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A proposal to enhance Australia's capability to manage epidemics

The critical importance of expert statistical input

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Executive summary

Given the high level of global mobility, pandemics are likely to be more frequent, and with potentially devastating consequences for the Australian community and its way of life. Whilst parts of Australia are experiencing a second wave of COVID-19, the country is in relatively better shape than most others. The number of people who have died or been seriously ill as a consequence of the virus, whilst tragically high, is nonetheless comparable with most of the best-performing countries.

That said, we believe there is a critical need for strategic statistical oversight of the whole process of anticipating, managing and learning from the current pandemic to improve the quantitative information and advice provided to policy makers. This proposal outlines quantitative aspects of a plan to enable Australia to deal more efficiently and effectively with future such events, thus enhancing both the social and the economic welfare of its people. Indeed, expeditious action may well assist materially in managing possible future waves of the current pandemic, and its aftermath.

A dispassionate assessment of Australia's health and economic response to the pandemic over the last six months reveals some very significant inadequacies in the data, statistical analysis and interpretation used to guide Australia's preparations and actions. Data to answer some of the most basic of questions about prevalence in population have not been available and remain unavailable. For example, one key shortcoming has been the lack of data to obtain an early understanding of the extent of asymptomatic and mildly symptomatic cases or the differences across age groups, occupations or ethnic groups and their reproduction characteristics. Another is the lack of early-warning indicators of the progress of the virus. In our view, this has meant

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that that Australian Governments and the National COVID-19 Coordination Commission have been significantly impaired in their ability to carry out their duties, and has resulted in undue reliance on 'one size fits all' interventions with a larger economic impact than may have been necessary.

For the strategy of finding and isolating positive cases to be effective, early detection is essential. Waste-water surveillance provides a 5-day advance warning of the presence of the virus, and is already in use in a number of countries, yet is receiving little attention from Australian health authorities.

Minimising the impact of a novel virus depends critically on ongoing acquisition, integration, analysis, interpretation and presentation of a variety of data streams to inform the development, execution and monitoring of appropriate strategies. Figure 1 captures the essential components of such an approach: four basic phases, from initial detection to post-pandemic, and critical steps in each stage to plan for acquisition of diverse data and to act expeditiously on the information they contain. A broad range of statistical skills, knowledge and know-how is needed to support most aspects of control, with sound independent statistical guidance being provided at the very highest levels of decision-making.

Pandemics such as the current episode are times of crisis. And in a time of crisis, it is essential that people and groups who are generally in (healthy) competition need to work collaboratively and collegially. Data, information, models and approaches need to be shared rapidly for learning, exploitation, critical peer assessment and comparison, so that the Government can be confident that it is receiving the best possible advice available as soon as possible.

It is our strong recommendation that a **multi-disciplinary** Task Force be established expeditiously to develop a Pandemic Information Plan. As well as those involved from the policy side, the membership should include a statistician with expertise in statistical modelling and analysis, an official statistician, an epidemiologist, a medical researcher, economist and public health official. Timely action by the Task Force may even prove to be of significant assistance in managing future waves of the current pandemic.

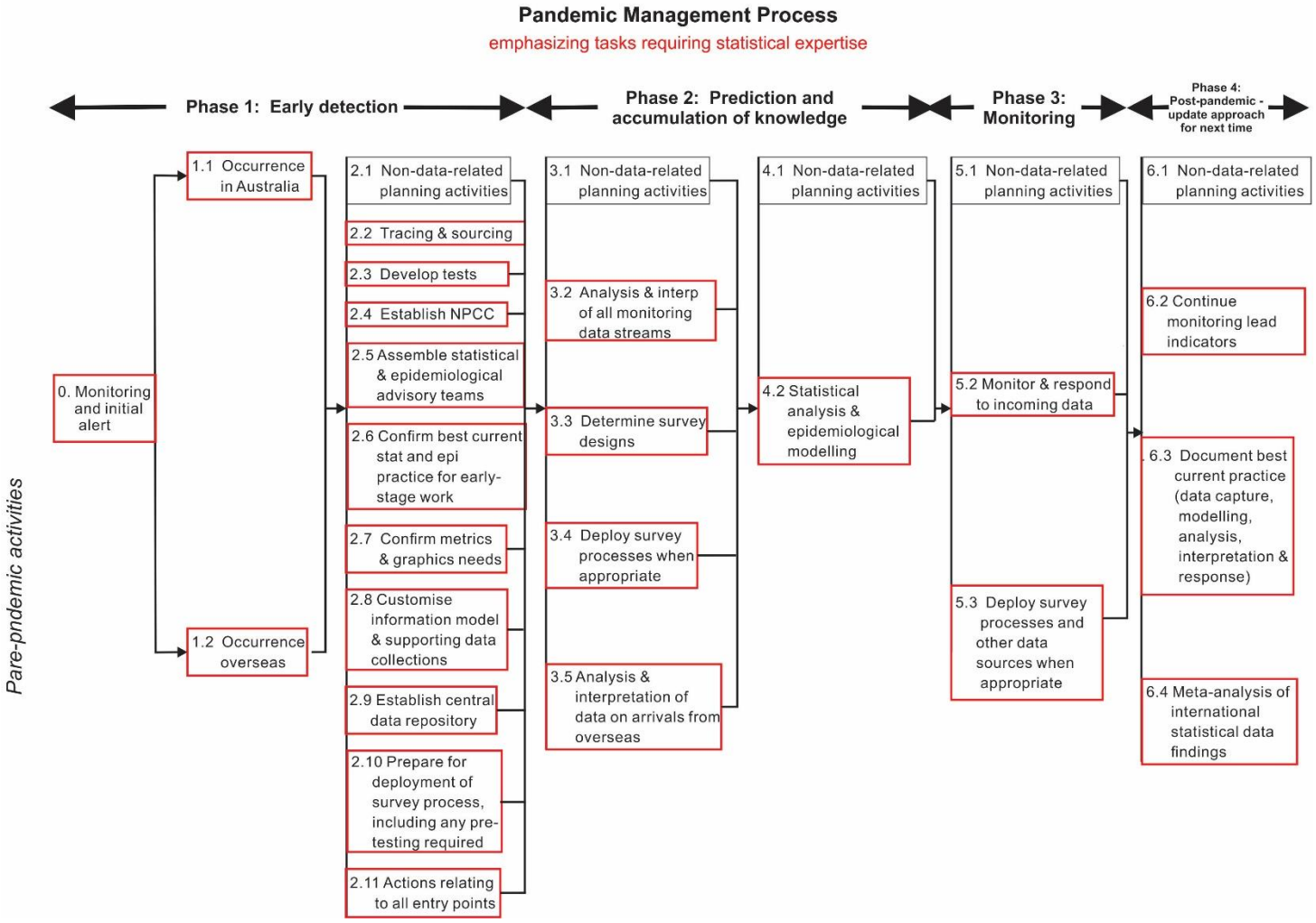

Figure 1 **Pandemic Information Plan**. The diagram represents management of a pandemic in three main phases, focusing on the requirements for data acquisition, expert analysis and interpretation, and presentation in each phase. Each box outlined in red involves tasks requiring statistical expertise. A variety of statistical skills, knowledge and knowhow is essential for efficient and effective management of the pandemic. NPCC = National Pandemic Coordination Commission. The top sequence of boxes 2.1, 3.1, … represents the other major planning processes not requiring input of significant statistical expertise.

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Introduction

Australian governments' management of the COVID-19 crisis has been significantly hampered by the lack of comprehensive quantitative information to inform many important decisions and actions.

This proposal sets out the diverse sorts of data that we believe are essential to gather during each phase of a pandemic, not just COVID-19, and the type of statistical expertise required to capture and analyse the data, and to present timely results in actionable format. The various elements are organised as a provisional Pandemic Information Plan, which has been prepared in consultation with leading Australian and international statisticians and other leading scientists who could be considered experts in disciplines related to the pandemic. It is important to have the data collection plans in place so they can be implemented at short notice if required.

The principal recommendation is that a Task Force be established to revise and complete the plan. The Task Force would also be tasked with establishing a generic pandemic information model, and identifying the necessary data collections.

Pandemics, whether they occur naturally or as the result of deliberate action, may well become more frequent. It is imperative that Australia be much better prepared next time around. So we need to extract from our experience with COVID-19 all the information that is required to inform policy. Indeed, should expeditious action be taken, the plan we set out may even provide material assistance in coping with later waves of COVID-19.

Learning from the COVID-19 experience

Whilst parts of Australia are experiencing a second wave of COVID-19, the country as a whole is in relatively better shape than most others. The number of people who died or were seriously ill as a consequence of the virus, whilst tragically high, is nonetheless comparable with most of the best-performing countries. That said, we believe that there is considerable scope for improving the statistical information available to inform policy makers than was the case this time around. A dispassionate assessment of Australia's response to the pandemic over the last six months reveals some very significant inadequacies in the information available to support Australia's preparations and actions. The main problems with the available information include:

1. **Early estimates of the extent of the pandemic and its impacts were far too high**, resulting in much more expenditure on the health system than was required as well as cancellations of surgeries. Estimates of the reduction in the reproduction number[3] used in these estimates (25% and 33%) did not take sufficient account of the combined impact of quarantine, isolation and social distancing and hygiene messages, irrespective of other restrictions, resulting in a significant over-estimate of the infection rate even with the worst case scenario (11.4%). Sensitivity analysis is one means of understanding the uncertainty around these estimates. It was used to a limited extent but did not seem to take sufficient knowledge of previous epidemics where over-estimated projections resulted in significant resource wastage (see Rhodes *et al*., 2020).
2. **The initial assumptions on asymptomatic cases, symptomatic cases being tested, *etc*. proved to be wrong**. There was no alternative initially to use assumptions based on knowledge gathered about the virus, mostly international, but proposals to collect useful Australian specific data through random surveys were ignored or rejected. For example, the initial assumption that there were no asymptomatic cases that were not pre-symptomatic was badly wrong as shown by international studies (*e.g*. Hao *et al*. 2020 and references therein).
3. **No processes were initiated to capture Australian data about some of the most basic questions**, such as

[3] The reproduction number, usually written *R*, is defined as the average number of people an infected person is likely to infect. It is also known as the reproduction fraction, reproduction factor or reproduction index.

a. How many people are infected by the virus?
b. How many people who are infected are not yet exhibiting symptoms (presymptomatic)?
c. How many people who are infected do not exhibit symptoms (asymptomatic)?
d. How many who are infected and exhibit symptoms but have not been tested?
e. How many people have recovered from the virus (only known for those who have been tested and were positive)?

4. **The curve that was flattened did not represent the actual number of positive cases** (although the correct curve would also have been flattened but not as quickly because asymptomatic cases and untested symptomatic cases were ignored and it was such cases that set off the second Wuhan wave so they are important in understanding the progress of the virus). **The actual number of positive cases can only be estimated reliably from testing scientifically random samples from the whole population and these should have been part of the testing regime as soon as sufficient tests were available**.
5. **There was little socio-demographic information available on the tracking of the virus and the extent of heterogeneity in the population based on this information[4]**. Yet it is obvious that infection rates, the effective reproduction number and case fatalities will vary very considerably between sub-populations. There are now reports that super-spreaders may be the cause of the majority of infections. This has policy implications because the risk management and messaging should be quite different for each of these sub-populations. As a consequence, health outcomes are not as good as they might have been and the balance between health and economic goals has been less than optimal.
6. **The level of dispersion of the virus (known as k) has not been estimated**. This tells you about the relative importance of super-spreading events to the spread of the virus. This is extremely important in understanding the need for emphasis on curtailing super-spreading settings especially as restrictions are eased.
7. **Alternative data sources such as waste water testing have been given little if any attention by the health authorities** even though they can provide early warning of a

[4] For pandemics, the key socio-demographic characteristics seem to be geography, age and gender, industry and occupation, and ethnicity.

second wave and have been used in Singapore, some cities in the USA, the Netherlands, Paris, Barcelona, the UK, Switzerland, and will soon commence in New Zealand. The Australian research[5] is also well advanced but there are important statistical issues in the efficient and effective design and analysis of the testing (including procedures to minimise false positives as a result of any lack of specificity in tests) that need to be resolved.

7. Measures of excess deaths are probably a better measure of the actual fatalities resulting from the pandemic. This removes some uncertainty around the true cause of death particularly when people are co-morbid. It also includes deaths from other causes because medical services are not being sought or are not easily available because of pressures on the health system. There were 815 excess deaths in Victoria over the March/April 2020 period, much higher than other States, suggesting that COVID-19 might have had a higher prevalence than thought at the time.

[5] And there are some surveillance activities, *e.g.* in the NSW snowfields: https://www.afr.com/politics/federal/ski-resorts-on-high-alert-after-covid-detected-20200730-p55gv2

Models

Epidemiologists use a variety of models, and the information needed to support the models is broadly consistent. For the purposes of illustrating the information requirements, we have used this model from Harvard University given by Hao *et al.* (2020).

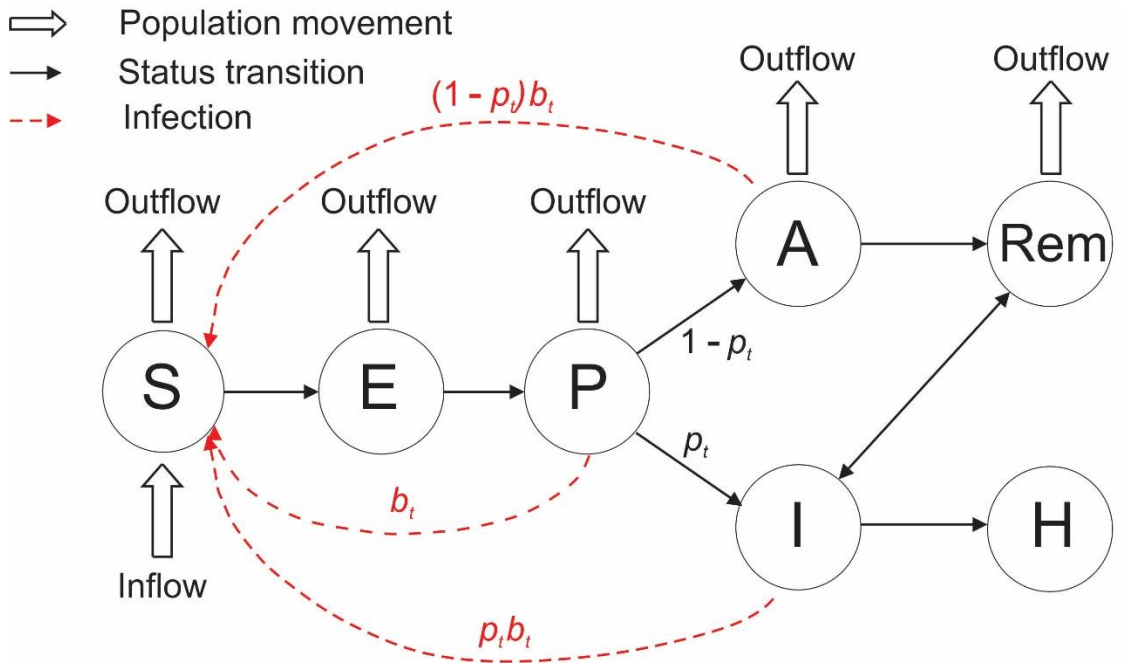

Figure 2 *(This diagram has been slightly modified from the corresponding diagram in Hao et al.* (2020).) Illustration of the SAPHIRE model. Hao *et al.* extended the classic SEIR model to include seven compartments and their relationships:

S susceptible **E** exposed **P** pre-symptomatic infectious **I** ascertained infectious
A unascertained infectious **H** isolated **Rem** removed

Two parameters of interest are:

$\boldsymbol{p}_t$ the ascertainment proportion (or ascertainment rate)
$\boldsymbol{b}_t$ the transmission proportion (or transmission rate)

with the subscript *t* indicating that they change over time. In particular, $\boldsymbol{p}_t$ changes quite a bit with the level of testing, especially if there are lots of asymptomatic cases.

At present, only **I** is known with reasonable accuracy, and then only to the extent that testing is accurate, but all compartments are important for understanding the path of the virus. The reproduction number should be based on b_t, but in fact is currently being based on $p_t \times b_t$. The ascertainment rate will vary with the level of testing and how closely targeted it is to problem

areas. Increases in $p_t \times b_t$ could be for this reason, not because the underlying number of infections has increased. There have been several instances of significant increases of targetted testing occurring during the COVID-19 pandemic leading to widespread public misinterpretation of current infection numbers and risks.

Figure 2 only describes the highest level for each compartment but it is important to distinguish some sub-populations. These could be based on age, region, ethnicity, or Industry/occupation as was done in the UK using a national random survey. The behaviours of these sub-populations differ quite significantly in the UK in terms of risks of infection, and it will be the case in Australia as well, but this is only known anecdotally at present.

The unascertained (A) component contains a number of different categories – pre-symptomatic, asymptomatic, symptomatic but not yet ascertained (tested). Knowledge of each is important for understanding current infections levels as well as the efficacy of the testing protocols.

Regular scientifically random surveys of sufficient size will enable both A and I to be estimated and hence p_t and b_t. If the samples are large enough they will enable the compilation of odds ratios (as in the UK), as shown in Table 1, thereby providing insights into how the risks vary by sub-population. It will also provide estimates of most of the currently unknown basic components and sub-components in the Model, as shown in Table 2.

The Rem component includes two main categories - infected and deaths. Some of the infected may also be re-infected. There is some uncertainty about traditional methods of recording causes of death particularly for people who are co-morbid. A better measure may be excess deaths. This will also include the more than usual deaths of people who didn't or couldn't access the required health assistance because of pressures caused by the pandemic.

Quantity	Model Parameter	Status	Best data source
Susceptible	**S**	Known	ABS population data adjusted for those who have immunity
Exposed	**E**	Good approximation	Mainly population ABS data
Pre-symptomatic infectious	**P**	Unknown	Random Survey
True infection rate	$\boldsymbol{b_t}$	Unknown	Analysis is mainly based on $\boldsymbol{p_t} \times \boldsymbol{b_t}$
Ascertained infectious	**I**	Known	Epidemiological data but in national survey in UK only 29% of positive persons at time of test showed symptoms
Symptomatic but not tested	**A** part	Unknown	Random Survey
Pre-symptomatic	**A** part	Unknown	Random Survey
Asymptomatic	**A** part	Unknown	Random Survey
Ascertainment rate	$\boldsymbol{p_t}$	Unknown	Random Survey (In UK only 29% of positive persons at time of test showed symptoms)
Recovered, including Recovered and Re-infected	**REM** part	Known	Epidemiological data and follow-up of sample of infected cases
Deaths	**REM** part	Known	Epidemiological data and excess deaths
Isolated	**H**	Unknown	Number of persons who should be isolating should be known but the proportion who are actually isolating is unknown

Table 1 Sources of answers in the SAPHIRE compartmental model for some basic questions.

Heterogeneity and Dispersion

An important aspect of the impact of COVID-19 is its variable impact on different sub-groups of the population. It is vitally important to be able to characterise this heterogeneity in order to manage the pandemic effectively. Customising strategies according to geography, age, industry/occupation, ethnicity or some combination of these, may enable the development of interventions having far less impact on people's well-being and the economy. There are several ways in which information about heterogeneity can be used to advantage, including:

- Reducing the impact of compulsory isolation, by better localisation.
- Helping to inform the most effective health interventions for different sub-populations.
- Better targetted communications combined with better feedback mechanisms to ensure that important messages have been received and understood.

There are different ways at looking at heterogeneity. It may refer to (a) the probability (odds) of obtaining the virus, (b) the reproduction characteristics, or (c) risk of serious illness or death.

Table 2 shows the odds ratios for swab-positive for different sub-populations in England UK. They are derived from a scientifically random survey of 100,000 people conducted to understand COVID-19 infections. These ratios can be interpreted as the incidence of the virus compared with the reference group for that particular variable (*i.e.* age, occupation and ethnicity).

Age Group	Odds Ratio	Occupation	Odds Ratio	Ethnicity	Odds Ratio
5-12	1.1	**Care home worker**	7.7	**Asian**	1.9
13-17	1.1	**Health care worker**	5.2	**Black**	1.3
18-24	2.0	**Other key worker**	1.9	**White**	Reference
25-34	1.2	**Other worker**	Reference	**Mixed**	1.4
35-44	Reference	**Not regular worker**	1.3	**Other**	1.5
45-54	0.97				
55-64	0.68				
65+	0.52				

Table 2[6] Community prevalence of SARS-CoV-2 virus in England during May 2020: Odds Ratios for Swab Positive to COVID–19. There are several points to note:

- **Gender.** There is no statistical evidence for gender differences.
- A**ge.** (1) The odds ratio for children is slightly higher than that of the reference group (35-44 year olds).

  (2) The odds ratio for 18-24 year olds is double that of the reference group.

  (3) The odds ratio for 65+ year olds is half that of the reference group.
- **Occupation.** The odds ratios for care home worker and health care worker are extremely high. They do not explain the differences by age.
- **Ethnicity.** The odds ratio for people of Asian ethnicity (who were mostly of South Asian ethnicity in this study) is significantly higher

[6] Derived from a paper by Riley *et al*. (2020) and based on a national random sur*ey*.

In Australia, the anecdotal evidence suggests that the age and occupation patterns may be similar to the UK. Also, it appears that the relative prevalence in migrant population has been higher than for the rest of the population in the second Victorian wave of COVID-19.

It is also important to understand the heterogeneity in reproduction characteristics. It may enable answers to the following questions and development of appropriate interventions:

- What are the characteristics of the super-spreaders, including the settings for super-spreading events?
- What is the rate of reproduction for children given they are mostly asymptomatic but less likely to socially distance?
- What do we do to reduce the reproduction number in high risk workplaces such as medical centres, care facilities and meatworks?

Knowledge of the heterogeneity characteristics of fatality rates is essential in order to make sensible decisions about protections for those most at risk (*e.g.* aged care residences).

As indicated above, geography, age, occupation/industry and ethnicity are likely to be important sources of heterogeneity. There may other important characteristics (covariates) like general health (particularly diabetic status), ability to work from home, number of recent close contacts and travel movements.

To provide a simple example of the impact of heterogeneity on the reproduction number (R), if 20% of the population has an effective reproduction number of 2.5 or higher say (defined by geography, age, occupation/industry etc) and 80% of the population has an effective reproduction number of less than 1.0, then the overall reproduction number will be a weighted combination of the two with the weights dependent on the number of active cases in each sub-group. R will be close to that of the first sub-group if that also, as expected, has the highest number of active cases. Reducing R below 1 for the population as a whole requires (1) targeted interventions to the first sub-group, (2) less stringent interventions for the second sub-group but sufficient to keep their reproduction number below 1, (3) interventions to minimise leakage between the two sub-groups (*e.g.* border restrictions, protective clothing) and (4) steps to reduce the risk for those most at risk (*e.g.* the elderly). If this can be achieved, it should result in the desired health outcome but with a lower impact on the overall economy.

One limitation of the reproduction number is the averaging nature of the models underpinning the estimates. To partially overcome this, many of the models also incorporate what is known as the dispersion factor[7] (k). It is a measure of how much some infected people transmit the virus and how little others do and therefore the relative importance of for super-spreading events. Knowledge of k is important, including the characteristics of those most likely to be super-spreaders. There does not seem to have been much work in Australia in understanding dispersion with COVID-19, possibly because of the lack of suitable data to understand it. The common data source is test-and-trace data but it has to be retained in a way that it can be used subsequently for statistical analysis.

A low value of k means that a relatively small number of infected individuals are driving transmissions. It follows that if you can identify and reduce the situations that disproportionately drive transmissions, then the focus can be on these situations and other measures can be less disruptive. This is particularly important in the latter stage of a pandemic when the focus is on preventing future outbreaks. International estimates of k for COVID-19 suggest it could be relatively low, so control of super-spreading events would be quite important. The main controls could include potential super-spreading settings such as night clubs and pubs, work settings like aged care residences and meat works, and large social gatherings like weddings and entertainment events.

The Proposal

At present, epidemiological data (tests undertaken, number of positive cases, deaths) are the main sources for learning about the pandemic. These are supplemented by mobility indicators from sources such as Google GPS mobility data as well as and Apple and City Mapper data relating to requests for directions. Occasional small-scale surveys have also been conducted on the number of close contacts. However, there are several other important, indeed essential

[7] An interesting introduction to the reproduction number and the dispersion factor can be found at There's also an interesting video at https://www.youtube.com/watch?v=IgKw4rhIx5c.

sources of data[8] that should also be tapped to inform intelligent management of a pandemic. These sources include:

(a) infection testing of people randomly selected[9] by scientific random surveys of the Australian population or from sub-populations most affected by the pandemic[10]

(b) specific studies of high-risk environments such as hospitals, aged care centres, meatworks

(c) capturing test-and-trace data in a form where it could be used for subsequent statistical analysis

(d) capturing additional important demographic and socio-economic information from each person who is tested, whether through the random sample or the targeted testing

(e) information from ABS household and business impact surveys

(f) waste water surveillance programs (*e.g*. Daughton 2020)

(g) capturing data on daily numbers of close contacts possibly from the ABS Household Impacts of COVID-19 Survey together with the relevant demographic and socio-economic information

(h) more indirect sources such as data from smart thermometers, internet search engines, social media conversations, routine blood testing for other purposes, … . The potential information in such data requires further investigation for validity once data are available.

To the best of our knowledge, of these potential data sources, (c) exists, as does (g) but only on a small scale and irregularly.

[8] A discussion of how and when these sources of data may be relevant is provided in Table 3.

[9] The way of choosing such random samples may, in fact, be quite sophisticated, to ensure that it is done cost-effectively.

[10] In this connection, see the article "The opportunity lost by not introducing random testing earlier", reporting an interview with Professor Sir David Spiegelhalter FRS, Professor of Understanding of Risk at the University of Cambridge. Also, the article "Random testing in Indiana shows COVID-19 is 6 times deadlier than flu, and 2.8% of the state has been infected" by Nir Menachemi, Professor of Health Policy and Management, IUPUI, provides just one example of the important discoveries that can be made about the prevalence of a virus only by conducting a random testing process.

Table 3 contains the range of data that might be used to inform a pandemic. This begs the question: *Why hasn't all this information been available for COVID-19?* Important reasons include:

- the Departments of Health uses a single source for tracking the virus – epidemiological data and forecasts mostly based on epidemiological models developed at the Doherty Institute[11]
- aside from ABS advice relating to official statistics, lack of clear, independent, authoritative and reasonable professional statistical advice resonating at the highest level of government
- lack of an information model specifying what data are needed and for what purpose
- lack of open sharing and collegial behaviour by those scientists advising the Departments of Health

Pandemics such as the current episode lead to crises. And in a time of crisis, it is essential that people and groups who are generally in (healthy) competition work collaboratively and collegially. Data, information, models and approaches need to be made available for learning, exploitation, critical peer assessment and comparison, so that the Government can be confident that it is receiving the best possible advice available. The Pandemic Information Plan set out on the following pages seeks to correct these deficiencies.

[11] Indeed, the failure of epidemiological modelling has been in evidence in many countries, not just Australia. See Ioannidis *et al*. (2020) for a detailed analysis. To quote from their first paragraph,

> "COVID-19 is a major acute crisis with unpredictable consequences. Many scientists have struggled to make forecasts about its impact …. However, despite involving many excellent modelers, best intentions, and highly sophisticated tools, forecasting efforts have largely failed."

Data type and current usage	Explanation	Potential use
Epidemiological data on tests, deaths, *etc.*	These are the core data traditionally used by epidemiologists. Some geo-demographic detail would be available.	It is used in all phases to provide headline statistics. It is used to monitor the progress of the virus. It is used to provide inputs into models including the models to estimate the effective reproduction number.
Test-and-trace data	This data would be collected as part of the testing protocols	It could be used to provide information to support the estimation of the reproduction number and the dispersion factor. Socio-demographic analysis would be possible if this data were also collected.
Testing people randomly selected from the Australian population or from sub-populations. Data would be acquired on an ongoing basis. The sample survey process may be based on a combination of stratified random sampling and a longitudinal study, and tuned to specific pandemic management requirements.	This provides the only means of obtaining reliable estimates of several important unknown quantities (*cf*. Step 2.6). The ABS, in partnership with a health care provider, can prepare and deploy the process, which should provide vital monitoring information about the progress of the pandemic in different areas and amongst different subpopulations, and about the effect of interventions. See Appendix 4.	Relevant to both Phases 2 and 3. Because the process requires significant resources to deploy, and you are trying to survey a relatively rare population, it is likely to be applicable only when the virus has attained a certain level of prevalence. See Appendix 4. Pooled testing arrangements could be used if there are resource shortages for analysing tests.
Specific studies of high-risk environments	For example, hospitals, aged care centres, meatworks, … .	Targetted surveys for environments that may require special interventions.
Capturing important demographic and socio-economic information from each person who is tested	Once people have returned a positive test for the virus, several covariates can be captured readily, providing an important observational data resource.	All phases and all relevant data sources. The information should inform the sample survey design and help focus collection of WWS data (d) and data from indirect sources (f)
Information from ABS household and business impact surveys	This would be similar sample surveys to those currently conducted the ABS.	The content of these sample surveys may vary over time depending on the issues of concern so also have a role in the recovery phase as well as Phases 2 and 3.
Waste Water Surveillance (WWS)	If a suitable test is available, WW Surveillance is a relatively inexpensive way of providing early-warning surveillance for detecting small levels of the virus	Primarily Phases 2 & 3, but possibly Phase 1 as well, depending on the availability of a proven WW marker. Widespread use as described in Appendix 2,

	at the community or population levels.	particularly in combination with techniques like pooled testing. May have important 'upstream' application relating to detection of the virus among prospective travellers to Australia, for example by WWS for vessels arriving in Australia.
Capturing data on daily numbers of close contacts outside the household	This would be collected through household sample surveys, perhaps as a data item in the household survey referred to in (b) or as a by-product of the random sample for testing. If the sample survey was large enough, it would allow separate estimates for important sub-populations based on geography, age, occupation group and ethnicity.	Relevant to phases 2 and 3. This is a more direct proxy for reproduction behaviour than the mobility indicators currently being used and could be used to support estimates of the effective reproduction number. It can also be used to study the effectiveness of restrictions to help control the virus.
Mobility data from Google GPS and direction seeking software	This is available from Google GPS mobility data and Apple and City Mapper data on request for directions subject to privacy provisions.	This can be used to analyse the effectiveness of restrictions. It can also be used in combination with epidemiological data to obtain estimates of the effective reproduction number. It is relevant to both phases 2 and 3. A significant limitation is that it is only available for Smart Phone users who may not be representative of the population as a whole.
Indirect sources such as data from smart thermometers[12], internet searches, social media conversations, …	None of these sources is necessarily specific to a pandemic virus, although separately, and in combination, they may provide a rich observational data base to track spatio-temporal evolution of a virus. See Appendix 3.	All phases, in combination with other data. Very cheap to capture real-time data.

Table 3 Possible sources of data required to manage a pandemic

Experts often do not have the time to keep on top of a rapidly growing, very diverse and often contradictory scientific literature. They can miss important developments. They can be wrong – no-one is infallible. Better recommendations are likely to arise from contestable advice. If it

[12] See *e.g.* https://www.zdnet.com/article/smart-thermometers-deployed-to-track-coronavirus-spread-in-real-time/.

involves multiple disciplines, the advice is more likely to be based on a range of different perspectives.

Figure 3 displays three basic phases for managing a pandemic:

- Phase 1 relates to early detection of the onset of a pandemic, and the data sources that might assist in this regard.
- Phase 2 is concerned with triggering all the structures, data collection, capture and repository mechanisms and services needed to inform management of the pandemic.
- Phase 3 lists the main monitoring data source activities required.

The figure clearly omits a large amount of complex activity that does not depend directly on data and analysis, although statistical and operations research techniques can be used to ensure these actives are performed effectively. This is captured in the single line of steps across the top of the chart.

It also omits data related to understanding the economic and social impacts of the interventions to control the pandemic and what is required to support the economic recovery. In these areas, the ABS has the main responsibility for providing the required data and, based on past performance, it would be expected that they would collaborate closely with the key users on their statistical requirements as they have with the COVID-19 pandemic.

It is immediately evident from the figure that there is a very large requirement for expert statistical advice. At present, very few of these steps are in place, and aside from the ABS there is little or no ongoing high-level statistical input.

The numbers associated with the process steps in Figure 3 correspond to subsections of Appendix 1 to this document, with varying levels of detail provided depending current knowledge. Table 3 also provides a discussion of how the data sources relate to the pandemic management phases. The table includes the data sources being used at present.

Prior to the commencement of the three phases, there should be agreement on the information requirements to support the responses to a pandemic (referred to as the information model). In fact, this should be done as soon as possible so there is a 'blueprint' if a pandemic eventuates in the future. This would include addressing questions such as:

(a) How will we make early detections of the presence of a pandemic? What geographic-level data would be available?
(b) What models should we use for tracking the path of the virus and for forecasting?
(c) What data items do we need to support those models?
(d) What disaggregations do we need (*e.g.* geography, age, sex, occupation, ethnicity)?
(e) What information do we need to understand the impacts on businesses or households?
(f) What information should be used to monitor the potential for second and subsequent waves?

There will no doubt be other information requirements that could be considered by the proposed multi-disciplinary Task Force. Measures of uncertainty are also important. The Task Force should also consider the most appropriate data collections so that they can be deployed at relatively short notice if required.

The effective reproduction number (R_{eff}) and dispersion number (k) play important roles in understanding the path of epidemics. The information requirements needed to support these require particular attention.

We believe that the gross population estimate of R_{eff} is of limited use even if studied at the State/Territory level. R_{eff} may be below 1 at this level but it might be much higher for some groups. It needs to be studied and estimated at sub-population level, as it will vary considerably across different sub-populations as anecdotal evidence (or survey evidence in the case of the UK) suggests for COVID-19. This type of analysis will help identify groups where customised interventions and messaging are needed. Surveys in the UK show infections are much higher for young adults, certain occupation groups (such as health and home-care workers, unfortunately) and certain ethnic groups. Had this information been available for use in Victoria for managing COVID-19, there might have had a more nuanced response to the management of the risk. Knowledge of the dispersion number is also important for targeting interventions especially as the number of infections get to more manageable levels.

There may not be sufficient data available to estimate the reproduction numbers at sub-population levels at present but there are surrogates that have been used internationally by

statisticians but appear not to be used in Australia. For example see Riley et al (2020), the odds ratio is a less data intensive way of looking at sub-populations. Furthermore, there is considerable international research taking place into the estimation of reproduction and dispersion numbers so better methods may become available[13].

In particular, we believe that a well-designed scientifically random survey of the relevant population plays a very important role in satisfying many of the information requirements. It can also be used to underpin micro-simulation models to better understand likely patterns of transmission. Such surveys have been conducted in many places outside Australia.

[13] The Royal Statistical Society is planning a meeting later in 2020 that will be specifically addressing the issue of estimating the Reproduction Number.

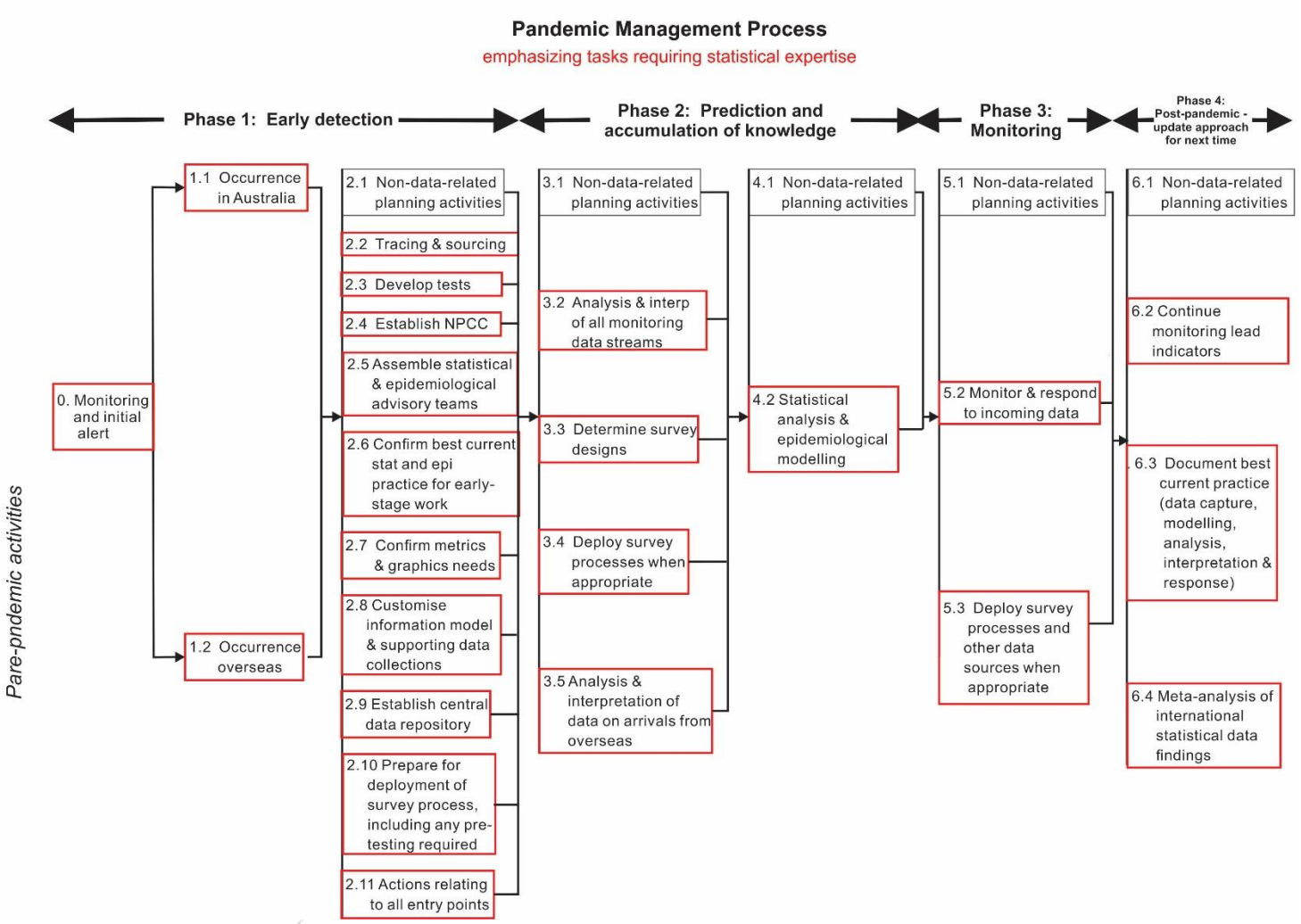

Figure 3. (Same as Figure 1; repeated here for convenience.) The diagram represents management of a pandemic in three main phases, focusing on the requirements for data acquisition, expert analysis and interpretation, and presentation in each phase. Each box outlined in red involves tasks requiring statistical expertise. A variety of statistical skills, knowledge and knowhow is essential for efficient and effective management of the pandemic. Each of the numbers corresponds to more detailed information in the associated Technical Proposal. NPCC = National Pandemic Coordination Commission, currently termed the NCCC. The top sequence of boxes 2.1, 3.1, … represents the other major planning processes not requiring input of significant statistical expertise.

Return to normalcy

A key decision is whether the underlying strategy is suppression or elimination. For COVID-19, the National Cabinet agreed on a suppression strategy. Monitoring (Phase 3 on Figure 3) is crucial to both. A return to normalcy requires early detection so that testing, isolating and tracing can be put in place quickly and systems do not get overwhelmed by large case numbers. If detected and controlled early, the interventions do not need to be as economically and socially damaging. In particular, it could avoid the huge damage due to disruptions caused by moving in and out of different levels of restrictions.

For COVID-19, the reliance has been on epidemiological data for early detection but there can be significant lags in detection which can make its management more difficult. Waste-water surveillance and testing provides an opportunity to detect viruses much more quickly. Studies at Yale University estimate that it is a 5 day leading indicator of people showing up positive in testing, assuming they do get tested (see https://globalnews.ca/news/6958321/sewage-coronavirus-ottawa-yale/). It also provides a means of testing for any form of transport arriving in Australia which will be crucial for managing the global travel component of the return to normalcy.

Waste-water surveillance is a key element of Box 5.2 and deserves more attention than it has been getting to date in Australia with COVID-19. A good spatial sample design is crucial to ensure the probability of detecting traces of the virus whilst ensuring the tests are being used efficiently. The spatial sampling design would need links to data about the population (*e.g.* Census data) from which the waste-water has been derived.

As with all tests there is the risk of false positives, depending on the degree of sensitivity of the tests. If tests are not perfect, multiple tests should be taken to minimise the chance of reacting to what might be a false positive test.

A well designed waste-water surveillance system will require waste-water experts, public health officials, statisticians and epidemiologists working in close collaboration.

Concluding remarks

1. There is a critical need for strategic statistical oversight of the whole process of anticipating, managing and learning from the current pandemic to improve the quantitative information and advice provided to policy makers. This has not been the situation in Australia – or indeed, in many other countries – to date.
2. The Australian Governments' responses to the COVID-19 pandemic may have proved effective to date but the information available to them was far more limited than was available in many other countries.
3. The costs of collecting and analysing additional data are very small compared with the human and economic costs of a pandemic. The additional data will provide important insights that would not be available from the data used during the first wave of the COVID-19 pandemic.
4. Tests based on a national, scientifically random survey are one important response (undertaken in most Western European countries) but have been rejected in Australia seemingly because of concerns about wasted tests. They are not wasted if they provide information on the actual level of infection with socio-demographic characteristics (*e.g.* children) including asymptomatic and symptomatic cases that have not been tested. Furthermore, they are not wasted if supplemented by data on characteristics such as the number of close contacts in the previous 24 hours. If test analysis resources are limited, pooled testing arrangements could be instituted with input to the design by statistical experts.
5. Test-and-trace is a vital response to pandemics. It also can provide a rich source of data for understanding the path of the virus but needs to be managed in a way that it can be used for subsequent statistical analysis.
6. There is much to be learnt, at relatively low cost, from less direct data sources such as Waste Water Surveillance to provide early alerts to the presence of a virus.
7. Potentially, other sources such as smart thermometers, internet search engines, social media conversations, routine blood testing for other purposes, could be used for early alerts. These need to be investigated.

We strongly recommend a multi-disciplinary Task Force be established to determine the information requirements for managing a pandemic and how they might be met. The membership should include a statistician with statistical modelling and analysis expertise, an official statistician, an epidemiologist, a medical researcher, an economist and a public health official.

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Appendix 1. Detailed discussion of the steps in the Pandemic Information Plan

Phase 1: Early detection

Step 0 Monitoring and Initial alert (*cf*. Figure 1)

If not already in place, processes should be instantiated ready for deployment as the situation demands. This relates particularly to "upstream" activities that may hinder or prevent the arrival of the virus in Australia. Statisticians skilled in the analysis of large and complex spatio-temporal data will need to be involved, to develop the basic methods for extracting helpful and timely information, and to devise and implement interactive graphical displays that make it easy for decision-makers to interrogate the information.

Step 1.1 Virus initially detected in Australia

Step 1.2 Virus initially detected overseas

Take the first step towards deploying the agreed data collection processes.

Step 2.2 Tracing and Sourcing

There are two forms of tracing. The first form is when a positive infection has been ascertained in a person. Statistical expertise is required to determine the optimum contact tracing arrangements (it is a limited resource) and the data that should be obtained as part of tracing. The full statistical potential of this important source of data has not been realised for COVID-19. For example, it could be used to learn the characteristics of super-spreaders and the dispersion factor (k). The second form will depend on how the virus has been detected. The relevant data streams (*e.g.* through waste water testing) will need to be explored, possibly in conjunction with new sources of data, to ascertain the initial location and spread. There is a clear need for statistical expertise.

Step 2.3 Develop tests

Biostatistical methods are an indispensable part of the development, evaluation and deployment of tests; for example, analysis of the sensitivity and specificity of tests and procedures for overcoming deficiencies in these tests.

Step 2.4 Establish the National Pandemic Coordination Commission (NPCC)

Depending on the charge for the NPCC, a senior expert statistician needs, ideally, to be a member of the NPCC. The statistical skills available within the ABS is very important but the statistical skills required for a pandemic go beyond those available in the ABS.

Step 2.5 Assemble statistical and epidemiological advisory teams

We reiterate our earlier comment:

> *Pandemics such as the current episode are times of crisis. And in a time of crisis, it is essential that people and groups who are generally in (healthy) competition need to work collaboratively and collegially*.

There will be plenty of honour and glory to share, provided that the pandemic is managed well.

Step 2.6 Confirm best current statistical and epidemiological practice for early-stage work

Step 2.7 Confirm metrics and graphics needs

This absolutely vital step has been, in significant part, overlooked to date, and to the extent that it has been addressed in Australia there are important deficiencies and misunderstandings. Quantities that need to be estimated are described in the section on Models.

At present, no reliable method is in operation to provide satisfactory estimates of all the components of the Model. Such estimates would need to be based on selecting people randomly from the (Australian) population and administering tests, which has yet to be done (see Phase 2).

To manage the response to a virus efficiently, it is essential to understand how these quantities are changing over time, and the differential effects of a number of variables, including

(i) regions and parts of cities and towns

(ii) age groups

(iii) ethnic communities

(iv) industries and workplaces

(v) interventions

Step 2.8 Customise information requirements and supporting data collections

Each pandemic will have its own characteristics although the core information requirements will be the same. Epidemiologists, statisticians, health policy officials and economists should collaborate on actual information requirements for this pandemic. This should happen under the oversight of the NPCC.

Step 2.9 Establish the central data repository

It is important that there be a central data repository be established so that all AUTHORISED persons (only) can access the same data and undertake the research effort required to support Government decisions. It would be centralised in a logical sense but may comprise more than one physical data base. However, there would need to be a Data Custodian to manage the repository, the integrity of uploaded data, authorisation of access, the security of the data bases, and to ensure the confidentiality and privacy requirements are met.

Step 2.10 Prepare for the deployment of survey process, including any pre-testing required

See Appendix 4

Step 2.11 Actions relating to all entry points

The statistical data requirements should be determined whether quarantine is used or not. You would imagine that some testing would be done on arrival. Information such as countries visited in the last 2 weeks would be important to associate with the test data. Only the main country visited is currently collected on Incoming Passenger cards.

Phase 2: Prediction and accumulation of knowledge

Step 3.2 Analysis and interpretation of all monitoring data streams

Statistical expertise is essential. Epidemiological data will be a very important data source. Epidemiologists will have the main responsibility for the interpretation of this data with support from statisticians especially when modelling is not straight forward. There will be other important data streams such as random surveys, waste-water sampling and 'big data' sources.

Statisticians should have the main responsibility for the analysis, interpretation and presentation of these data for the use by the NPCC, health policy officials, epidemiologists and others.

Step 3.3 Determine random sampling survey design

Assuming the ABS address file is used as a framework for the survey, and they are involved in the data collection together with a health partner, this would be primarily a responsibility of the Australian Bureau of Statistics.

Step 3.4 Deploy survey processes when appropriate

This would be the responsibility of the service provider, the ABS in the case of surveys for which they are responsible. External statistical advice may be useful in determining when the prevalence of the virus is sufficiently high to justify a random survey. The survey does not need to be deployed nationally. It could be deployed at the State/Territory or the sub-State level depending on where the virus is present.

Step 3.5 Analysis and interpretation of arrivals data

Statistical expertise essential for the compilation and analysis of data obtained in respect of international arrivals.

Step 4.2 Statistical analysis and epidemiological modelling

Epidemiologists in collaboration with statisticians, especially on the fitting of models, when data are subject to uncertainty.

Phase 3: Monitoring

This is the phase when the first wave of the pandemic has largely finished but there is a need to guard against second and subsequent waves.

Step 5.2 Monitor and respond to incoming data streams

Early detection is crucial to the management of the pandemic. The main data sources will be waste-water data, epidemiological data, and potential Google search and social media data. If a valid test for waste-water surveillance is available, the tests should be ongoing using pooled

sampling arrangements to reduce the cost of the testing and analysis. Statistical expertise is essential in their presentation and interpretation especially when the numbers are relatively small.

Step 5.3 Deploy survey process and other data sources when appropriate

Australian Bureau of Statistics has the main responsibility for surveys they conduct. External statistical advice may be useful in determining when the prevalence of the virus is sufficiently high to justify a random survey. The survey does not need to be deployed nationally. It could be deployed at the State/Territory or the local level depending on where the virus is present.

Phase 4: Post-pandemic

Step 6.2 Continue monitoring lead indicators

See Step 5.2.

Step 6.3 Document best current statistical practice (data capture, modelling, analysis, interpretation and response)

There is strong international collaboration among statisticians, both formally under the auspices of Institutes like the International Statistical Institute, and through informal networks. For example, there has been a lot of collaboration between UK and Australian statisticians. There should be comparisons of the strengths and weaknesses of different statistical practices to attempt to identify best practice for particular circumstances.

Step 6.3 Meta-analysis of the different statistical findings

Meta-analysis of the different statistical findings (*e.g.* asymptomatic cases and their demographic profile) would also be worthwhile. As one example, the survey conducted by the UK Office of National Statistics showed that only 29% of the persons who tested positive showed symptoms at the time of the test. This was especially the case for children and young adults.

Appendix 2. Waste Water Surveillance for COVID-19

- The use of waste water sampling to detect bacteria, toxins and viruses is a well-established practice. The more recent research has been around the tests to identify COVID-19 and whether they work effectively.
    - Statisticians around the world are developing ways of using sewage to locate new infection hotspots and track a second wave of COVID-19.
    - The CSIRO/UQ collaboration (see below) has had initial success in detecting the COVID-19 gene.
- Waste Water testing could provide early warnings of community wide emergence or resurgence. It can also solve the problem of insufficient clinical diagnostic testing. It could also serve to better target and direct the application of diagnostic testing. It might be the only way of targetting rapid and relatively inexpensive mass testing of a local population. Surprisingly, it has not been used widely by epideiologists or public health officials. (Daughton, 2020)
- The tests are being extensively trialed in around 3000 sites around the world. A positive outcome is that successful tests would provide real time data. The consensus appears to be that the tests will detect presence or absence of COVID-19 with a reasonable degree of accuracy (knowledge of the extent of false positives and negatives will be important to assess whether multiple tests are needed). They are not so confident about using this data to estimate the level of prevalence but presumably there would still be signals of the highest risk areas.
- Waste Water testing is close to being ready for deployment in Australia (see below). It has already been used successfully in Singapore and in a number of US locations and there are definite plans to implement at every waste water treatment facility in the Netherlands in a few months' time following successful trials there. There are also plans to do so in UK (they have recently announced a sampling study) and South Africa. The New Zealand CMO regards it as part of their surveillance system. Government funding has been allocated for the development of a waste water sampling scheme. Testing waste water works for asymptomatic cases.
- The South Australian Government said they about to roll out a system in collaboration with Water Research Australia but the main game seems to be with CSIRO Land and Water Research (led by the Queensland Chief Scientist) and the Queensland Alliance for Environmental Health Sciences at UQ. They seem well advanced in their work and have stated that the next step is to develop a capacity to

deliver a national program. They also said that the tests can be used to identify areas where more extensive testing can take place.

- CSIRO are also part of a new global scientific collaboration, COVID-19 WBE Collaborative, which brings together more than 50 global experts in water-based epidemiology (WBE) to share testing methods and data on wastewater-based surveillance for the current and future disease outbreaks.
- The next step is to build the capacity to deliver a national program.
- The test kits are expensive and in limited supply so optimum design is important. It may also need to be 2 phase (a form of group testing). This is what is being proposed in Connecticut *i.e.* the first stage sampling would be at a site with fairly large population coverage with more localised sampling only taking place where positive cases are detected.
- There are some very important statistical issues involved in the design and analysis of waste water sampling.

Appendix 3. Other potentially useful data streams

Smart thermometers

- https://www.nytimes.com/2020/03/18/health/coronavirus-fever-thermometers.html
- https://www.advisory.com/research/health-care-it-advisor/it-forefront/2020/04/qa-kinsa-real-time-disease-tracking-covid-19
- Price appears to be from USD30.

Google searches

- Patient data on " a specific combination of cough and diarrhea, along with anosmia (a loss of taste or smell) and excessive sweating, …" https://venturebeat.com/2020/04/21/ai-indicates-which-symptoms-might-be-leading-indicators-of-covid-19/; see specific preprint https://arxiv.org/ftp/arxiv/papers/2004/2004.09338.pdf

Appendix 4. Outline of proposed Random Sample Survey process

In the study of the prevalence of COVID-19 in the UK in May 2020 by the RSS Covid-19 Task Force (Riley *et al.* 2020), the authors conclude by suggesting that

> "… [a] nationally-representative population-based surveys of SARS-CoV-2 infection may greatly improve situational awareness. An important feature of the data presented here is that they are independent of service-oriented testing processes, the representativeness of which varies substantially over time and space. Repeated rounds of studies similar to that reported here will enable continued monitoring of key epidemic properties, including R estimates at regional and local levels, to guide locally-optimized interventions."

We recommend the following arrangements for developing and implement a random sample survey process for Australian purposes. This would complement the data obtained through existing testing regimes.

- It should be conducted by the ABS partnering with health authorities and possibly epidemiologists and other health researchers
- The ABS address file should provide the framework from which the sample is selected. All persons within the selected household, including children, should be included in the survey.
- Those areas not affected, or minimally affected by the pandemic, should be excluded.
- Stratification and optimum allocation would be used to improve the efficiency of the sample design. There would be some clustering in the design to improve cost-effectiveness but, since probabilities of selection will be known, unbiased estimates can be obtained.
- There should be a separate sample of workplaces at high risk using the ABS Business Register. This would include samples of health workers identified through their workplace (if not already done through existing testing regimes). Sufficient information should be obtained to adjust for the fact that these persons will have multiple chances of selection in the survey.

- The ABS would use its usual survey procedures and through a telephone or internet interview following initial mail contacts to maximise response. I t would obtain the required socio-demographic information (including occupation/industry), information on the number of close contacts and permissions to undertake virus testing. The actual testing would be managed by the health authorities.
- The usual contact tracing arrangements would apply to positive cases detected.
- The survey should not be undertaken until there was a critical mass of at least 30 cases per week. For a sample of 10,000 per week, and a population of 4 million in the target areas, this will occur when it is forecast to be 12,000 active cases (adjusting for asymptomatic cases and symptomatic cases that have not been tested). If the target population is 1 million, this will occur when there are 3,000 active cases. The survey should be deployed when it is expected that there will be at least 30 cases identified in the sample. In Melbourne, there was more than 6000 cases at the end of July.
- The sample size would accumulate over time increasingly improving the accuracy of the data on the characteristics of persons who are positive to the virus. It would also enable longitudinal analysis.
- The information collected by the ABS would be under the provisions of the Census and Statistics Act. The ABS would be responsible for compiling and publishing aggregate tables. Authorised researchers would be able to do research based on the microdata.
- The accuracy of the survey is quite dependent on the proportion of persons who are prepared to take the test. If this could be made compulsory, as has been done for breath testing for alcohol or illicit drugs, a more accurate survey would result. The required legal provision should not be part of the Census and Statistics Act.

NOTE: The Office of National Statistics in UK conducted a successful national random survey for COVID-19 in partnership with the Ministry of Health and analysts from Oxford University and Imperial College. It would be worth talking to them about what worked well and which aspects of the survey could be improved.

Appendix 5. Short Bios – NF & DT

Dr Nick Fisher is Principal of ValueMetrics Australia, an enterprise that carries out research and consulting primarily in the area of Performance Measurement. After 30 years as a statistical consultant and researcher in CSIRO, he left his position as a Chief Research Scientist in May 2001 to found ValueMetrics Australia. Whilst in CSIRO, he led the development of CSIRO's Organisational Performance Measurement (OPM®) system, which has been applied successfully in a number of private and public enterprises, and has been part of graduate programs at Wollongong University and Mount Eliza Business School. He has published over 130 articles and books on a range of statistical and management topics. A book entitled *Analytics for Leaders: A Performance Measurement System for Business Success* was published by Cambridge University Press in October 2013.

Nick carries out research and consulting in Performance Measurement, with particular emphasis on improving quantitative reports to Boards and top management, focusing on stakeholder satisfaction (customers, employees, partners, ...). His current interests relate to Performance Measurement and improvement processes in connection with Research Quality, Corporate Culture, Safety Culture, and the deployment of Government policy, and Strategic Planning, in which areas he has consulted to a wide variety of business, industry and Government clients in Australia and overseas. Current projects include the introduction of strategic planning and associated measurement throughout the Mellon College of Science at Carnegie Mellon University, and coordination of an international project to develop Data Science courses for high school students and their teachers.

Formal qualifications include a PhD from the University of North Carolina, and a DSc from the University of Sydney. He is professionally accredited by the Statistical Society of Australia and by the American Statistical Association and is a Visiting Professor of Statistics at the University of Sydney. He is a Past President of the Statistical Society of Australia, and of the International Society for Business and Industrial Statistics.
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Dennis Trewin AO FASSA was the Australian Statistician and head of the Australian Bureau of Statistics from July 2000 until January 2007. Prior to that he was Deputy Australian Statistician and, from 1992 to 1995, Deputy Government Statistician in New Zealand. He has worked as a statistical consultant on assignment with a range of countries and with the UN, OECD and World Bank.

Dennis has held a number of other positions such as an Australian Electoral Commissioner, an Associate Commissioner at the Productivity Commission for the study into the Not for Profit Sector, and a Trustee and Board member for the Australian Government Superannuation Fund. He has been Chairman of the Advisory Board of the ARC Centre of Excellence for Coral Reef Studies, Chairman of the Policy and Advocacy Committee of the Academy of Social Sciences of Australia and the Australian Mathematics Trust. He is or has been an Adjunct Professor at Swinburne, Curtin University, University of Canberra and the University of the South Pacific, and a Council Member of the University of Canberra.

He has been recognised as an Officer in the Order of Australia, received a Centenary Medal for his contribution to statistics and an honorary doctorate from James Cook University.

He has been a Past President of the Statistical Society of Australia, and is professionally accredited by the Statistical Society of Australia. Internationally, Dennis has been President of the International Statistical Institute and the International Association of Survey Statisticians. He was Chairman of the Global Executive Board for the 2005 round of the World Bank's International Comparison Program.