliable data profile for each case. This would form the cadre of salient data on infections, test subject locales in the community and provide a regional focus for surveillance measures to trace potential contagion propagation.
- Access by front-end test staff and laboratory staff can be controlled through a combination of role-based and least privilege identity and access management controls supported by multi-factor authentication.
- The cloud backend would need to be resilient and therefore potentially mirrored to another Availability Zone within the Region or another regional data center in line with legislative adherence and compliance [55, 56].

C. Administrative Support

- User profiles and access control measures would need to be managed so that accounts and credentials were maintained to access the DTTTS core services.
- As a cold-standby system a support function would be needed to ensure IaaS aspects are not out-of-date or updated/modified as required. This is especially relevant to ensure the system is resilient and would perform as required during a future pandemic situation.
- At periodic intervals templates and builds would be inspected, updated, tested and validated through approved penetration tests of the Cloud backend. This could be coincided with scheduled business continuity exercises to prove the functional integrity of the system and help mitigate cyber security risks in the process.

D. Cybersecurity

- The end-to-end system would need to be protected from cyber-attacks with defensive measures such as: (a) web application firewalls; (b) anti-distributed denial of service attack measures; (c) network routing and protocol filtering; (d) application level authentication; (e) schemas and data validation processes, and (f) security protective monitoring. This cloud-based system would operate out-of-band to the type of threats experienced during the COVID-19 pandemic such as ransomware attacks launched through phishing emails to facilitate ingress [57, 58].
- An adequate secured architecture, supply chain security regime for front-end devices, protective measures for end-to-end and data-at-rest security and adequate cyber hygiene would all be essential to thwart nefarious actors who have recently victimized global healthcare organizations [59, 60].

E. Monitoring

- An NHS or similar Operations Center would be needed to monitor, track and coordinate with local authorities in order to manage active cases. A technical support team would be needed to maintain the system whilst in both active and dormant states.
- Performance monitoring would be needed to ensure reliability and management of resources when scaling horizontally and/or failures of components within the system.

F. Service

- The solution and supporting service could be provided as a UK Government Cloud package using public cloud service providers [61]. The cyber security controls would be assessed for entry to the marketplace against standards such as the ISO27001 series including 27017:2015 and ISO270018:2019. The environment could be designed against guidelines provided by the National Cyber Security Centre and system implementation scrutinized by government cyber security professionals.

G. Legal

- The US has been using cloud computing to host medical data for several years [62]. In compliance with the US Health Insurance Portability and Accountability Act of 1996, the Healthcare Information and Management Systems Society has developed a framework to protect the processing and storage of Personally Identifiable Information (PII) and medical data in the cloud [63]. This provides a useful reference point for a UK cloud implementation.
- The NHS digital service specifies that the use of cloud computing is permissible, within the bounds of complying with the General Data Protection Regulations (GDPR) of the European Union. GDPR also promotes the use of pseudo anonymization and full anonymization techniques for PII data [64]. However, the use of pseudo anonymization means that the data must remain under the purview and auspices of the Department of Health and therefore controlled with government oversight.

H. Governance

- An IaaS implementation would enable the government to have more control over its installations, updates, operation and tear-down. A scalable or scaled up database cluster would be needed to support this solution. When no longer required the data could be securely backed up from the cloud to government premises and the cloud infrastructure could be torn down; safe in the knowledge that any residual data or meta-data is encrypted at rest prior to deletion in the Cloud.
- It is envisaged that the Department of Health would oversee the DTTTS whilst parliament would need to pass laws to enforce such a rigorous health-based testing approach; ensuring that the data is only to be used for medical epidemic testing purposes, infection tracking and tracing the chains of transmission.

VII. CONCLUSION

Lessons need to be learned from the 2020 pandemic as another could happen in the future. The inability to restrict viral propagation has had the effect of significantly impacting the UK's economy in the longer term [65]. For the majority of nations in the West inadequate testing arguably enabled the infection rate to be significantly steeper than countries with effective testing regimes like South Korea and Germany [66].

The current pandemic will most likely not extinguished without a robust control such as a vaccine to ensure SARS-Cov-2 does not resurge itself in the autumn and winter months; at the time of writing, tests are starting on a vaccination, but it may not be available until 2021 [67]. Without an advanced computerized system to test, track and trace it may only take a small number of infected individuals to reignite the flames of the SARS-Cov-2 [68]. It is important and particularly poignant that SARS-Cov-2 virus is also unable to resurrect itself as a 'second wave' of infections [69].

It is astounding that pre-emptive tracking and tracing has not been a highly debated focus of discussion during this crisis. That said, better tracking and tracing is also needed to assist in epidemiological surveillance activities. For example, the Cheltenham Gold Cup Festival was held during the week of 9 March and there are now suspicions that as a result the infection rates in Gloucestershire are consequently higher than other counties in the South West [70]. However, without adequate epidemiological surveillance this is just supposition.

Evidence from Icelandic research is revealing that SARS-Cov-2 was widespread in the UK much earlier in the pandemic than has been first thought [71]. Hence, better diagnostics are required to recover from a situation such as the COVID-19 pandemic but also in preparation of the next epidemic [72]. For instance, the axing of the US warning program established during the last Administration [73] will have certainly been a gap in their pandemic control measures. Sir King, former Chief Scientific Advisor to the UK Government has articulated that South Korea was able to scale rapidly to test up to 20,000 people per day [74]. This example shows that adopting a big data approach in testing, tracking and tracing proved successful; albeit they used quite intrusive measures such as locations of credit card purchases and geo-location tracking [75].

In the UK's case, retrospective and reactive approaches include the NHSX urgently developing its own contact tracing smartphone application [76]. However, medical experts in the US have had a mixed reception to this type of technology [77]. As these technologies will undoubtedly come to fruition, they should not be considered a comparative measure to the definitive data collection, processing and storage conducted by a DTTTS type system; but these apps should perhaps be considered as an indicative source because the reliability of public sourced data will be questionable and should only act as a guide. Building on the German experience [13], a DTTTS type implementation would provide a proactive control measure that could provide definitive data based on PCR testing. This type of system would enable reliable hotspot monitoring, followed by tracking and then tracing by surveillance teams on the ground; thus, avoid the UK being caught on the backfoot again at the beginning of any future epidemic or pandemic.

In effect, testing at the start of an epidemic at the border points requires less resources all round than when a virus firmly takes hold in the population. Using a DTTTS enables hotspots to be identified and tracked, supported by surveillance to trace infections to effectively contain an outbreak. Some aspects of a DTTTS approach are being adopted by the UK government such as some traditional surveillance [78], strong confidence in virtual contact tracing using the NHSX application and the creation of a Biological Alert Center to track infection rates [79]. Interestingly Professor Ham, a health policy academic, has said that the NHSX smartphone application is likely to become a "side show" [80].

Of course, SARS-Cov-2 could eventually burn itself out like MERS, SARS and the Bubonic plague but it will still leave a massive death toll [81]. If we take action in preparedness to contain a future pandemic from the outset - using a DTTTS like system with definitive test data to track and trace using epidemiological surveillance - then we will have tried our best to avoid revisiting the 2020 situation. Recent experience has shown that the sheer number of people requiring a test overwhelmed the UK's testing and laboratory capacities and a rapid infection rate overawed the existing surveillance measures. This put the UK at a distinct disadvantage for many weeks and cost thousands of lives [82]. Being more prepared for the next pandemic could avoid difficult choices that have been highlighted by Sir King. He has stated that by not suppressing the virus the UK government is only managing it; by living with it, the government is effectively reintroducing herd immunity [83, 84].

VIII. Future Work

As an island state our inability to manage or control passenger ingress at the UK's borders was our Achilles heel - as it was with many other nations - allowing the SARS-Cov-2 virus to freely propagate from the start [85]. Fundamentally we as a species have a duty to protect people who are vulnerable through age, health reasons or biological make up. Without such considerations the post-COVID-19 world could become a game of viral Russian Roulette; leaving the vulnerable at the mercy of a highly infectious virus that can persecute weaknesses which are not necessarily known at the time of infection [86].

The importance of a system to test, monitor, track and trace at pre, intra and post-pandemic stages to survey infection rates in the population is essential. To achieve this a system must be scalable from the outset to monitor, contain, and respond to any infection that takes hold and propagates into the populace. This approach requires test kits at the front-end starting with transport hubs. Trained staff would be required at the front-end as well as sufficient laboratory capacity and a cadre of traditional epidemiological surveillance teams rather than relying on virtual contact tracers in the case of the NHSX application [87, 88]. Future swab test kits could be variable depending on any future pandemic virus type and would need to be rapidly produced. Therefore, the right equipment for the task would need to be speedily distributed as needed. All these dependencies need to be considered and planned for in preparedness for the next event.

Understanding recent failures is an essential ingredient for the recipe of future success. There might even be new measures that are still being validated, such as rapid screening of individuals without using the questionable heat sensor approach. An example of this is the proposed use of canines who could be trained to sense and detect volatiles from viral infections; this would help the border force filter and whittle down the passengers who need swab type testing at transport hubs; this is in a similar way to using dogs to detect other diseases like cancer [89, 90]. Such an approach would speed up the process of identifying test subjects without using less reliable methods, such as random selection, and minimize inconvenience to passengers, time taken to screen people and consequently reduce the number of front-end tester resources needed at the border.

Acknowledgment

The purpose of this paper is to highlight challenges that have been experienced during the 2020 global health crisis and to better protect society in the future.

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