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Smartphone-Based COVID-19 contact tracing apps – antipodean insights

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Smartphone-Based COVID-19 contact tracing apps – antipodean insights

Paper presented at ITS Europe conference in Gothenburg, June 2022

Bronwyn E. Howell and Petrus H. Potgieter*

Abstract

The COVID-19 pandemic has elicited a plethora of responses from health authorities. Even as vaccines have become more readily available, contact tracing has retained a central role (Fetzer & Graeber 2021; Ferguson et al. 2020; Pierucci & Walter 2020). Huge resources have been applied to expand testing and tracing capabilities for this disease, including smartphone applications aimed at identifying and managing contacts with infected person (Howell & Potgieter 2021; Li & Guo 2020). Yet, despite these nontrivial investments, the body of academic literature evaluating the effects of the smartphone-based applications effects – either in respect of the extent of their use or their effect on infection transmission rates – remains scant.

In this paper we build on and extend prior analysis of data up to November 2021 (Howell & Potgieter 2022) of uptake and usage of New Zealand’s QR code-based application New Zealand COVID Tracer (NZCT). Because of the unique circumstances in New Zealand, which has been one of the last countries in the world to experience entrenched widespread community transmission of COVID-19, we are able to explore the effects of a number of different independent variables on the uptake and use of the application, including changes in the level of community transmission as a proxy for the risk of infection and various policy interventions, including mandatory requirements to use the application on entering virtually every business or community premises nationwide from 7 September 2021 – regardless of the level of either lockdown or infection risk in different parts of the country.

Rather than focusing on the effects of the application on infection rates, our paper focuses on the nexus between policy settings, pandemic state and application performance, using a framework derived from multidisciplinary international literature. This framework

- incorporates data and changes in policy settings between December 2021 and (around) May 2022 for New Zealand; and
- includes an international comparison with regard to
 - conformity to privacy and security norms,
 - fitness for purpose and
 - feasibility and effectiveness

in a longitudinal study of the usage and effects of smartphone-based COVID-19 contact tracing applications.

We find that, consistent with previous evaluations, NZCT has likely had negligible effect upon the rate of infection transmission in New Zealand, due to the comparatively low number of scans made by each active user on any given day. Rather, the application has proved to have possibly been an impediment to effective public health management of the pandemic as actual infection rates have increased, due to the large number of “false positive” locations identified leading to bottlenecks in testing facilities. While theoretically contact tracing has a role to play within an elimination strategy, both contact tracing and location-based applications such as NZCT supporting it cannot scale up effectively when infection rates increase.

Somewhat paradoxically, as the infection risk to individuals increases, the public health benefits and ability to process application information reduce. Yet, benefits still may remain for individual decision making from Bluetooth-enabled proximity indicator functions and the management strategy shifts to accommodating the infection. This suggests that the design and use of smartphone-based contact tracing applications should change as the characteristics of the virus and local infection patterns change. New Zealand offers a live experiment where the application did not change as these other factors changed, leaving an ill-suited application in mandatory use long

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after it was of any practical use. End users rapidly realised this ineffectiveness, when mandatory use was made optional, scanning usage collapsed, even though residual value remained in the Bluetooth proximity capacities.

While our empirical analysis focuses on New Zealand and NZCT, the framework developed for inquiry and our broader findings are generalisable for use in evaluating other smartphone-based contact tracing applications and policies in other pandemic contexts.

1 Introduction

The COVID-19 pandemic has elicited a plethora of responses from health authorities. Even as vaccines have become more readily available, contact tracing for long retained a central role (Fetzer & Graeber 2021; Ferguson et al. 2020; Pierucci & Walter 2020). Huge resources have been applied to expand testing and tracing capabilities for this disease, including smartphone applications aimed at identifying and managing contacts with infected person (Howell & Potgieter 2021; Li & Guo 2020). Contact tracing as a tool in epidemic management is much older than the current pandemic but smartphone based applications had previously been a tool only in theory (Cebrian 2021).

There is a growing body of literature, over a wide range of academic disciplines (health services, engineering, social policy and economics – to name a few), describing the applications and evaluating their implementation, acceptability and/or effectiveness. The vast majority of these evaluations were undertaken at a single point in time, within the particular policy and pandemic state contexts in which the application was developed and/or implemented. By now, many of these applications have been in use for two years already. In the absence of experience or evidence, many were initially speculative in their assessments. Others did have the benefit of data to support the evaluations, but were assessed at a specific point in the evolution of both the policies governing application use and the variant of virus prevalent (e.g. Alpha, Delta, Omicron, etc.) when the data were collected.

While undoubtedly much has been learned from individual evaluations, we suggest that future policy-making regarding contact tracing and the development and use of smartphone applications, both in relation to COVID-19 and other infections, will be better informed by a more nuanced evaluation taking into account the particular challenges posed by the different (and changing) objectives of the jurisdictions where the applications were deployed and the characteristics of the different versions of the virus. To that end, we develop a framework for analysing the effectiveness of various smartphone-based contact tracing applications given the dynamic states of pandemic management policies, contact tracing strategies and virus states observed over the period from May 2020 to the present. We apply the framework to evaluate the performance of the New Zealand application New Zealand COVID Tracer (NZCT). This analysis builds on and updates our longitudinal analysis of NZCT, documented in the conceptual analysis at implementation in May 2020 (Howell & Potgieter 2021) and empirical analysis from May 2020 to November 2021 (Howell & Potgieter 2022).

We conclude that if smartphone contact tracing applications are to be useful, their purpose must be clearly defined and the application well-aligned to delivering it. Automated applications primarily intended to empower end-users to manage their own exposure to risk (e.g. decentralised, Bluetooth-based proximity alerts) perform different roles from applications primarily intended to facilitate centralised management of population risks (such as NZCT). Centralised contact tracing systems are challenged when infection numbers are very large and incubation periods are short (or become shorter), so expectations of them must be confined to what is possible given these constraints.

2 Background

Case investigation and contact tracing form part of a multi-pronged approach (alongside other strategies such as lockdowns and border closures) enabling public health authorities to “fight” (or more correctly, control) the spread of infectious diseases (CDC, 2020). During Case Investigation, public health staff work with a patient (index case) to identify individuals with whom they have been in sufficiently close contact while infectious and thus likely have transmitted the infection. Contact tracing is the process by which the contacts identified are contacted, warned of their potential exposure to infection, and given instructions about how to proceed now that they have this knowledge. Depending on the closeness of contact (corresponding to likelihood of becoming infected), these instructions may be to monitor for symptoms (low risk) through to isolation and immediate presentation for testing (high risk).

The earlier that individuals likely to be infected are notified of their risk, and the earlier they take the requisite actions, the greater is the expected effect on slowing down the rate at which the infection passes through a community. If the number of index cases is small, and contact tracing is fast and effective (i.e. correctly identifies the people who have actually been infected, but not the “false positives” who have been in contact but not infected), then infection transmission can be stopped (i.e. infection is eliminated from the community). And even if the

infection cannot be eliminated, effective contact tracing can slow the rate at which transmission occurs, thereby spreading out demand for the scarce health care resources needed to treat infected individuals (e.g. doctors, nurses, hospital places, etc.). Thus, it can contribute towards more efficient utilisation of health care resources and reducing the likelihood that hospitals will be overwhelmed (Verrall, 2020).

Smartphone-based contact tracing applications have a role to play in supporting case investigation and contact tracing when they enable faster identification and notification of close contacts of infected individuals, and do not increase demand on other parts of the health care system. For example, if an application identifies close contacts likely to have been infected, but an even larger number of “false positives” who have not been infected, and instructs all to present for testing, then testing demand increases. It will take longer to test and analyse the proportion of samples that are from truly infected individuals, thereby slowing down the time taken to isolate and treat them, relative to the case without the application (Howell & Potgieter, 2022).

Evaluation of smartphone-based contract tracing applications therefore must be done in the context of the wider systems they support. If their primary purpose is as tools to assist in achieving public health objectives (e.g. virus elimination, smoothing demand for health care resources), then their design and performance measures will differ from those of an application (independent of public health activities) primarily intended to inform an individual of their level of risk from sources that they would otherwise not have been aware. Furthermore, it would be expected that design and use of the applications would evolve as both policies and the characteristics of the virus evolve in response to it.

A large and growing body of literature now exists on the use of smartphone-based applications for COVID-19 management. Zetterholm et al. (2021) provide a comprehensive international review of recent studies, finding that acceptance and use of the applications varies across national cultures and sociodemographic strata, but can be classified across eight dimensions: trust; privacy; social responsibility; perceived health threat; experience of technologies; performance expectancy and perceived benefits; and understanding. Some, such as Munzert et al. (2021), Williams et al. (2021) and Samuel et al. (2022) focus on consumer perceptions and experience, and their effects on uptake and utilisation. Other studies, such as those of Martin et al. (2020), Meijerink et al. (2021) and O’Connell et al. (2021), examine the different technologies underpinning the applications, notably the use of Bluetooth for measuring proximity between devices for a specified period of time as a proxy for the identifying close contacts. Some examine specific applications in particular contexts, with detailed empirical assessment of outcomes (e.g. Vogt et al. (2021) in New South Wales, Australia) while others take a regional perspective (e.g. Albertus & Mazoka (2022) – Africa; Akinbi et al. (2021) – East Asia).

3 Evaluation framework

The inevitable consequence of the innumerable of applications and analyses that has emerged has been, as Du et al. (2020) observe, a veritable “Tower of Babel”. This has led to calls such as that of Colliza et al. (2021) for some general principles to be used to evaluate and compare applications in a way that facilitates learning for ongoing policy development. Our paper in part rises to this challenge.

We propose the evaluation of such apps along three axes.

1. Conformity to norms
2. Fitness for purpose
3. Feasibility and efficiency

The three axes are to some degree mutually dependent, inevitably. We discuss the three axes in the subsections that follow.

3.1 Conformity to norms

Naturally, any app that authorities encourage the entire population to use, should conform to legal and reasonable expectations of privacy and not expose users to possible discrimination. Furthermore, the app should offer reasonable value to users under the expected levels of uptake in the targeted population. This is a complicated balance that should be carefully considered as privacy and security concerns (especially) will affect uptake and utility. In Western democratic societies such as New Zealand, privacy concerns have been of primary importance.

The issue goes beyond the trade-off between privacy and effectiveness described elsewhere (e.g. Seto et al. 2021). It also touches on what users might consider as a reasonable contribution (through use of the app) to the public good. A very detailed discussion of technical (and other) desiderata was included in a list of guidelines for such apps as early as April 2020¹ and even though they are perhaps a bit idealistic, represent a good checklist for

¹Chaos Computer Club, 10 requirements for the evaluation of “Contact Tracing” apps, <https://www.ccc.de/en/updates/2020/contact-tracing-requirements>.

evaluating applications with regard to conformity to societal and legal norms.

The utility which individuals derive from using the app will depend on how widespread the use of the app is so there are likely to be strong network effects. These effects are attenuated when infection is widespread however: if an individual is almost certain to have encountered another individual with an active infection within (say) any week, then the utility will be low. This indeed, is one of the reasons for contact tracking and tracing having traditionally been employed for diseases with a small number of infections and relatively well-defined transmission opportunities.

While existing studies have classified applications along a dimension of centralised and local/distributed control, this has been based upon whether the data collected by the application is stored and managed in a centralised database or on the handset, and has been used primarily to address matters of privacy and technical efficiency (e.g. Schneider et al., 2021; Panchal et al., 2021). We suggest that these technical matters are more properly addressed in relation to Conformity to Norms and/or Feasibility. For our purposes, the matter of centralisation versus decentralisation relates to the purpose of the application – either a centralised (population-based) purpose or a decentralised (individual one). We note that in our literature review, we found no papers that discussed or distinguished applications along this dimension, which we consider is fundamental to assessing Fitness for Purpose.

3.2 Fitness for purpose

Apps should fit the purpose for which they are being deployed, corresponding to the state of development of an epidemic. If the goal of public epidemic management is virus elimination, then the app should support elimination. If the objective is contact tracing and isolation of possible infected individuals until such time as their status can be determined (“containment”), then the app should support that. If the policy objective changes (for example, an elimination strategy is abandoned, to be replaced by a containment strategy), then the purpose of the application, and hence its functions, will necessarily change. Thus, fitness for purpose must be considered dynamically.

Central to consideration of ‘Fitness for purpose’ is the role of contact tracing in pandemic management in the first place. Historically, contact tracing has been used to reduce spread in a population of diseases with relatively low levels of incidence and specific, well-defined and easily-controlled means of transmission, such as tuberculosis and some sexually-transmitted infections. It is a time-intensive activity, hinging on case investigation, and requires considerable level of skill interviewing the index case to identify close contacts needing further follow-up, and discretion in notifying them, to ensure

- the privacy of the index case is respected but
- that communication of what the contact must do next is both clear and adhered to.

Contact tracing is effective when cases are small in number, but is very costly to scale up when infection numbers increase. It was known, before the COVID-19 pandemic, to be effective when transmission is localised and most cases can be identified but not so much when transmission is widespread and chains of transmission not very well known (Dhillon & Srikrishna 2018).

When the incubation period of the disease is long, there is time for for the necessary information to be gathered and contacts notified before they pose a significant infection risk to others. But as the incubation time shortens (e.g. Delta compared to Alpha COVID-19 variants), the physical ability to process the necessary information and act in sufficient time reduces. The infectiousness of the illness is a further factor. The higher the probability that an index case will infect an individual with whom sufficient contact is made (e.g. Omicron compared to Delta), the faster the infection will spread and the less time there is for contact tracing activities to take place if they are to be effective.

As observed in the United Kingdom in 2020, contact tracing activities became untenable as case numbers rose exponentially during the first wave of COVID-19 infection (Williams et al. 2021). Schneider et al. (2021) recommend that applications supporting centralised contact tracing activities should be employed only in the management of isolated outbreaks (to facilitate elimination strategies) or when outbreaks are in decline (i.e. when the number of new cases falls to a threshold manageable within physical resources) and the threshold of manageable case numbers has been reached. Expectations for the applications therefore need to be adjusted as these (exogenous) factors change.

However, this presumes contact tracing applications are intended only to support public health policy objectives of constraining infection spread. The applications may serve another purpose, simply by informing individuals that they have been in close contact with an infected individual, thereby prompting changes in individual behaviour that would not have occurred if that information had not been available, regardless of any wider public health objective being pursued. Risk as addressed by public health authorities is a population-based concept, with infection and efficiency outcomes measured at an aggregate level. For an individual, there are only two possible

states: exposed to infection and not exposed. What matters for individual decision-making is uncertainty about which state the individual is in. If an application's purpose is simply to inform an individual that requisite contact has occurred, then the individual can make behavioural choices accordingly (e.g. not isolate if there is no contact and hence no risk of being infected; be more alert to symptoms and self-manage testing activities if that is an option). In this case, the effectiveness of the application is less affected by the issues of scale, incubation time and infectiousness, although it can have implications for demand for specific health care services (e.g. testing resources).

3.3 Feasibility and efficiency

Whatever the app's purpose, it should be possible to achieve that purpose with existing ancillary services such as testing, quarantine and manual contact tracing. Testing facilities should have the capacity to conduct the number of tests that are likely to be in demand as a result of contacts identified (including with the app) and similarly for manual tracing (which is very labour intensive). It should also be efficient so that the demand that the app induces for other services such as testing, does not reduce the efficiency of those services. An overall assessment of the efficiency of Australia's COVIDSafe app over a six-month period in 2020 by Vogt et al. (2022) concluded, for example, that the app alone had prevented zero public exposures to the virus. That is, it identified no additional close contacts that had not already been identified using the standard manual contact tracing activities. Contact tracers had a negative view of the app, as they found accessing and processing the additional information time-consuming. The authors of the study acknowledge that low take-up in the population had likely been a factor contributing to the low number of contacts identified by the app, but did recognise that poor integration of the non-app tracing data with the app data as a systemic failure.

Howell & Potgieter (2021) identified the features

1. population adoption rate and actual usage;
2. percentage of actual contacts identified by the app (true tracking positives);
3. percentage of identified contacts who are not actual contacts (false tracking positives); and
4. the ease by which the app allows authorities to reach identified contacts (tracing efficiency)

as critical to the effectiveness of smartphone tracing apps. Furthermore Kim & Paul (2021) found that "nearly 75% to 95% of the population need to participate in automated contact tracing for it to be effective". In their analysis this minimum fraction can be identified as

$$f_e^{\min} = \sqrt{\frac{f_T p_t}{f_c r_c}}$$

where p_t is the likelihood of transmission in a close contact, f_T is a parameter indicating what fraction of close contacts have to be sufficiently rapidly traced and quarantined (in order to suppress the disease, so this is related to characteristics of the virus) and f_c and r_c relates to the willingness of individuals to be tested and the effectiveness of the testing procedure, respectively. Since f_e^{\min} is therefore (all other things being equal) proportional to the square root of p_t , a four-fold increase in the latter parameter will lead to a doubling of the minimum participation fraction. If we had had $f_e^{\min} = 0.6$ *quo ante* then a doubling would imply an infeasible solution.

Kim & Paul (2021) take "effective" to mean that an outbreak of the disease can be suppressed. We see therefore, from their analysis, that for variants that are much more easily transmissible, the strategy of elimination would have become (mathematically) impossible. They also identify a useful efficiency measure as

$$\eta = \frac{f_e^2}{(f_e^{\min})^2}$$

where f_e is the fraction of actual app users in the population and show that this corresponds to the ratio of the actual number of individuals that will be notified to the minimum number of individuals that should be notified to suppress the disease. Again, we see that for a fixed f_e changes in the disease parameters f_T and p_t will rapidly reduce the efficiency as measured by η .

4 The New Zealand experience

New Zealand's COVID strategy was initially based on eliminating the virus, and came with some of the strictest border protection and lockdown provisions in the world. International borders began to be closed to non-New Zea-

land residents from February 2020, and from March all New Zealand-resident returnees were required to undergo 21 days of quarantine, initially self-managed but by May in a limited number of government-managed facilities. This effectively stopped migration into the country, with only a handful of essential (or otherwise privileged) individuals obtaining the strictly-rationed quarantine places. Combined with one of the strictest lockdown policies (Gibson 2022) observed (96 on the Oxford scale – effectively home isolation of the entire population, except for access to and delivery of essential food and health and public safety services) and intensive contact-tracing, the result was community transmission of the original virus variant being effectively eliminated by the end of April 2020 (Howell & Potgieter 2020).

Between May 2020 and August 2021, any detection of the virus outside the government facilities was accompanied by a rapid return to national lockdown, with gradual relaxation in areas remaining free of infection, until it could be determined that elimination had been re-established nationwide (two notable occurrences were in August 2020 and February 2021). A similar strategy was adopted when the Delta variant was detected in the community in August 2021, leading to an initial national lockdown that morphed into an extended lockdown in Auckland, lasting until December. Community transmission of Delta had not been achieved by the time arrival of the Omicron variant seemed inevitable (December 2021). At this time, the lockdown strategy was abandoned in favour of one based on individuals' vaccination status, intended to manage demand on health care resources. Although it was not articulated as such, this marked the end of New Zealand's virus elimination strategy and a shift to what has come to be termed a "containment strategy". Nonetheless, border controls were not relaxed for New Zealand residents until February 2022, with gradual relaxation of foreigners from April 2022 (these will not be fully removed until July 2022 – brought forward from the original October plan).

4.1 The New Zealand COVID Tracer app

New Zealand COVID Tracer (NZCT) was introduced by the New Zealand government in May 2020, to support the elimination strategy. Its primary purpose is to help people keep a digital diary of places they visit by scanning a unique QR code displayed at all registered premises or locations entered (e.g. at all business premises, public venues and on public transport). When downloading the application, individuals register their contact information in a central health system-managed database. All scanning data is saved on the handset and deleted after 31 days, in accordance with local privacy laws. When a person tests positive for COVID-19, the diary can be uploaded to the contact tracing service, which can help identify locations of interest where unknown contacts may have become infected. Users of the application who have visited these locations can be notified electronically of potential exposure, along with instructions on how to proceed (e.g., self-isolation, testing schedule); non-users are notified through other contact tracing processes (e.g. public notifications; liaising with premises managers to identify and notify close contacts).

In July 2020, users were able to manually enter information when visiting sites that did not display a QR code; in December 2020, a Bluetooth proximity identification facility was added. While use of the application was initially voluntary but strongly encouraged, scanning became mandatory for all registered users at all COVID-19 alert levels on September 7, 2021, following the establishment of the Delta variant of the virus in late August 2021. Compulsory use remained in force during the Omicron outbreak beginning in February 2022, but was rescinded from April 4 2022.

The New Zealand case study facilitates analysis of application effectiveness at different states of the the dynamic interaction of policy changes and virus evolution because of that country's comparative early success of its virus elimination strategy (elimination being defined, as per Wilson et al. (2021) as zero transmission of the virus in the community). This offered a long period where baseline application use could be established. Changes in application use could then be linked to changes in policy following initially, small localised outbreaks brought quickly under control and then latterly, more widespread outbreaks of the Delta version of the virus (with shorter incubation times) and subsequently the Omicron version (with a higher infection rate).

We find NZCT's purpose was primarily to enhance the ability of existing contact tracing services to quickly shut down small local outbreaks to deliver the government's elimination strategy (that is, to manage health risk at the population level). Yet its low use volumes likely offered negligible informational advantage over other contact tracing information in this context. Instead, when infection numbers climbed rapidly following the more widespread outbreak of the more infectious Delta variant in August 2021, information obtained from the application led to over-identification of possible contacts, and testing systems became overwhelmed. Policy changes at this time included making NZCT use mandatory, although it was rapidly becoming evident that the elimination strategy was unachievable.

While policy changes at this time made use of the application mandatory, overload contributed to over-much information when outbreaks moved beyond very small local areas during the Delta outbreak, resulting in over-use of testing and reductions in contact tracing effectiveness. Use of the application persisted (at the same low levels, albeit with more users) whilst it was mandatory, but when infection numbers expanded dramatically during the

Omicron outbreak, testing systems broke down, and government policy switched from an elimination strategy to a management strategy, application use collapsed because it no longer served any purpose for either individual risk management or delivery of government policy.

4.2 App usage data

Figures 1 to 4 trace the number of end user applications registered and downloaded (Figure 1), the number of scans taken and manual entries registered (Figure 2), the number of registered businesses and locations and the number of unique QR codes displayed (Figure 3) and the number of devices active on any given day (either recording at least one scan or manual entry, or being recorded as having Bluetooth tracking activated on a given day) (Figure 4).

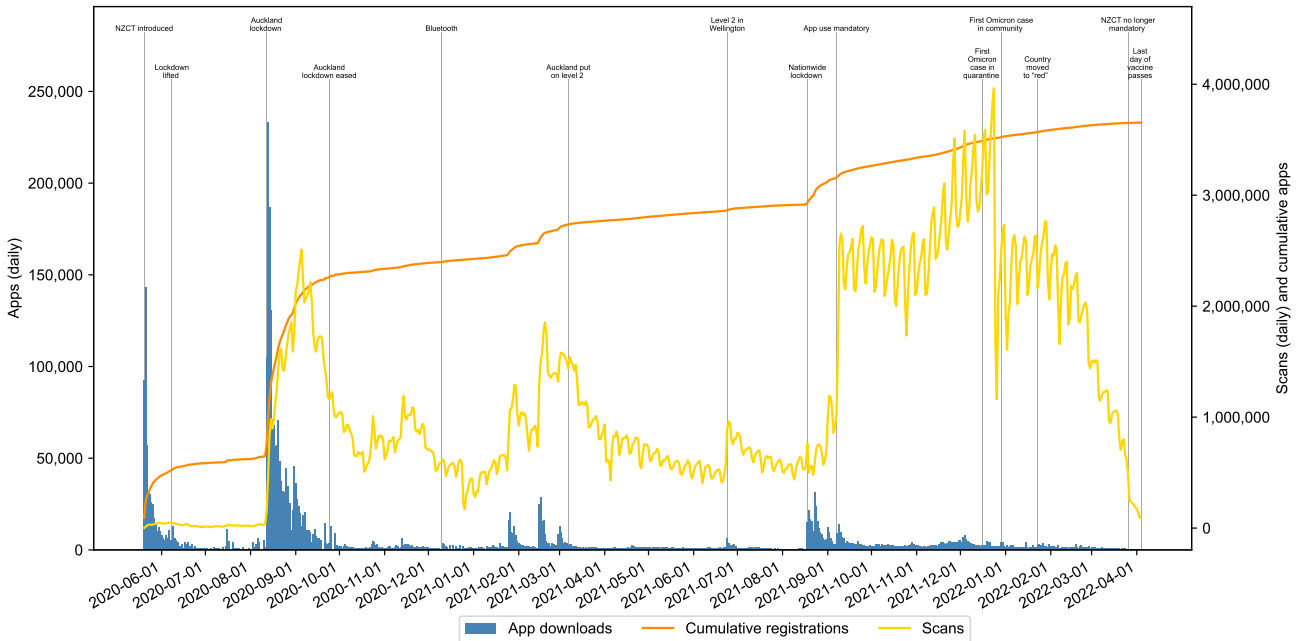


Figure 1: NZ COVID Tracer – App Downloads and Scans

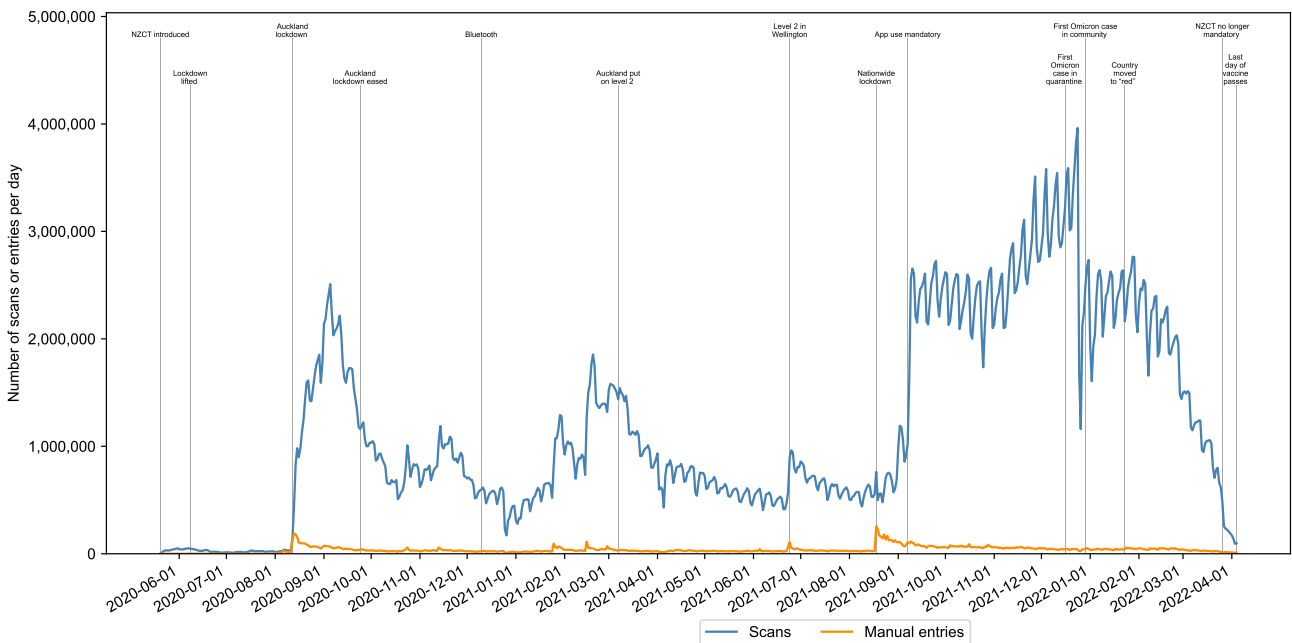


Figure 2: NZ COVID Tracer – Scans and Manual Entries

While the number of applications registered was substantial (nearly 75% of New Zealand’s population of 5 million by April 2022), daily scanning activity was low, except for times when community outbreaks were in place. Usage

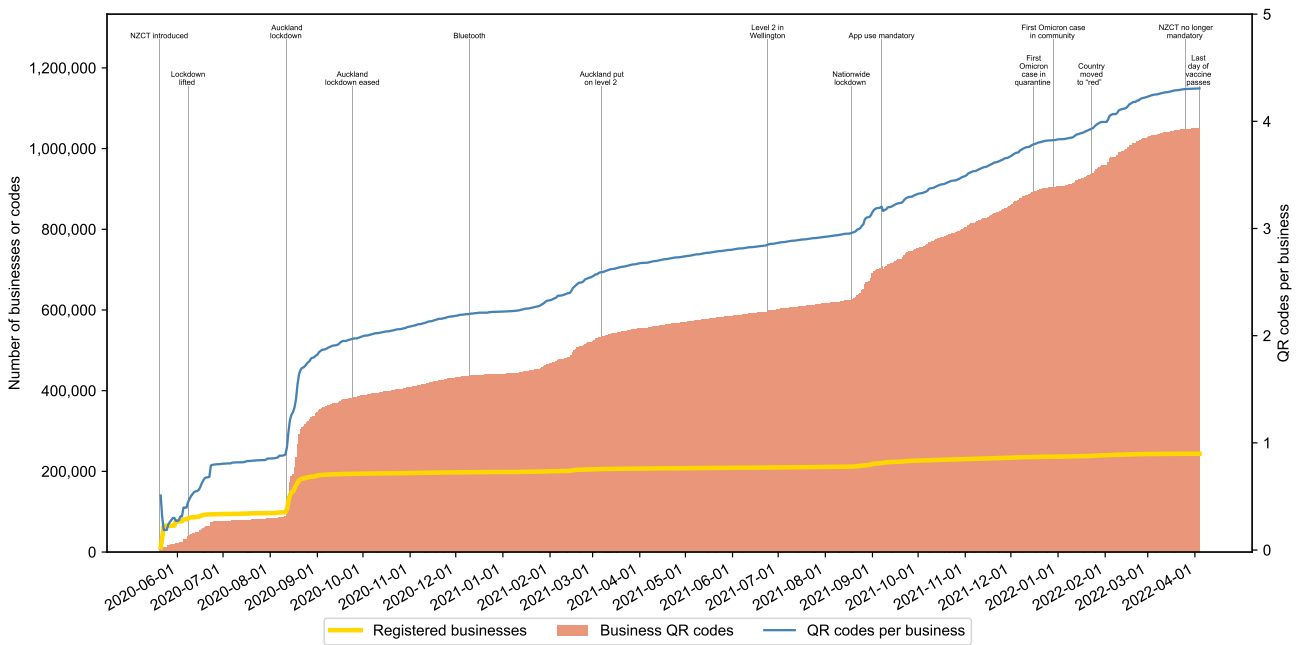


Figure 3: NZ COVID Tracer – Business Activity

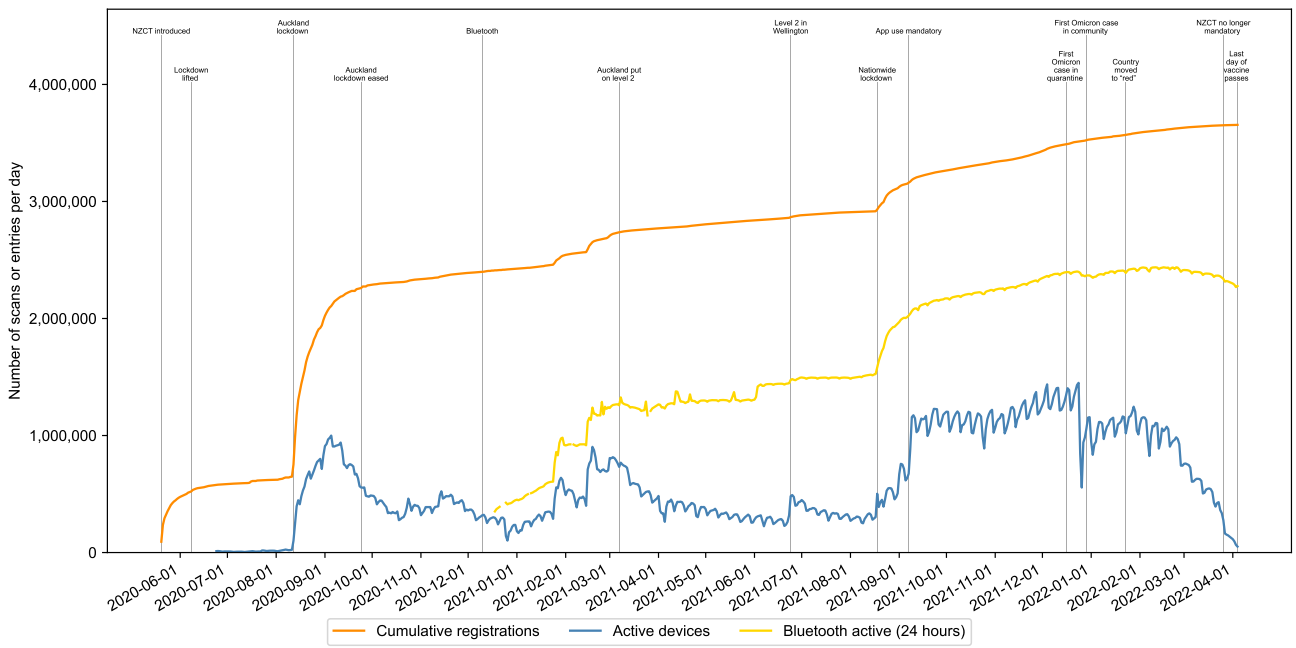


Figure 4: NZ COVID Tracer – Device activity

became sustained only following the Delta outbreak in August 2021, when scanning was made mandatory and an extended lockdown was in place. Scanning fell significantly from the end of December 2021, when the lockdown-based eradication strategy was replaced with the containment strategy, despite the higher risk of infection faced as the Omicron variant took root. Scanning activity collapsed in March 2022, following the announcement that this would no longer be mandatory.

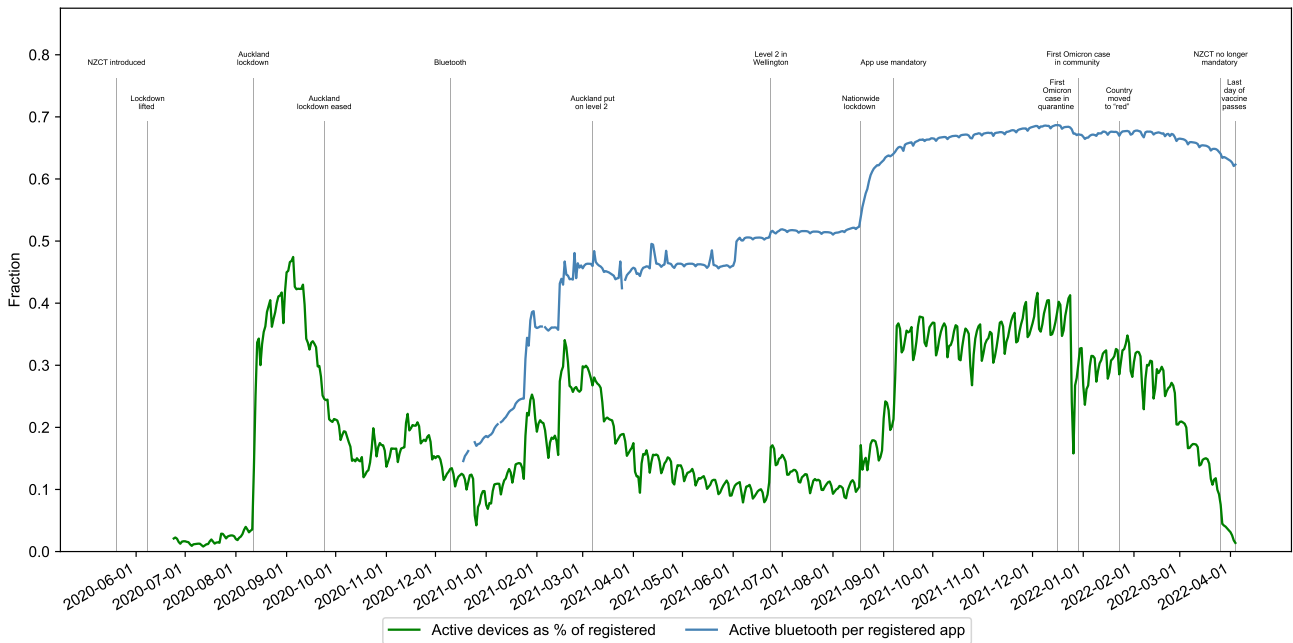


Figure 5: NZ COVID Tracer – Percentage device activity

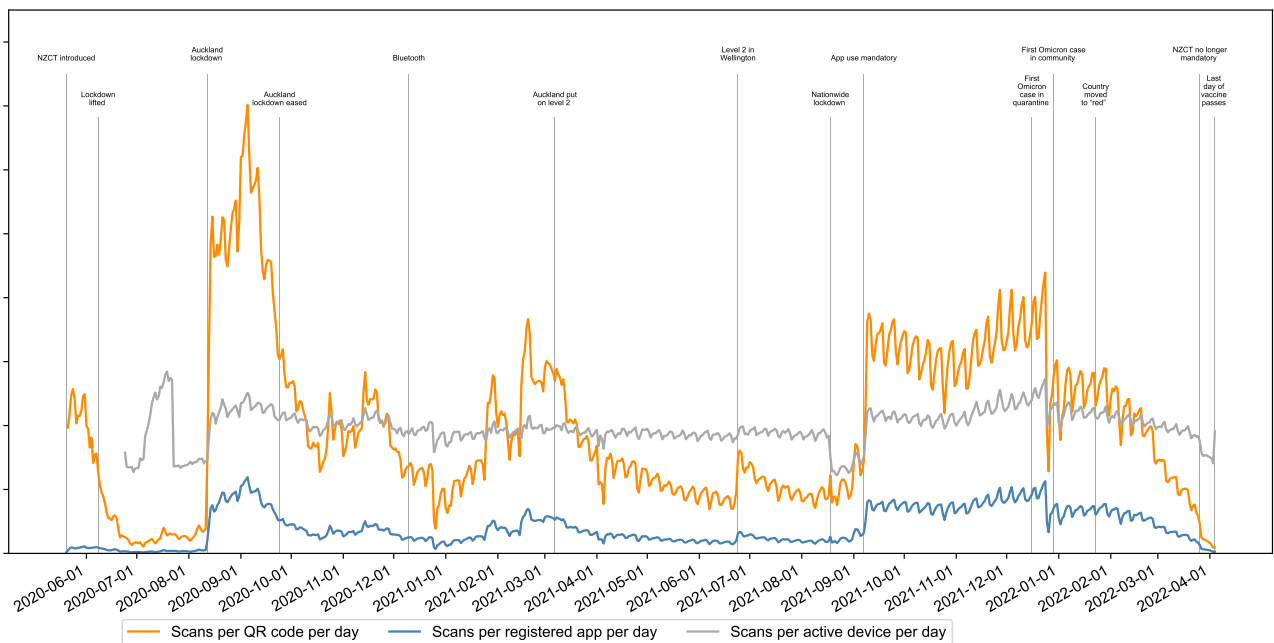


Figure 6: NZ COVID Tracer – Daily scanning activity

Figures 5 to 8 show the levels of scanning and device activity as a percentage of the number of applications registered and devices active on a given day. These show that the increase in scanning observed following the August 2021 Delta outbreak and usage mandating was due to an increase in the number of active devices per day, rather than individuals scanning more codes on any given day. Even at peak usage during outbreaks, on average fewer than 40 percent of registered users scanned at least one code on a given day. Active devices were observed to scan or record fewer than three codes (premises or locations visited) per day. While the number of active devices fell off dramatically following the December 2021 changes, activity per device fell away much more slowly, with the small number of active devices still recording 1.5 locations a day in April 2022.

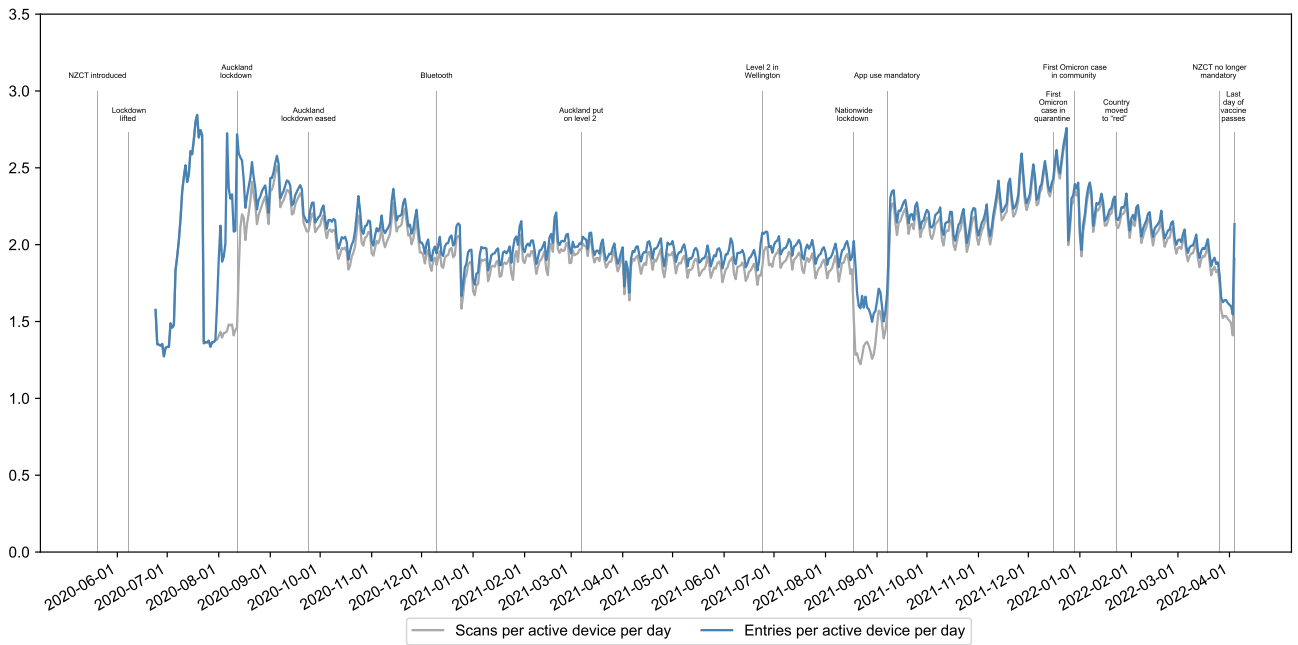


Figure 7: NZ COVID Tracer – Daily activity per active device

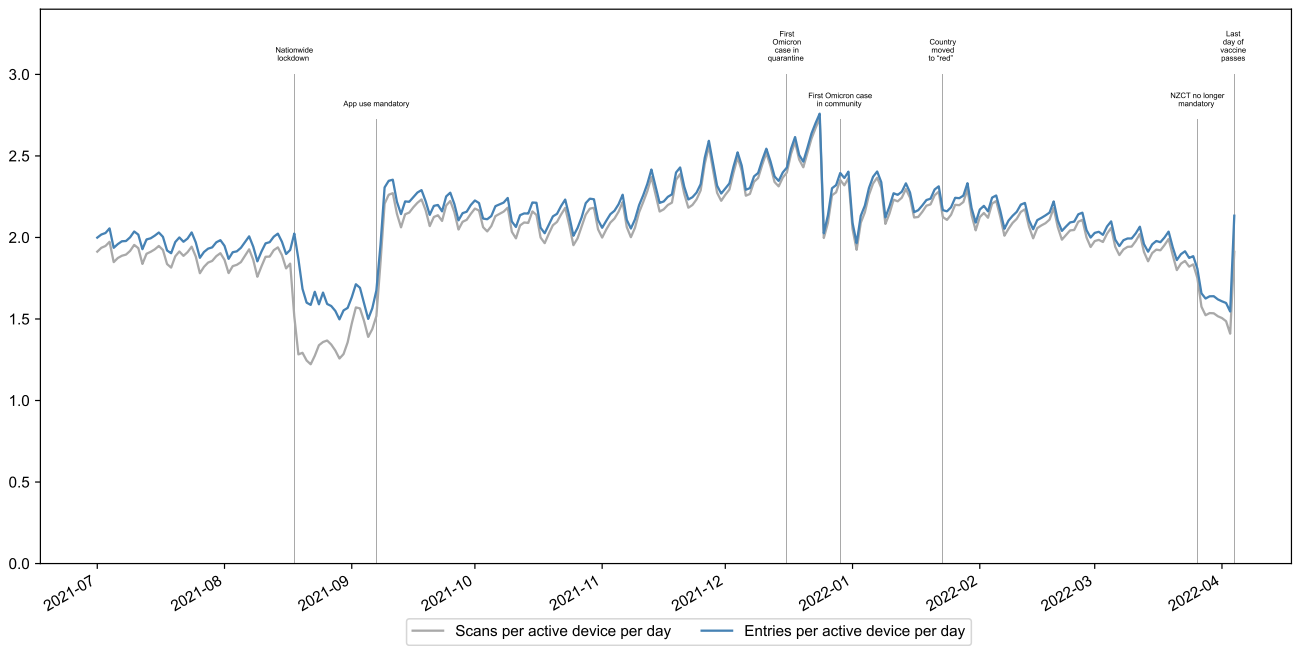


Figure 8: NZ COVID Tracer – Daily activity per active device (since July 2021)

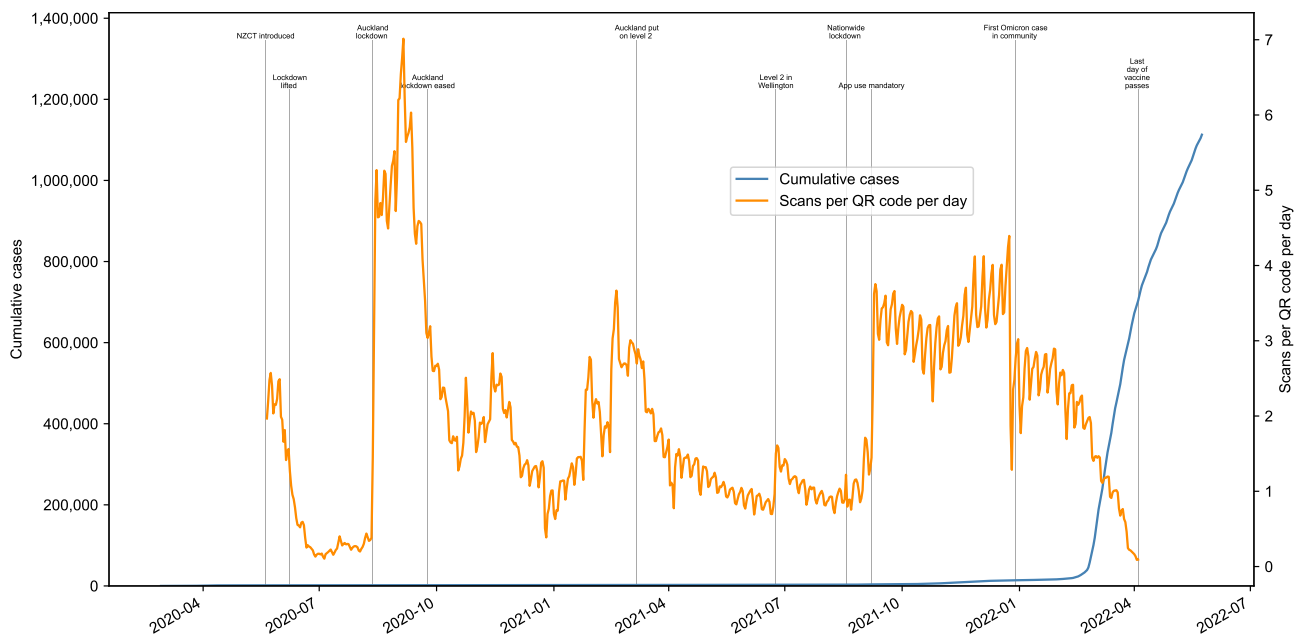


Figure 9: New Zealand cases (cumulative) and scans per QR code

Figure 9 illustrates the total number of cases in the country against the QR code scans per day. Howell & Potgieter (2021; 2022) asserted, using data up to November 2021, that NZCT scanning activity has more closely followed individuals' perceived risk of infection rather than being a response to government mandates. However, the drop in usage following the rapid increase in cases during the Omicron outbreak appears to defy this conclusion. As individual infection risk has increased, individual propensity to use the application, and premises' willingness to display QR codes, has collapsed. That is, NZCT was a tool of the elimination strategy; when the elimination strategy was replaced with a containment strategy, it ceased to be relevant for individual users. This is despite continued official encouragement to use the application².

At its inception in May 2020, NZCT was positioned as an adjunct to support the public health-based contact tracing process. When case numbers were low, during the original and subsequently Delta outbreaks, contact tracing was largely able to keep pace with the increased infection numbers. Stresses were placed on the testing system, especially during the Delta outbreak, as an overly-conservative approach initially saw large time windows being used to identify potential contacts. This resulted in long queues at testing stations and stresses placed on laboratory systems to process large numbers of tests. However, as the actual number of infections detected was low, contact tracing was able to scale up sufficiently. Testing logjams were also partially addressed by the decision only to follow up a small subset of locations of interest identified with the application. For example, supermarkets and retail outlets were dropped as there was negligible evidence of infections being passed amongst customers at these locations, although higher-risk hospitality venues remained of interest. At this stage, it was noted that data collected using the Bluetooth feature was not being used, because of the time required and the lack of familiarity of both contact tracers and end users with the processes necessary to upload this information.

However, with the arrival of Omicron, the shorter incubation period and rapidly increasing number of cases have rendered contact tracing infeasible. Within days, it became clear that pooled laboratory testing processes suitable when the proportion of positive samples in a pool was low could not cope as the infection likelihood increased. Laboratory PCR testing was largely replaced by self-administered RAT testing, with self-reporting of an individual's positive status replacing laboratory-managed case reporting. At best, reported cases were an imperfect subset of actual community infections. The decision was made to redeploy the scarce resources used for contact tracing to other activities managing the Omicron outbreak. The breakdown of contact tracing led to the breakdown of public support for and use of NZCT. While the Bluetooth component could still have been used to alert individuals automatically of their contact risk, this suggests that the public perception of the app was more closely tied to the elimination strategy than with a personal protection strategy. While an automated Bluetooth alert system could still have been used to alert individuals even though contact tracing had broken down (and indeed it is implied that this is occurring on the Ministry's website³ this does not appear to have been done in practice. It is now the

²Using the NZ COVID Tracer app is still important to help you identify where you have been and who you need to tell if you test positive for COVID-19." <https://www.health.govt.nz/covid-19-novel-coronavirus/covid-19-health-advice-public/covid-19-information-household-and-close-contacts/covid-19-contact-tracing-locations-interest/covid-19-contact-tracing-locations-interest-map>

³Keep your Bluetooth on – notifications will be sent to people who have been close to someone with COVID-19"

responsibility of those testing positive on self-administered RAT tests to inform their close contacts themselves.

5 Analysis

In this section we evaluate the New Zealand experience, briefly look at the international experience and consider the context of elimination versus containment strategies.

5.1 Evaluation of the New Zealand experience

The New Zealand case can be evaluated along the three axes of the framework we proposed above: Conformity to norms; Fitness for purpose; and Feasibility and efficiency.

5.1.1 Conformity to Norms

Overall, NZCT delivers a mixed result on conformity to norms. While participation in NZCT was voluntary and non-discriminatory (provided users had a suitable smartphone), it ceased to be voluntary for those who had downloaded it once use was mandated for those who had downloaded it in August 2021. While refusers faced no official sanction for not scanning, social sanctions (for either scanning or non-scanning, depending on the norms of the user's social groups) were likely non-trivial. Privacy and data economy were addressed by the minimal amount of data collected (other than centrally-held contact information) being stored locally on the handset and deleted when past usefulness. The need for manual uploading of the information to contact tracers aided privacy and trust norms to be addressed, but ultimately the need for manual intervention likely rendered the Bluetooth component of the app unsuited to utilisation during times of high infection.

In terms of reasonable expectation of individual utility for users, any app used to support an elimination strategy will necessarily not be rate very highly as the possibility of individual infection is very low. Tretiakov & Hunter (2021) report that perceived societal benefit was a more important driver of use than individual benefit. Figure 6 shows that there was variable perceived utility as the number of QR codes scan per day rose sharply when Auckland went into lockdown in August 2020, presumably as a response to perceptions of risk. The same was true when Wellington went into level 2 lockdown in June 2021 although the effect was possibly localized and shows up as a less sharp increase on the country-wide average of scans per day, probably since Wellington is a much smaller city.

5.1.2 Fitness for Purpose

NZCT performs poorly overall on Fitness for Purpose. NZCT was introduced as a tool to support an elimination strategy. Its high user compliance costs likely led to low overall use, even though the number of users and scans increased when made compulsory, as shown in the Figures above. While theoretically useful when community infection rates were low, it became a liability as these rose (with Delta) and the incubation period shortened (with Omicron). Making its use mandatory, then reducing the amount of information circulated on locations of interest identified using it reinforces the lack of fitness of a QR code location-based app for any purpose other than supporting an elimination strategy. This usage change also likely reduced the levels of trust and goodwill built up for it.

The failure to recognise the changed purpose of NZCT from a tool capable of supporting public health objectives to one supporting individual behaviours when infection rates rose stands as a lost opportunity. Proximity-based Bluetooth capability was embedded in the app, but has not been capitalised upon for this different purpose. Bluetooth data was not used initially because it did not support contact tracing. More recently, it has not been used because (presumably) it still requires individual user permission to be granted and manual intervention for the handset-held information to be uploaded and utilised to alert other users.

5.1.3 Feasibility and Efficiency

NZCT attracted a high percentage of registered users, but poorly on all other feasibility and effectiveness measures. Regarding epidemiological sense and purpose, while contact tracing per se was essential for maintaining New Zealand's elimination strategy, it is most unlikely that the additional information provided by NZCT contributed significantly to identifying contacts not identified by other contact tracing processes, given the low numbers of scans taken on average. Rather, it more likely interfered with the speed at which community cases could be identified when infection rates increased, by clogging the testing processes.

<https://www.health.govt.nz/covid-19-novel-coronavirus/covid-19-health-advice-public/covid-19-information-household-and-close-contacts/covid-19-contact-tracing-locations-interest>

In order to evaluate the features 2, 3 and 4 of

1. population adoption rate and actual usage;
2. percentage of actual contacts identified by the app (true tracking positives);
3. percentage of identified contacts who are not actual contacts (false tracking positives); and
4. the ease by which the app allows authorities to reach identified contacts (tracing efficiency)

identified by Howell & Potgieter (2021), we have requested information required to do so from the NZ authorities but have not yet had a response. Vogt et al. (2022) evaluated the effectiveness of the Australian tracker app in New South Wales over a period of six months. Admittedly, usage among cases was low (22%) and the Australian app functions on a different basis than the NZ one, being based on Bluetooth proximity detection. Nevertheless, they found a 61% rate of false tracking positives and fewer than 0.06% of contacts identified overall (17 out of 25,300) being due to the app. If we adjust these numbers by assuming a four times higher usage (88% instead of 22%) and scale the additional positive contacts by the square (16, due to the network effects), that would still imply fewer than 1% of contacts proceeding from app use adjusted for conditions in NZ. Vogt et al. (2022) also reported the Australian app as not having been considered useful by New South Wales public health staff.

New Zealand testing facilities were overwhelmed by demand several times (including February 2022⁴) but the data to determine the extent to which the app might have contributed to this, is not available. Figure 9 shows that use of the app collapsed as widespread community transmission took hold towards the end of 2021.

5.2 Contact tracer experience elsewhere

There is a paucity of empirical studies on the contribution of digital contact tracing applications to the epidemiological outcomes of any disease, although the potential of mobile applications in this regard have been published since at least 2014 (Cebrian 2021). Effectiveness of the applications is usually measured by the number of cases identified using the app that would not otherwise have been picked up as by Vogt et al. (2022) for New South Wales or by that number and the number of those who had actually changed their behaviour as the result of a notification. Rannikko et al. (2022) report on a detailed study in the Pirkanmaa region of Finland (population over half a million, over half of which Koronavilkku app users). For 4,557 PCR-positive COVID-19 cases in their study in late 2021, a total of 18 non-household exposures were found that had not been identified in traditional contact tracing calls. Only 8 of these 18 users reported having changed their behaviour, e.g. by getting tested themselves.

Modelling studies are far more numerous. For example, Pollmann et al. (2021) model a large number of parameters in a homogeneous population without manual contact tracing and determine that for a realistic subset of the parameters, even a perfect digital contact tracing cannot contain an epidemic outbreak. They also observe that the benefits of digital tracing disappear very rapidly when many cases do not seek out testing. Indeed, as Menges et al. observed in 2020 in the Swiss canton Zurich, the behaviour of users can change quite rapidly when an outbreak occurs and when the digital tracing system requires voluntary release of positive test data.

Australia, Finland, New Zealand and Switzerland all started the epidemic with reasonable manual contact tracing systems in place and the question arises whether digital tracing had a more significant effect in countries with less well developed infrastructures. By this we not only mean countries where the infrastructure might not have been adequate on the side of health authorities but also those where a large part of the population might be difficult to trace because of not having a formal address, being undocumented⁵, not having a stable phone number and many other reasons. However a digital exposure notification system would in these cases still require extensive testing capacity to be available and to be used. In Africa, for example, this has not been the case and 31 out of 46 countries were reporting fewer than one test per one thousand people per week in March 2021 (Adebisi et al. 2021).

In the first phase of the pandemic, some countries in Asia used involuntary data collection (mobile phone records, camera footage, financial transaction records etc.) in conjunction with traditional contact tracing in order to localize and control outbreaks of the disease (Kleinman & Merkel 2020). This should be distinguished from the digital app approach taken in New Zealand and other western countries which was based on voluntary participation and the protection of privacy of all individuals, including index cases. In western-oriented societies, concerns about user privacy and confidentiality as well as possible inequities of access and application have been very prominent (Gerli et al. 2021).

It has long been known that resources devoted to contact tracing might be more profitably applied to screening for a particular disease (Armbruster & Brandeau 2007), even if the disease is endemic. The pre-2020 literature iden-

⁴“Overwhelmed laboratories struggling to keep up with demand of processing COVID tests call for PM to see reality firsthand” <https://www.newshub.co.nz/home/new-zealand/2022/02/overwhelmed-laboratories-struggling-to-keep-up-with-demand-of-processing-covid-tests-call-for-pm-to-see-reality-firsthand.html>

⁵Also an issue in developed nations (Gerli et al. 2021).

tified, through modelling, what contact tracing might be effective in reducing the reproduction rate of a disease to below 1. This depends on parameters of the disease as well as cooperation by the population at risk. Klinkenberg et al. (2006) modelled the likely efficiency of tracing that would be effective for SARS, smallpox and influenza and concluded that effectiveness was likely for SARS and smallpox but not for influenza.

5.3 Elimination versus containment

New Zealand explicitly adopted a COVID-19 *elimination* strategy in 2020. Elimination⁶ is usually understood to mean that clinical infections can no longer be found (Noah 2019) but this was never going to be the case as people were still allowed to enter the country from abroad and infections were found in this group. A 2017 influenza containment plan was rapidly turned into the 2020 elimination strategy which is less inappropriate than it sounds if we consider that what NZ called “elimination” was in fact an extreme form of containment – usually taken to simply mean that a disease is no longer a public health problem.

Given that “elimination” had been a thinly disguised containment strategy⁷ all along, especially once it had become clear that vaccines do not prevent re-infection and transmission, the cost-effectiveness of NZ Covid Tracer as intervention should be considered. Here one should take into account not just the cost of developing, distributing and support the app, but also the opportunity cost of other interventions and the unintended side-effect (people queuing to scan a code might have been a transmission risk) but that it the subject of future work.

6 Conclusion

We have evaluated NZCT in a framework which we developed, using usage statistics to support our conclusions. The overall qualitative evaluation of the app is moderately poor (somewhat mixed on two of our three axes, poor on one). Modelling studies and experience show that contact tracing can be useful during the outbreak of a new disease and in New Zealand it surely was useful in containing earlier and localized outbreaks. There is little (or no) evidence that NZCT contributed significantly to contact tracing however and it is clear that contact tracing became useless early in 2022 when the number of detected cases increased sharply. For a disease that cannot be suppressed – and all evidence points to COVID-19 being such an illness – contact tracing (even with a digital component) can only delay its spread. NZCT should finally be judged against the cost of setting it up (for the government, \$6.4m according to reports⁸) and the cost of compliance for businesses and individuals – in monetary terms as well as in convenience cost and possible additional exposure through taking part in the scanning process.

The pre-2020 literature is clear about the limited range of conditions under which contact tracing works in general and one of the originators of the digital tracking concept (Cebrian 2021) and his collaborators (Kong et al. 2021) have been early skeptics. The standard alternative to tracking is widespread screening. In New Zealand tracking was heavily emphasized while the import of rapid tests was suppressed (Summers et al. 2021). Although the country has still had a low overall COVID-19 death toll, it is no foregone conclusion that the app contributed anything at all to it.

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⁶Elimination is not the same as *eradication* which means that the risk factor is no longer present in the usual world, as is the case for smallpox.

⁷A disguise still in fashion in the People's Republic of China in mid-2022.

⁸“Covid 19 coronavirus: Tracer App cost \$6.4 million to set up” <https://www.nzherald.co.nz/nz/covid-19-coronavirus-tracer-app-cost-64-million-to-set-up/YUXDAQ5RCCCKEXMIZZSON6A5AHE/>

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