Indicator framework to evaluate the public health effectiveness of digital proximity tracing solutions

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Contents

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Key messages

- **Digital proximity tracing (DPT) is a new technology that has been increasingly adopted by countries to support conventional contact tracing efforts in combating the COVID-19 pandemic.**
- **This indicator framework is designed to support the evaluation of the public health effectiveness of DPT.**
- **The way DPT is implemented varies between countries, therefore the indicator framework provides a menu of options, which allows countries to choose indicators that are most suitable and feasible to measure in their setting.**

Executive summary

As they respond to the COVID-19 pandemic, countries worldwide have increasingly looked to digital technologies in support of public health measures for contact tracing. Digital proximity tracing, an approach that typically use smartphones or purpose-built devices to capture anonymized interactions between individuals and subsequently issue alerts, has shown promise in contributing to national contact tracing strategies. However, given that digital proximity tracing is still an emerging technology, methods for assessing and monitoring its effectiveness remain unclear. This document therefore seeks to provide national public health authorities with a list of indicators, developed in consultation with a broad range of national and regional stakeholders, that can be used as a basis for a standardized evaluation of the public health effectiveness of digital proximity tracing.

This indicator framework is intended for use by relevant national health authorities, public health and related institutions and their partners involved in the planning, implementation, monitoring and evaluation of contact tracing activities. It will be of most relevance to those with responsibility and oversight for the development and deployment of national digital proximity tracing solutions.

The proposed indicators aim to provide information on:

- the adoption and use of digital proximity tracing in the population;
- the capacity of digital proximity tracing to detect contacts at risk of infection;
- the speed with which digital proximity tracing solutions can notify contacts in comparison to conventional contact tracing mechanisms;
- barriers and enablers of digital proximity tracing approaches.

The document also provides a reflection on operational factors that may have an impact on the monitoring of digital proximity tracing applications (apps) and proposes different options for data collection for the indicators.

The information gained from these indicators can be used to assess and improve different aspects of digital proximity tracing implementation. This will help to increase its effectiveness in preventing transmission of SARS-CoV-2 and when evaluating its usefulness in the context of other pandemic mitigation measures.

1. Introduction

Systems for digital proximity tracing[1] emerged during 2020 as public health technologies aimed to mitigate community transmission of SARS-CoV-2, the virus that causes COVID-19. Their use, in combination with traditional methods of contact tracing, have offered new potential for health authorities to limit or interrupt chains of SARS-CoV-2 transmission.

Many countries worldwide adopted first generation digital proximity tracing solutions as part of their national test, trace and isolation strategies. Such solutions also featured prominently as public advocacy measures and a means to contribute to the adjustment of national public health and social measures.

While much discussion took place throughout 2020 regarding the merits of different design and implementation approaches and their associated privacy implications, methods for assessing and monitoring the effectiveness of digital proximity tracing remain unclear. The purpose of this document is therefore to provide national public health authorities with a list of indicators, developed in consultation with experts working on implementing digital proximity tracing in different countries. These indicators can then be used as a basis for a standardized approach for evaluating the public health effectiveness of digital proximity tracing.

At present, there is a lack of empirical data on the effectiveness of digital proximity tracing approaches. Monitoring and evaluation will therefore be important as different designs are implemented.

Objectives, scope and intended audience

The overall objective of this indicator framework is to provide a set of indicators to guide national health authorities in the monitoring and evaluation of their digital proximity tracing solutions.

The specific objectives for the indicators are to provide information on:

- the adoption and use of digital proximity tracing in the population;
- the capacity of digital proximity tracing to detect contacts at risk of infection;
- the speed with which digital proximity tracing solutions can notify contacts compared to conventional contact tracing mechanisms;
- barriers and enablers of digital proximity tracing approaches.

The scope of this document is focused on indicators for the monitoring and evaluation of the public health impact of digital proximity tracing solutions. It does not seek to provide guidance on aspects of design, configuration or implementation but may refer to such in the context of defining and describing the indicator framework.

This document is intended for use by relevant national health authorities, public health and statistics institutions and their partners involved in the planning, implementation, monitoring and evaluation of contact tracing activities. It will be of most relevance to those with responsibility and oversight for the development and deployment of national digital proximity tracing solutions.

Method

At the time of development of this document, no comprehensive public health indicator framework for digital proximity tracing was available in scientific literature. The indicators in this framework were developed and curated by public health and digital health professionals from the European Centre for Disease Prevention and Control (ECDC) and the World Health Organization (WHO) with expertise in digital health and contact tracing. These experts have been heavily involved in the development of guidance on both contact tracing and digital proximity tracing since the start of the pandemic and regularly participate in regional and global meetings on contact tracing. A review of literature on digital proximity tracing between April and December 2020 was conducted to help inform the development of the indicators[2] [1-9].

A subsequent curation process was done through consultation with national public health authorities, WHO Regional Focal Points for Digital Health and Innovation, and other stakeholders involved in the evaluation and implementation of digital proximity tracing solutions. These consultations took place between September 2020 and February 2021 and were conducted as virtual meetings with groups of experts from different countries, or bilateral calls with several experts from a single country. Written feedback was obtained from some experts. Only those indicators most feasible to collect in different settings and with the most public health relevance were selected for inclusion in the final list.

No conflicts of interest were identified during the consultation with the experts.

Use of the indicator framework

While efforts have been made to ensure the applicability of this indicator framework across different digital proximity tracing design and implementation scenarios, there may be a need for its adaptation to meet local contexts and constraints. The ability of health authorities to collect data for each indicator will depend on a range of factors specific to national implementation, including the design and methodology of digital proximity tracing employed, applicable national legislation and how

1 Terms frequently used to represent the same or a similar technological approach include digital contact tracing, digital proximity tracking, exposure notification service, contact tracing app etc. The term digital proximity tracing is used in this document.

2 The PubMed database was searched using different combinations of search terms such as ("COVID" OR "SARS") AND ("digital contact tracing" OR "exposure notification" OR "proximity tracing" OR "proximity tracking" OR "contact tracing app"). A total of 50 articles were identified and reviewed.

testing and conventional contact tracing services are organized.

The indicators proposed in this framework are suggested metrics for consideration by national authorities and can help support evidence-based decision-making by policy makers and public health authorities, in line with World Health Assembly resolution WHA67.23 on Health intervention and technology assessment in support of universal health coverage [10] and work towards the strategic objectives of the WHO Global Digital Health Strategy 2020-25 [11].

There are different ways in which this indicator framework can inform decision making processes. For example, because digital proximity tracing is still an emerging health technology there is a need to evaluate its effectiveness in preventing onward transmission of SARS-CoV-2. Therefore, some of the proposed indicators can inform analytical models to assess the impact of this intervention on transmission.

The indicators can also be used to refine the implementation of digital proximity tracing by helping Member States to:

- identify populations where an app is under-utilized and understand barriers to uptake and adherence;
- identify ways in which an app can be better integrated with other elements of public health services, such as testing;
- refine and calibrate the exposure notification settings of an app through an iterative process, in order to optimize its performance.

Finally, if several countries collect data on these indicators, the results could facilitate harmonization and standardization and further the exchanges of best practices. Comparison between countries would need to take into account the differences in the implementation of digital proximity tracing apps.

2. Digital proximity tracing rationale, design, operation and limitations

This section gives a brief overview of the rationale, design, operation and limitations of digital proximity tracing solutions and outlines a number of considerations relevant to their monitoring and evaluation.

Rationale

Rapid identification and notification of all exposed contacts is the cornerstone of an effective contact tracing strategy, and this is particularly relevant for SARS-CoV-2 because individuals can readily transmit the virus before showing any symptoms. Consequently, by the time a person becomes symptomatic and a positive SARS-CoV-2 test result is received, those with whom they have been in close contact prior to symptom onset may already be infectious before conventional contact tracing services are able to reach them.

The working hypothesis of digital proximity tracing is that it has the potential to substantially slow down the community transmission of SARS-CoV-2 in three main ways. First, it allows the automated notification of exposed contacts once the index case tests positive for SARS-CoV-2. This can lead to faster notification of contacts (compared to conventional contact tracing), faster quarantine of these contacts and, consequently, faster interruption of transmission chains. Second, digital proximity tracing can still function in widespread community transmission contexts, when conventional contact tracing is at capacity due to high volumes of cases and limited resources. Third, digital proximity tracing does not rely on the infected individuals' recollection of their previous encounters and their ability to name contact persons and therefore has a wider reach than conventional contact tracing. These are important drivers for the introduction of a digital solution to support national contact tracing systems.

It is important to acknowledge that digital proximity tracing is new and that its value in protecting populations and aiding national public health authorities depends on many assumptions and imperfect technologies. As such, digital proximity tracing solutions should be seen as a complement to, and not a replacement for, traditional public health approaches to contact tracing.

Any effort for contact tracing, digital or otherwise, can only be effective if there is a strong and agile public health infrastructure in place that includes adequate health services personnel, testing services and a response infrastructure. Strong community engagement and awareness of the public health benefits of the app and the steps taken to safeguard data privacy are needed to enhance buy-in, voluntary participation and sustained adherence to app usage.

Working definition of digital proximity tracing

For the purpose of this document, a working definition of digital proximity tracing is offered below:

'Digital proximity tracing' refers to a technological approach to public health contact tracing that typically utilizes smartphones or purpose-built devices to capture anonymized interactions between individuals, and subsequently issue alerts, if conditions are met that indicate a period of close proximity to someone who later returns a positive diagnosis of infectious disease.

While it is recognized that several different approaches and technologies can be employed for proximity tracing, this document builds on solutions using Bluetooth®[3] Low Energy as the basis for the exchange of anonymous 'keys' between devices participating in the proximity tracing network. WHO strongly recommends that proximity tracing tools based on the geolocation data of users should not be used [12]. As such, the evaluation

3 Bluetooth SIG

of GPS-based solutions is not included within the scope of this document.

Design and operational factors affecting the monitoring of digital contact tracing

Solution architecture

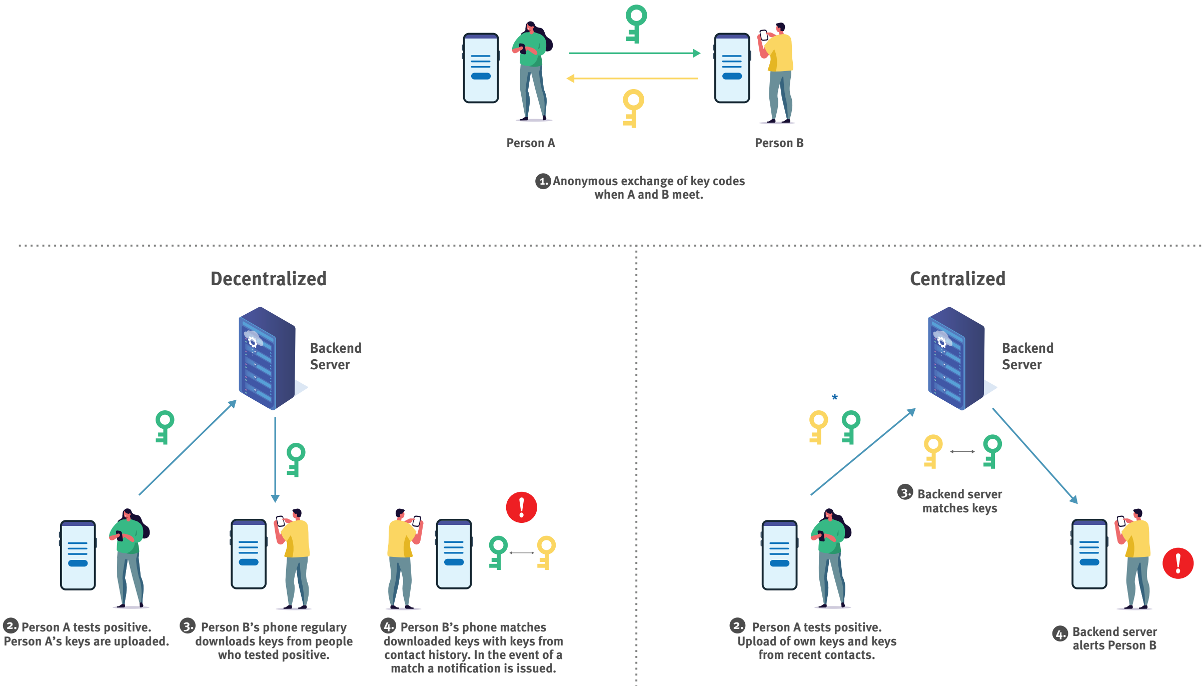
The extent to which effectiveness can be monitored will depend in part on the design (architecture) employed. Different architectures preserve the privacy of individuals participating in the proximity tracing network differently and as such, vary in their ability to derive public health knowledge from the data that flows through them. A discussion of the pros and cons of each architecture is beyond the scope of this document. Detailed information on design architecture and data flows has been documented in the EU toolbox for digital proximity tracing [13]. Figure 1 below illustrates how data flows in decentralized and centralized architectures for Bluetooth based digital proximity tracing.

Privacy considerations

Protecting the personal data and privacy of individuals participating in digital proximity tracing networks is paramount to ensure that human rights and civil liberties are not threatened, and public trust is garnered. Any implementation of digital proximity tracing should include national legislation and accountability mechanisms to regulate the use of data stored on servers and participating devices. Important data protection principles such as informed consent, data minimization and purpose limitation should be implemented. Furthermore, any data captured should not include the identity or geographical coordinates of an individual. WHO, the European Union and other bodies have published guidance on ethical and privacy considerations to guide the use of digital proximity tracing solutions [12, 14-16].

Both architectures outlined above incorporate privacy-preserving measures into their design but carry differences in their ability to enable public health analysis. Solutions built using the decentralized architecture will be limited in their capacity for public health analysis, which means that health authorities may be required to employ alternative approaches (such as data donation or surveys) to enable information to be collected for different indicators. Other architectures that employ a more centralized design approach can allow

Figure 1: Centralized vs. decentralized digital proximity tracing approaches



When two users' smartphones are in close proximity, they exchange their respective anonymous key codes. If Person A tests positive for COVID-19, he or she updates his/her new status in the app. With the **decentralized approach**, the smartphone only uploads Person A's keys to the back-end server. All keys from infected users are downloaded by the application on Person B's phone and, the key matching is performed locally, and alerts issued accordingly to inform the contacts that they have been exposed. With the **centralized approach** the smartphone uploads Person A's keys as well as the other keys gathered from its previous contacts, such as B. The key matching is performed on the centralized server, which subsequently notifies possible at-risk contacts.

*Note that the amount of data shared with the central server can vary depending on the type of centralised architecture implemented. In some countries, only the keys of the contacts are shared with the central server.

for more extensive public health analysis, but inherently offer a lesser degree of privacy-preserving capability.

Method for registering and processing a positive diagnosis in the digital proximity tracing app

Individuals who are diagnosed with COVID-19 can register their status in the digital proximity tracing app. To validate the positive diagnosis and avoid system misuse, this is typically done by entering an activation code supplied by the relevant health authorities or using a national digital identity mechanism. If the process of issuing an activation code or registering the diagnosis in the app is delayed, this will reduce the ability to issue exposure notifications and hence the overall effectiveness of the approach.

Proximity settings and calibration

Calibration refers to the process of optimizing exposure notification settings to ensure that people at risk are notified without also notifying too many people who are not at risk. Public health authorities have to ensure that time and distance settings are broad enough to 'capture' contacts most at risk. More detailed information on calibration of digital proximity tracing apps are provided in ECDC's guidance on mobile applications in support of contact tracing for COVID-19 [17].

Interoperability constraints

At present, different systems of digital proximity tracing (i.e. different national solutions) are not immediately interoperable. The European Commission has developed the European Federation Gateway Service to ensure that cross-border exchange of exposure notifications can take place between European Union Member States, primarily between decentralized systems [18, 19]. The proposed indicators do not specifically measure issues around interoperability.

3. Introduction to the indicators

The indicators presented here should be considered as a starting point. It is recommended that public health authorities consult with those responsible for the design and implementation of digital proximity tracing solutions and staff involved in conventional contact tracing to ascertain the merits of applying each proposed indicator. This will also be necessary to determine what data is or can be made available to populate or refine indicators, as required.

Countries are heterogeneous in their approaches to integrating digital proximity tracing solutions with testing and conventional contact tracing services. As such, the list of proposed indicators should be seen as a menu of options for public health authorities to choose from, while taking the local implementation context into account.

If evaluation metrics are published on the basis of these indicators, it is recommended that they include details and limitations of the technology being used and a flowchart, or similar visual aid, to illustrate integration with testing services and conventional contact tracing services. While local adaptation may be necessary (as outlined above), there is also value in attempting to use the proposed indicators to the extent possible without modification, to facilitate standardized comparison between countries.

4. Options for data collection

The capacity to collect data for each of the indicators in this framework may vary across countries due to differences in design architecture, integration of the overall surveillance and response strategy, and the local legal, privacy and governance context. There is therefore variation in the type of data that can be collected and the sources they can be collected from (app controller, public health authorities, surveys, etc.). Different options for data collection in the context of digital proximity tracing are listed below.

- **Data obtained from the digital proximity tracing network.** Minimal and unidentified data can be collected via the app controller to perform public health analysis. However, the ability to do so is highly dependent on the solution architecture used (centralized versus decentralized). Measures for protecting the privacy of individuals using digital proximity tracing should not be compromised in efforts to collect more data for public health analysis.
- **Integration with conventional contact tracing:** In many countries, digital proximity tracing is integrated with conventional contact tracing – for example by asking app users who receive an exposure notification to call public health authorities. If such contact is established, it provides an opportunity to ask app users additional questions relevant to some of the indicators proposed in the framework. Depending on the manner in which digital proximity tracing is integrated with conventional contact tracing, there may be other opportunities to obtain data relevant to several indicators, for example, around timeliness.
- **Data collected at testing services:** Public health authorities can also collect data from people who book tests or who receive positive test results. This can be done in a variety of ways, including by phone, online or via the app.
- **Surveys:** Primary data collection through surveys will be essential for the collection of some of the proposed indicators. This is particularly relevant when the apps are based on a decentralized architecture, and limited data are available through the app, or when a deeper understanding of the indicator in specific socio-demographic groups is needed. Ideally, for the surveys to be representative of the population, simple random sampling should be conducted. However, depending on the disease incidence level, coverage of the app and operational feasibility, non-randomized observational studies may be the most feasible approach. Interpretation of survey results should account for

survey design limitations, potential confounders (such as age and other socio-demographic factors), recall bias, and social desirability bias (such as answering in a way that would make the respondent appear more responsible). Depending on the indicator of interest, surveys can be conducted among different groups:

- general population;
- app users;
- app users having experienced a particular in-app event, such as receiving an exposure notification or entering their positive test result in the app;
- contacts interviewed by contact tracing teams;
- people presenting to testing facilities.

Decision makers should carefully consider the advantages (e.g. more targeted study population) and disadvantages (e.g. perceived loss of privacy) of administering an online questionnaire through a link provided in the digital proximity tracing app. In the case of surveys targeting confirmed cases using the app, the user should only be prompted to answer the survey after entering the diagnosis authentication code. Considerations for data privacy and confidentiality should be clearly stated.

- **Data donation:** App developers can enable an option where users can consent to upload additional epidemiologically-relevant information about themselves to public health authorities – e.g. age. Users may be more motivated to do so if they are informed that the upload of such data may enable public health authorities to better understand the epidemiological situation in the country and transmission dynamics. Such data should only be retained for a limited period of time in compliance with local regulations, and security and confidentiality should be ensured. Public health authorities should be mindful of how this request would be perceived by populations and whether it risks limiting uptake of the app or deterring individuals from confirming their positive status in the app. To mitigate this risk, it is recommended that any option for data donation to the app be presented to the user after the confirmation of positive status has been completed in the app.

5. Considerations for the monitoring and evaluation of digital proximity tracing solutions

The following considerations should be taken into account as part of any effort to monitor and evaluate the effectiveness of digital proximity tracing solutions:

- **Proportion of the population actively using digital proximity tracing:** the proportion of the population required to be using a digital proximity tracing solution in order to demonstrate a positive public health impact has been a topic of much debate and research. Any monitoring of digital proximity tracing effectiveness will need to take adoption and utilization rates into account, including any regional/geographic variation.
- **Ability of Bluetooth technology to accurately measure distance:** the inherent inaccuracy of Bluetooth Low Energy technology used to estimate distance and calculate duration can impact the reliability of digital proximity tracing solutions. This can lead to false-positive or false-negative measurements of exposure being recorded.
- **Not all individuals or population groups will be able, or want to use digital proximity tracing solutions:** this may be due to a range of factors, such as lack of trust or doubt as to their usefulness; not having a compatible smartphone device; or exclusion due to lack of internet access, disability, age or limited digital literacy. This marginalization of some segments of the population can lead to inequity in the benefits offered by digital proximity tracing solutions. Countries should therefore seek to determine the proportion and characteristics of the app-using population to contextualize the data obtained from their assessment.

6. Data reporting and analysis

The indicators are mainly intended for national public health authorities to evaluate their digital proximity tracing solutions. There may, however, be some value in comparing indicators across countries through publications or seminars to facilitate mutual learning.

Table 1 provides an explanation on how to calculate each indicator (numerator and denominator) and proposes data sources for each component of the indicator. Given that the sources of the data used for the indicators may vary between countries, detailed decisions on how to collect, analyse and interpret the data should be made at the local level.

7. Limitations of the indicator framework

The ability to use the proposed indicators to facilitate comparison between countries will be limited by differences in how digital proximity tracing apps are implemented between countries, both in terms of the technology used and the level of integration with testing and conventional contact tracing services.

Consequently it is important, as noted above, to facilitate result interpretation and comparison between countries by including details and limitations of the technology being used in any publications and providing a flowchart, or similar graphical representation, to illustrate the approach to integration with testing and conventional contact tracing services.

Specific considerations and possible limitations for each individual indicator are included in Table 1.

8. Glossary of terms

Active use: refers to a device used in a digital proximity tracing network. The device is operational and communicates periodically with servers and other devices on the network (e.g. retrieves keys from a central server). Active use can be measured in a number of ways and will depend on several factors including the choice of architecture for the digital proximity tracing network. Suggested methods for measuring active use include subtracting the number of apps uninstalled from the numbers installed or calculating an average of the number of devices that retrieve 'infected' keys on a daily basis from the digital proximity tracking server.

Activation code: a one-time code typically issued by health authorities to an individual that has received a positive COVID-19 diagnosis. The action of this individual entering the code into their digital proximity tracing app triggers the process of key-matching and issuing of exposure notifications to those devices satisfying proximity criteria. In some instances, a national digital identity scheme can replace the need for use of a one-time activation code.

App controller: the national authority responsible for setting up and operating the digital proximity tracing solution which also oversees use of digital proximity tracing data.

Operating system provider platform for app distribution: refers to the proprietary distribution platforms of mobile device operating system providers used to distribute application software to registered clients (e.g. through the App store, Google Play Store, Huawei AppGallery, etc.).

Bluetooth Low Energy (BLE): A low power wireless communication standard that can be used over short distances to enable smart devices to communicate. In the context of digital proximity tracing, Bluetooth Low Energy allows for the exchange of anonymous 'keys' between devices participating in the network. Bluetooth Low Energy is a trademark and standard defined by the Bluetooth Special Interest Group (SIG).

Effectiveness: the extent to which an intervention works under real-world conditions (i.e. in practice) rather than controlled conditions. Effectiveness studies assess whether the intended effects of an intervention are achieved.

Exposure notification: refers to a message issued by a participating device to alert the user that they have recently been in proximity to an individual who has received a positive COVID-19 diagnosis and has shared their diagnosis via their digital proximity tracing app.

Keys: also referred to as Bluetooth beacons or temporary exposure keys. These are randomly generated, encrypted BLE identifiers exchanged between participating devices that are in close proximity to one another, according to defined distance and duration criteria. These keys provide the basis for anonymous 'matching' of devices and the subsequent triggering of exposure notifications.

Participation: refers to a device that is registered and enabled, and for which consent has been provided, to allow it to function on a digital proximity tracing network. (See also 'Active use'.)

Table 1. Indicators

The following tables present a list of indicators that can be used by national health authorities to evaluate the public health effectiveness of digital proximity tracing (DPT) apps. The super script letters in the calculation column refer to the suggested source of data for each indicator component:

- Population data[a]
- Data from operating system provider platform for app distribution[b]
- Data from app controller[c]
- Data from public health authorities[d]
- Survey[e]

A. To what extent is the mobile app used?

Indicator	Calculation	Suggested frequency	Rationale	Data source	Considerations
A.1: Proportion of total population who have downloaded the app.	Number of downloads[b]/Total population[a].	• Weekly; • Bi-weekly.	This indicates the coverage of the app in the population. The higher the coverage, the more effective the app is likely to be in terms of reducing transmission.	• Population data[a]; • Data from operating system provider platform for app distribution[b].	Modifications: • Instead of total population, use population who use smartphones (possible sources: International Telecommunications Union (ITU) or national telecoms regulator). This will indicate the extent to which there is room for improvement in terms of encouraging people to download the app. • The denominator can also be modified to look only at eligible target population based on compatible phones and age range. Possible bias: • People may have more than one device and may download the app on both. • In cases where the population of smart phone users is taken as a denominator, note that people may have devices with operating systems that are not compatible with the underlying DPT technology.
A.2: Proportion of total population that actively uses the app.	Number of apps that are in active use[b or c]/Total population[a].	• Weekly; • Bi-weekly.	This indicates the coverage of active app use in the population. The more people who actively use the app, the more effective it is likely to be in terms of reducing transmission.	• Population data[a]; • Data from operating system provider platform for app distribution[b] (numbers installed but not uninstalled); • Data from app controller[c] (number of phones that retrieve infected keys daily from server).	Modifications: • Instead of total population use population who use smartphones (possible sources: ITU or national telecoms regulator). This will indicate the extent to which there is room for improvement in terms of encouraging people to use the app. • The denominator can also be modified to look only at target population in eligible age-range. Possible bias: • People may have more than one device and may download the app on both. • In cases where the population of smart phone users is taken as a denominator, note that people may have devices with operating systems that are not compatible with the underlying DPT technology.
A.3: Proportion of all positive tests that occur among app users.	Number of activation codes issued[d]/Number of all positive tests reported by national public health authority[d].	• Weekly; • Bi-weekly.	This indicates the app usage or app distribution among positive cases.	Data from public health authorities[d].	A pre-requisite for this indicator to work is that activation codes are only issued to app users and not to all people testing positive. For countries where this is not the case, an alternative to this indicator could be to use the number of positive codes entered into the app as a proxy for the number of positive tests among app users. However, this could underestimate the true proportion since some cases might not upload their authentication code.
A4: Proportion of positive tests among app users that are entered into the app (positive tests uploaded).	Number of activation codes entered into the app[c]/Number of activation codes issued[c, d].	• Weekly; • Bi-weekly.	This would indicate the proportion of app users who enter their positive result in the app.	• Data from app controller[c]; • Data from public health authorities[d].	A pre-requisite for this indicator is that activation codes are only issued to app users and not to all people testing positive.
A.5: Rate of positive tests among app users relative to the rate of positive tests reported in the general population.	Number of activation codes issued per week[c,d]/100 000 active users[b,c]. versus Number of positive tests reported by national PHA per week[a]/100 000 population[a].	• Weekly; • Bi-weekly.	This indicates the weekly (or bi-weekly) incidence rate among app users relative to the weekly (or bi-weekly) incidence rate in the general population.	• Population data[a]; • Data from app controller[c]; • Data from public health authorities[d].	A pre-requisite for this indicator is that activation codes are only issued to app users and not to all people testing positive. For countries where this is not the case, an alternative to this indicator could be to use the number of positive codes entered into the app as a proxy for the number of positive tests among app users. However, this could underestimate the true proportion since some cases might not upload their authentication code. Modifications: Can use downloads instead of active app users as a denominator for an approximation. Further analyses: The causes of a lower estimated incidence among app users should be explored further as there are several possible explanations: • the app can effectively reduce transmission among app users; • app users have different characteristics and risk behaviour; • app users have different levels of access to testing. Further analyses, such as surveys or case-control studies broken down by age and other locally relevant socio-demographic factors, could provide more insight.

Figure 2. Indicator A.1: Proportion of the total population who have downloaded the app

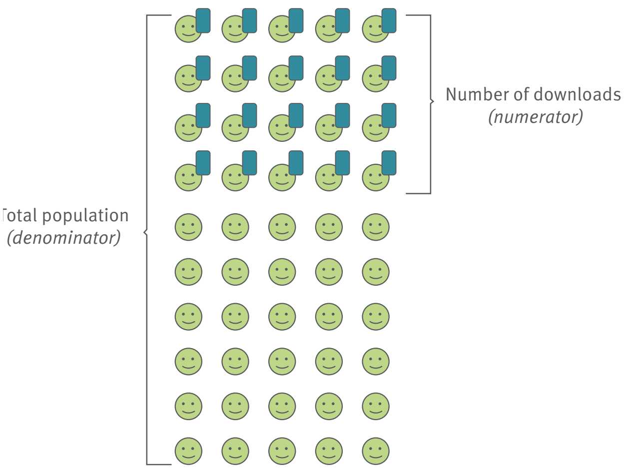


Figure 3. Indicator A.3: Proportion of all positive tests among app users

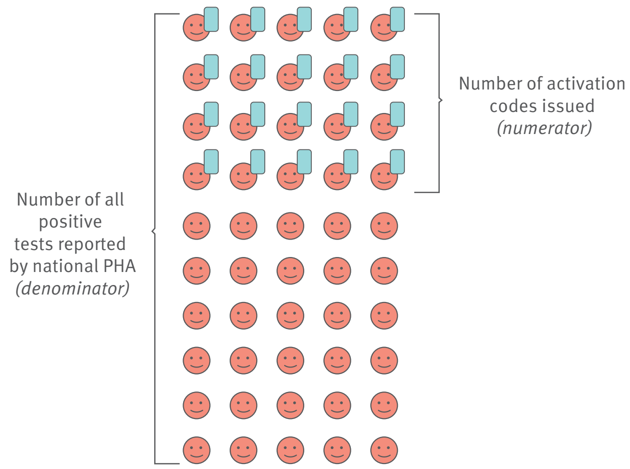
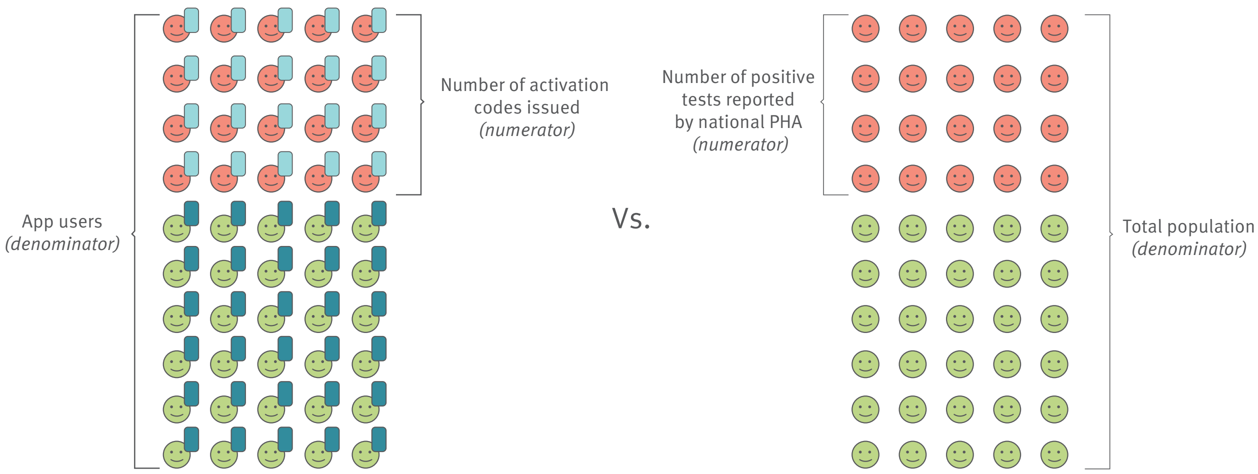


Figure 4. Indicator A.5: Rate of positive tests among app users relative to the rate of positive tests reported in the general population



B. Are mobile apps successful in detecting contacts at risk of infection?

Indicator	Calculation	Suggested frequency	Rationale	Data source	Considerations
B.1: Ratio of exposure notifications received to positive test results entered.	Number of exposure notifications received[c]/Number of positive test results entered[c].	• Weekly; • Bi-weekly.	This indicates the average number of contacts who were notified by the app per diagnosed case entering their positive test result into the app.	Data from app controller[c].	The interpretation of this result should take into account the exposure notification settings programmed in the app, such as the time and distance settings that would generate the notifications. Other factors such as population density, social behaviour, etc. may have an impact on this parameter. The feasibility of collecting this indicator may vary depending on the type of protocol in place (centralized vs decentralized). This ratio can be compared with the equivalent ratio for conventional contact tracing.
B.2: Proportion of diagnosed cases among app users who have previously received an exposure notification through the app.	Number of people with a positive test who were notified through the app that they had an exposure event within the 14 days preceding symptom onset (or sample collection if asymptomatic)[e]/ Total number of app users with a positive test[e].	Survey period	This indicates the overall effectiveness of the app in identifying and notifying people at risk among the population using the app.	Survey[e] of newly diagnosed cases among app users, conducted via testing facilities, an online questionnaire accessible through the app *or* during the conventional contact tracing team interview.	This data can only be collected in countries where the DPT app displays the date of exposure to the contact. *Note* that displaying the date of exposure to the contact person carries some risk of loss of anonymity for the index case. The 14-day period is derived from the incubation time for COVID-19 which is up to 14 days in most cases. *Note* that it is the date of exposure, not the date when the exposure notification is received that is of interest. Low coverage of the app could decrease the probability of receiving an exposure notification (this can be assessed via A.1a or A.1b), thus lowering the effectiveness of DPT. Modifications: If the date of exposure is not displayed, the date of exposure notification can be used as a proxy. However, since exposure notification can occur several days after exposure, this could over-estimate the number of diagnosed cases who had an exposure event detected by the app that is relevant to the case's current disease episode. This is because, in some cases the detected exposure could have occurred more than 14 days prior to the symptom onset.
B.3: Proportion of diagnosed cases previously notified only through the app (but not through conventional contact tracing) among all diagnosed cases.	Number of people with a positive test who were previously notified through the app (but not through conventional contact tracing) that they had an exposure event within the 14 days preceding symptom onset (or sample collection if asymptomatic)[e]/ Total number of positive tests[e].	Survey period	This estimates the additional contribution of apps in identifying people at increased risk of infection who were not identified through conventional contact tracing.	Survey[e] of newly-diagnosed cases conducted via testing facilities or an online questionnaire accessible through the app.	This data can only be collected in countries where the DPT app displays the date of exposure to the contact. *Note* that displaying the date of exposure to the contact person carries some risk of loss of anonymity for the index case. The 14-day period is derived from the incubation time for COVID-19 which is up to 14 days in most cases. *Note* that it is the date of exposure, not the date when the exposure notification is received that is of interest. Low coverage of the app could decrease the probability of receiving an exposure notification (this can be assessed via A.1a or A.1b), thus lowering the effectiveness of DPT. Modifications: If the date of exposure is not displayed, the date of exposure notification can be used as a proxy. However, since exposure notification can occur several days after exposure, this could over-estimate the number of diagnosed cases who had an exposure event detected by the app that is relevant to the case's current disease episode. This is because, in some cases the detected exposure could have occurred more than 14 days prior to the symptom onset.
B.4: Proportion testing positive among app users who present to testing services after receiving an exposure notification through the app.	Number of people who present to testing services after receiving an exposure notification through the app and who test positive[e]/Total number of app users who present to testing services after receiving an exposure notification through the app[e].	Survey period	This indicates the capacity of apps to detect people at risk among app users.	Survey[e] of newly-diagnosed cases among app users conducted via testing facilities.	This can be compared to the proportion who test positive among people presenting to testing for other reasons. Possible bias: • This indicator may be affected by the calibration parameters of the apps, which can influence their specificity and sensitivity in detecting contacts at risk of infection; • Interpretation of this indicator should take in consideration national testing policies for symptomatic vs asymptomatic contacts.

Figure 5. Indicator B.3: Proportion of diagnosed cases previously notified only through the app (but not through conventional contact tracing) among all diagnosed cases.

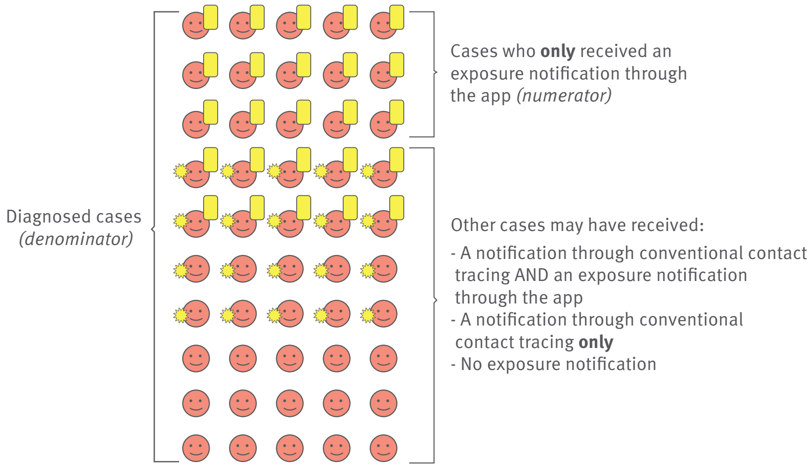
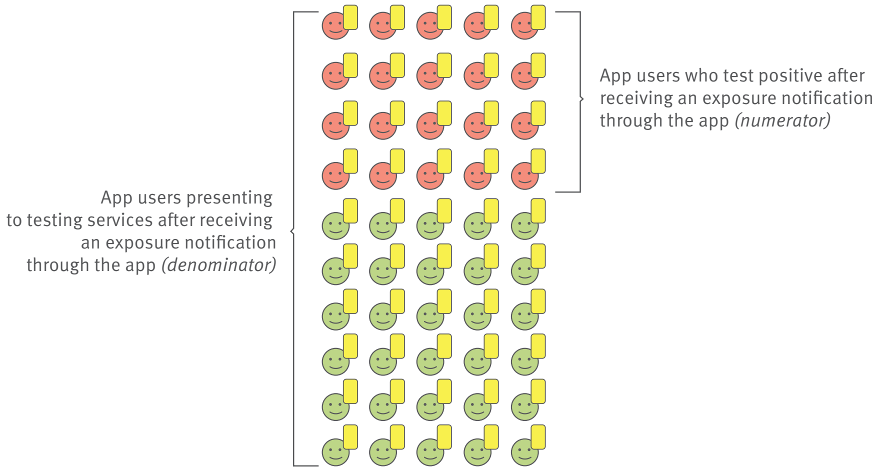


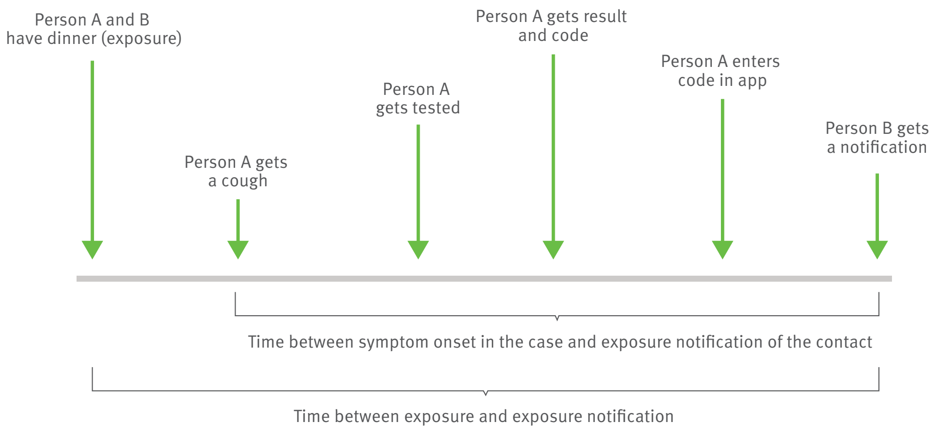
Figure 6. Indicator B.4: Proportion who test positive among app users who present to testing services after receiving an exposure notification through the app.



C. Are mobile apps faster in notifying contacts than conventional contact tracing?

Indicator	Calculation	Suggested frequency	Rationale	Data source	Considerations
C.1: Median (IQR) time between exposure and receipt of exposure notification through the app versus median (IQR) time between exposure and notification of contacts by conventional contact tracing services.	Date of exposure notification via app[e] – Date of exposure[e] versus Date of exposure notification via conventional contact tracing[d] – Date of exposure[d].	Survey period	Contact tracing aims to notify contacts as soon as possible. This would indicate whether DPT apps can shorten the time between exposure and exposure notifications, relative to conventional contact tracing.	Survey[e] data or data collected as people call public health services . Data from public health authorities on conventional contact tracing performance[d].	This data can only be collected through surveys in countries where the DPT app displays the date of exposure to the contact. Note that displaying the date of exposure to the contact person carries some risk of loss of anonymity for the index case. Notification delays in both DPT and conventional contact tracing could be affected by various factors such as: • delay between symptom onset and getting tested; • test processing delays; • test result issuance delays. Notification delays in DPT could be affected by various factors such as: • authentication code generation delay; • delay between code receipt and entering it into the app. Notification delays in conventional contact tracing could be affected by various factors such as: • delay in interviewing cases; • delays in notifying contacts. Modifications: If not possible to obtain timeliness data for conventional contact tracing, there is still value in measuring the timeliness of DPT apps on their own, without the comparison.
C.2: Median (IQR) time between symptom onset of index case and time of entering positive test result in the app versus median (IQR) time between symptom onset of index case and notification of contacts by conventional contact tracing services.	Date of entering activation code into the app[c] – Date of symptom onset[c] versus Date of notification of contacts by conventional contact tracing services[d] – Date of symptom onset[d].	Bi-weekly	Contact tracing aims to notify contacts as soon as possible. This indicator measures whether DPT apps can shorten the time between symptom onset in the index case and exposure notifications compared to conventional contact tracing.	Data from app controller[c] (via metadata embedded in the test result authentication code, which can include symptom onset date). Data from public health authorities on conventional contact tracing performance[d].	Notification delays in both DPT and conventional contact tracing could be affected by various factors such as: • delay between symptom onset and getting tested; • test processing delays; • test result issuance delays. Notification delays in DPT could be affected by various factors such as: • authentication code generation delay; • delay between code receipt and entering it in the app. Notification delays in conventional contact tracing could be affected by various factors such as: • delay in interviewing cases; • delays in notifying contacts. Modifications: If not possible to obtain timeliness data for conventional contact tracing, there is still value in measuring the timeliness of DPT apps on their own, without the comparison.
C.3. Median difference in notification speed between app and conventional contact tracing.	Date of notification via conventional contact tracing[e] – Date of exposure notification via the app[e].	Survey period	This would indicate whether digital proximity apps can shorten the time between exposure and exposure notification, compared to conventional contact tracing.	Survey[e] of contact persons who are notified via conventional contact tracing and asked if they have the app, if they received a notification from the app, and if so, how much earlier the notification came, compared to notification through conventional contact tracing.	Notification delays in both DPT and conventional contact tracing could be affected by various factors such as: • delay between onset and getting tested; • test processing delays; • test result issuance delays. Notification delays in DPT could be affected by various factors such as: • authentication code generation delay; • delay between code receipt and entering it in the app. Notification delays in conventional contact tracing could be impacted by various factors such as: • delay in interviewing cases; • delays in notifying contacts. Possible biases: Recall bias.
C.4 Proportion of new positive test results entered into the app within 24 hours of activation code issuance.	Number of positive test results entered into the app within 24 hours of activation code issuance[c] / Number of positive test results entered into the app[c].	• Weekly; • Bi-weekly.	This provides an estimate of the proportion of positive tests reported in the app in a timely manner.	Data from app controller[c].	Note that this timeliness can be affected by the duration of the activation code's validity.

Figure 7. Timeline for DPT used in indicators in section C



D. What are the enablers and barriers to app usage?

Indicator	Calculation	Suggested frequency	Rationale	Data source	Considerations
D.1 Reasons for use.	Frequency distribution of reasons associated with use of app.	Survey period	This will identify the key enablers of app use in the general population.	Survey of people using the app who will be asked about the reasons associated with their decision.	Examples of reasons for use: trust in science, perceive app as useful, think the pandemic is a serious issue, smartphone ownership, etc.
D.2 Reasons for non-use.	Frequency distribution of reasons associated with non-use of app.	Survey period	This will identify the key barriers to app use in the general population.	Survey of people not using the app who will be asked about the reasons associated with their decision.	Examples of reasons for non-use: data security and privacy concerns, trust in government, smartphone ownership, inertia, battery usage, lack of awareness of the app, perceive app as not useful, etc.
D.3 Socio-demographic characteristics of app vs non-app users.	Frequency distribution of key socio-demographic characteristics of app users vs. non-app users.	Survey period	This will identify differences in the key socio-demographic characteristics between app users and non-app users.	Survey (cross-sectional) of the general population (including app and non-app users) who will be asked about their socio-demographic characteristics.	Examples of socio-demographic factors: Age, gender, profession, smartphone ownership, nationality, ethnicity, employment status, income level, etc.
D.4 Risk behaviour of app vs non-app users.	Frequency distribution of risk behaviour of app users vs. non-app users.	Survey period	This will identify differences between app users and non-app users in key risk behaviour.	Survey (cross-sectional) of the general population (including app and non-app users) who will be asked about their risk factors.	Examples of risk factors: Smoking, use of protective mask, adherence to hand hygiene, adherence to social distancing, etc.

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