Selecting digital contact tracing and quarantine tools for COVID-19

Guiding principles and considerations for a stepwise approach

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1. Introduction

Background

As Member States ease restrictions put in place to suppress the outbreak of coronavirus disease 2019 (COVID-19), mechanisms to strengthen and sustain the "test, treat, trace and quarantine" paradigm[1] are more important than ever to contain the spread of the disease. By following a rigorous containment strategy, interventions can be targeted for infected and exposed individuals. In this way, society can progressively open up while limiting the risk of a COVID-19 resurgence, which could necessitate a return to non-pharmaceutical interventions – such as school closures, event cancellations and travel restrictions – that prolong social and economic disruption.[2]

Contact tracing has long been a fundamental public health function. Cases and contacts are interviewed to retrace events attended, locations visited, modes of transportation taken and people met. This information enables public health authorities to identify new potential cases or contacts, and isolate or quarantine them as appropriate (ideally prior to the infectious period). In this way, authorities can halt further transmission and "get ahead" of the outbreak.

Setting up and scaling up a workforce for manual contact tracing (contact tracers) requires significant resources. This represents a huge challenge for many Member States and can often be too slow, allowing transmission to continue unabated and undetected.[3] In addition, monitoring and enforcing isolation or quarantine measures that affect increasing numbers of people requires a separate large and capable workforce (quarantine officers).

Emergence of digital tools

Throughout the pandemic, digital contact tracing and quarantine (DCTQ) tools have emerged, creating a complex and rapidly evolving range of possibilities to consider. These tools are at different stages of development with varying levels of transparency and technical features that correspond to different effects on privacy. Most importantly, much of the technology has a limited track record, with scant evaluation and evidence.[4] Still, much depends on the context in which implementation of a DCTQ tool takes place, in terms of limiting the ability to generalize configurations or findings.

Although DCTQ tools may be instituted as part of a "new normal", Member States should realize that any single tool does not address all the steps required to achieve an end-to-end contact tracing and quarantine workflow. A strong public health workforce and infrastructure with manual contact tracing and quarantine capabilities are still required as part of a robust COVID-19 response, complemented by digital tools.

Member States should also consider legal and ethical dimensions during the design, implementation and operation of DCTQ tools,[5] to mitigate risks to privacy and comply with legal and regulatory frameworks. Doing so also fosters trust – a necessary aspect of any successful public health effort, especially one requiring people to embrace novel technologies.

2. Goal and guiding principles

Goal

This document aims to support Member States in the Western Pacific Region to assess the needs and opportunities of DCTQ tools, understand their conceptual and technological foundations, and consider the advantages and disadvantages of implementing them.

It is based on a high-level overview of the rapid evolution of DCTQ tools worldwide with a focus on the Western Pacific Region. This document is not normative or technical, as there are no best practices or lessons to share given the novelty and lack of evidence for DCTQ tools.

Target audience

Government officials at national and subnational levels advising on the design and implementation of DCTQ tools as part of the COVID-19 response.

Guiding principles

1. Contextualization and localization
Each Member State or subnational administration should conduct a needs assessment and map out the functions that would benefit most from implementing DCTQ tools, based on local social, legal, regulatory and technological contexts.[6,7]

2. Accountability and transparency
A governance framework should be in place with clear lines of accountability,[6] including a strict project management framework with detailed documentation practices. In addition, tools that are open-source can enable the public to more easily scrutinize security and privacy issues, which may assuage fears and help boost uptake in populations.

3. Data protection and privacy
Data collected by DCTQ tools should be secure, private and confidential, in line with data protection and privacy laws, regulations and frameworks, as well as cybersecurity protocols. All data use should be audited with oversight to monitor for breaches and abuse. De-identification and encryption should be deployed wherever possible to safeguard identities, contact information and health data.

4. Whole-of-government initiative
Public health interventions – DCTQ notwithstanding – should be consistent and coherent to maximize their impact and avoid confusion and loss of confidence. Whenever possible, decisions regarding DCTQ tools should be made jointly with a consensus among government ministries, subnational administrations and related bodies.

5. Multisectoral/multidisciplinary approach
Collaboration between the public and private sectors is likely required to ensure successful design and implementation, as well as community engagement and public consultation.[8] Expertise and perspectives from health and non-health disciplines (notably information and social sciences) should be involved throughout the process.

6. Equity and inclusivity
The deployment of digital technologies can widen the digital divide, leaving those without digital devices or skills behind, even though they may benefit most. Special consideration should be given for mobile, migrant, rural and vulnerable populations, as well as people with disabilities with respect to adoption and outcomes of DCTQ tools.

7. Proportionality and time limitation
Functions deployed as DCTQ tools should be proportional and relate directly to intended usage.[9] Personnel should only access specific data when needed (role-based access control) with time limits on data storage.

8. Usability and communications
User interfaces, functionalities and communications strategies should be co-designed with users and adhere to best practices for usability and accessibility. Communications should be clear, honest, consistent and continuous to calm anxieties and facilitate wider adoption, with authorities always taking care to alert the public of any issues that may affect their data, such as scams that masquerade as official tools.

9. Integration and interoperability
DCTQ tools should integrate well with other components of the COVID-19 response. Cross-border data exchange may also need to be considered.

3. DCTQ workflow and functions

DCTQ functions comprising the key phases

1 IDENTIFY	2 INFORM	3 QUARANTINE
[1a] Determine potential exposure based on proximity trail (Bluetooth)	**[2a]** Notify individuals based on proximity and/or location trails	**[3a]** Restrict access to public spaces according to individual risk level
[1b] Determine potential exposure based on location trail (GPS)	**[2b]** Notify individuals based on location check-ins	**[3b]** Restrict individuals to a private space for isolation/quarantine
[1c] Track locations visited based on location check-ins (e.g. QR code)	**[2c]** Notify individuals identified via recollection of named contacts	**[3c]** Provide documentation of isolation or quarantine
[1d] Integrate centralized databases (e.g. transportation, financial, CCTV)	**[2d]** Assign risk classification to individuals	**[3d]** Monitor spaces to enforce physical distancing in real time
[1e] Elicit recollection of contacts in a conversational manner	**[2e]** Publish case information (as line lists or maps)	**[3e]** Analyse mobility patterns at the population level
[1f] Self-report symptoms, travel history, contacts, etc.	**[2f]** Publish high-risk areas, events, flights, etc. (as text or maps)	

The high-level, end-to-end DCTQ workflow conceptually comprises three key phases: **Identify, Inform** and **Quarantine**.

The functions under each phase serve as building blocks either to design a novel/custom DCTQ tool or to assess/adapt an existing tool. Functions can be mixed and matched across and within phases to comprise a DCTQ workflow. The codes assigned to functions have no intrinsic meaning or set order. The decision regarding which functions to implement depends on the needs and gaps identified in a particular context.

Phase 1: Identify

This phase spans identification, investigation, tracking and matching of cases (both suspected and confirmed) and their contacts (both verified and potential).

[1a] Bluetooth low energy (BLE) can be used to detect and record encounters or so-called digital handshakes (defined using distance and duration criteria)[4] between individuals carrying Bluetooth-compatible devices, logging proximity trails, which do not contain location data.

[1b] On the other hand, the Global Positioning System (GPS) can be used to record precise locations visited by individuals' devices, logging location trails.

DCTQ tools are often exclusively Bluetooth or GPS based, but some combine both. By design, Bluetooth-based tools are widely considered to be more respectful of privacy than GPS-based tools, but no DCTQ tool is free of privacy risks.

[1c] Quick response (QR) codes can be scanned by individuals' devices as they visit locations, thereby maintaining a so-called digital diary of places visited over time.

For tools promoted as "privacy-preserving", the proximity trails (Bluetooth), location trails (GPS) and digital diaries (QR) are usually stored on an individual's device. They can be referenced or shared later with public health authorities if an individual becomes positive for COVID-19.

The technicalities behind data storage, data exchange, generation of unique temporary identifiers, mechanism for matching cases and contacts, and methods for reporting positive tests vary with each DCTQ tool. This may impact privacy and confidentiality to varying extents.

[1d] Centralized integration of data from different sources – such as airline passenger lists, credit card transactions, closed-circuit television (CCTV) cameras and telecommunications companies (also known as mobile network operators or MNOs) – can be used to retrace individuals' activities.[10] Tools that employ this function would infringe the most on privacy.

[1e] Information about symptoms, travel history and contacts can be gathered conversationally using newer technologies, such as chatbots augmented by natural language processing (NLP) and artificial intelligence (AI), or automated hotlines with interactive voice response (IVR). These serve to fully or partially automate conventional manual methods of contact tracing, in which a human contact tracer elicits information[11] in a conversational manner in person or by phone, SMS or email.

[1f] All the above methods can be supplemented by self-reporting of symptoms, travel history and contacts through a screening form or questionnaire. These data can then be analysed to produce a risk classification.

Phase 2: Inform

This phase encompasses methods for targeted notification of exposure risk to individual contacts or general notification to a population.

[2a] Targeted notification can be directed only to individuals with potential exposure to cases, as matched via proximity and/or location trails.

[2b] Alternatively, they can be matched via check-ins/digital diary entries.

[2c] Targeted notification can also be used for contacts identified by name via conversational means.

[2d] An individualized risk classification such as a coloured (red/yellow/green) QR code can be assigned and inform an individual of potential exposure and subsequent restrictions on movement. The assignment of this risk classification should be transparent to the individual to ensure understanding and trust.

[2e] On the other hand, generalized notifications can be used to inform a population or specific/local subpopulation. Publishing case information in the form of line lists or maps enables the public to self-monitor for symptoms if they crossed paths with cases and avoid high-risk settings from that point onward.

[2f] This could also be done by publication of high-risk areas/hotspots, events or flights derived from but not containing case information.

Phase 3: Quarantine

This phase is the actual step that will keep high-risk individuals for onward COVID-19 transmission away from others, based on information provided during the previous two phases. This phase includes methods to implement and/or enforce isolation, quarantine and physical distancing, as well as to inform planning of non-pharmaceutical interventions.

[3a] Individuals can be restricted from entering public places based on their risk classification, which can be verified by scanning a QR code at the entrance.[9]

[3b] Individuals can also be restricted to a specific location, such as a place of residence or quarantine facility**,** for isolation or quarantine. This can be done using geofencing (GPS) or a combination of background wireless signals (such as Bluetooth or Wi-Fi), and may employ both mobile and wearable devices (such as wristbands).[10] Leaving the boundaries of the location may trigger a text message or phone call from public health authorities.

[3c] Digital self-certification forms can be completed by individuals on a website or mobile application to demonstrate to their employers the need to self-isolate/quarantine (via a screening questionnaire) or attest to public health officers or law enforcement the reason(s) for leaving their place of residence. These forms can be printed out or accompanied by a QR code for scanning.

[3d] Individual behaviour (such as mask-wearing, physical distancing) and characteristics (such as body temperature) can be actively and continuously monitored in public places or workplaces. This can be done by cameras fixed in one location or mounted on a drone or robotic dog, with warnings issued by on-site human personnel or pre-recorded messages broadcast over loudspeakers so that appropriate action can be taken.

[3e] Population movements or mobility patterns can be tracked and analysed to inform broader public health planning, including the calibration of non-pharmaceutical interventions (such as building closures, travel restrictions, event cancellations). These data can be derived from MNOs or mapping services.

Importance of testing

While not the focus of this document, testing – the first part of "test, treat, trace and quarantine" – should be scaled up and strengthened.[1,4] Testing also includes screening and triage, either assessed by professionals or self-reported, as a means of determining who should be tested. The success of contact tracing and quarantine efforts depends on the ability to verify and temporarily separate individuals with COVID-19 from the public sphere. Testing allows patients to confirm diagnoses and inform human contact tracers or indirectly inform contacts via DCTQ tools about potential exposure so they can take necessary precautions (self-monitoring and quarantine).

Note on immunity passports/certificates

Immunity passports/certificates lend themselves to being implemented as digital tools. However, these are not discussed in this document since WHO does not recommend immunity passports/certificates given the lack of evidence surrounding antibody-mediated immunity.[12]

4. Proposed steps to implement DCTQ tools

The proposed steps are in a specific order, but some will overlap in scope and time:

1. **Assess the performance and resources of the current COVID-19 response** with a focus on capabilities and processes for contact tracing and enforcing isolation/quarantine.[13]

2. **Devise a strategy (goals, outcomes, targets)** for DCTQ based on needs, gaps and opportunities, in line with other components of the COVID-19 response.

3. **Select functions within the Identify–Inform–Quarantine phases** that will help achieve the strategy above, in line with legal, regulatory and ethical considerations, as well as the national/local context.

4. **Examine the array of DCTQ tools** to identify options for implementation or to provide a starting point for development.

5. **Form a coordination body or project team** with sufficient political support, oversight, governance and coordination/project management structures.

6. **Develop and operationalize the implementation and monitoring plan**, including timelines, communications strategy and mechanisms to address data protection and privacy.

Step 1: Assess the current response

DCTQ tools can only be effective when built upon a strong foundation, namely the existing contact tracing system. One great advantage is to have a system and workflow in which well-trained contact tracers can link close contacts to timely testing, medical services and social support. This capacity makes it easier to integrate digital tools to increase scale, efficiency and accuracy.

An initial assessment of the existing contact tracing system should examine all the steps involved, as per WHO guidance.[1,11] Robust linkages should be made with testing and case investigation workflows.

Questions for consideration include:

- Who are the key stakeholders, and which skills are required?
  For example: epidemiologist, contact tracer, care manager, contact follow-up monitor, data manager.
- What are the roles, responsibilities and workflows of the key stakeholders?
  For example: epidemiologists analyse data on cases and contacts; contact tracers collect and monitor data from close contacts; care managers coordinate resources.
- What is the capacity of the contact tracing and isolation/quarantine enforcement workforce?
- What are the plans to expand recruitment and training?
- What percentage of cases are being fully investigated in terms of identifying and conducting follow-ups with close contacts?
- How much time is taken during the contact tracing process to conduct the steps (and between steps)?
- What percentage of cases and contacts are being monitored for isolation/quarantine?
- What are the limitations and bottlenecks throughout the process?
  For example: shortage of contact tracers, delayed alerts to close contacts, insufficient coordination between contact tracers and testing facilities, data sharing and management issues, inter-jurisdictional or cross-border contact tracing.

Different arrangements and bottlenecks identified could lead to a different set of priorities to be addressed with digital tools.

Step 2: Devise a strategy

Clear and realistic goals, outcomes and targets should be formulated as part of a concise strategy for DCTQ. These should be linked to or embedded as part of the broader COVID-19 response.

Ideally, all close contacts should be traced for monitoring, but the subsequent demand for testing and contact tracing would place heavy and often unrealistic demands on capacity.

Questions for consideration include:

- What proportion of cases should be fully investigated with regard to close contacts?
- How much time should be taken for the contact tracing process and individual steps?
- How should workflows be reconfigured and the workforce trained once DCTQ tools are in place?
- What is the current epidemiological situation?
- Where are the specific locations that require the most support with DCTQ tools?
- What are the requirements for integration and interoperability with other systems, both within and outside the current jurisdiction?
- What is the strategy to calibrate non-pharmaceutical interventions?

Step 3: Select appropriate DCTQ functions

To help facilitate definition of requirements or selection of DCTQ tools for implementation, functions can be identified from the Identify–Inform–Quarantine framework (see figure on page 3) that will meet the goals, outcomes and targets from Step 2. Make sure to consider national/local characteristics, as well as legal, regulatory and ethical considerations.

Questions for consideration include:

- What are the levels of mobile phone adoption at national and subnational levels?
- What is the digital literacy level in the population?
- What is the age distribution of the population?
- How much trust exists within society and of the government?
- What are the legal, regulatory and ethical considerations and trade-offs with factors, such as social acceptability, technical feasibility and urgency?
- How can data and privacy be protected?

Step 4: Examine the array of available tools

Technologies for DCTQ are evolving rapidly. A variety of tools and apps have been developed by governments, private companies, nongovernmental organizations (NGOs) and academic institutions since the start of the pandemic. Many tools may appear similar but differ in small but important technical details that can have broader legal and ethical implications.

An overview is presented in the Annex. At this stage, minimal evidence exists regarding dimensions such as feasibility, usability, acceptability or effectiveness.

Examples from the overview can be assessed for relevance to national/local needs, and case studies examined for early-stage implementation considerations and challenges. The developers behind the tools should also be assessed in terms of reputation and capability.

Just as functions can be mixed and matched, the ideal solution may be a combination of features from existing tools. Therefore, a high-level decision is required to either adopt/adapt existing tools or design/develop a custom tool from scratch or on top of existing tools.

Questions for consideration include:

- How will needs and opportunities change over time?
- What are the requirements for hardware, software, data storage, bandwidth, security, accessibility and interoperability?
- Is the tool open-source or proprietary?
- How much automation will the tool provide?
- Are the developers reputable, experienced and capable?
- What is the internal technology workforce within the public sector?
- Should the decision be to adopt/adapt existing DCTQ tools or design/develop custom tools?

Step 5: Form a coordination/project team

Strong governance is key to achieving buy-in as well as ensuring adequate oversight and political support. Having the right team and internal/external partners involved will maximize accountability, user acceptance and the team's chances of success.

Team members should be drawn from relevant government bodies and the private sector, where appropriate. A mix of backgrounds will be required to guide a variety of tasks, including implementation, training and monitoring.

Questions for consideration include:

- Is there strong commitment from the leadership?
- What is the composition of the team?
- What form should the team take, and should it have subordinate bodies?
- How will the team fit within existing governance structures?
- How should the team interact with internal and external stakeholders, such as developers, donors and users?
- Is the reporting structure agile enough to avoid bottlenecks while judicious enough to avoid missteps?

Step 6: Develop and operationalize the implementation and monitoring plan

A phased project plan must be developed to encompass design, development, testing, implementation and monitoring/evaluation. The problem statement and scope of work should be clearly defined. Considerations should be made for scalability, sustainability, reliability, usability, interoperability and so on. Clear and consistent communications with the public will be vital to adoption and success.

An agile project management approach would likely be most appropriate given the tight time frames necessitated by the COVID-19 pandemic. Short- and long-term expectations should be aligned across all stakeholders.

Questions for consideration include:

- What are the mechanisms to address data protection and privacy?
- What is the project management approach?
- What is the operating model for the DCTQ tool?
- Is the implementation plan adaptable to evolving needs over time?
- How can monitoring and evaluation be implemented?
- What are the capital and operational costs?
- How will the DCTQ tools be financed, and will this be sustainable?
  For example: government budget, emergency fund for COVID-19, private sector, international donors, crowdfunding.

5. Specific considerations

Balancing sensitivity and specificity

Maximizing sensitivity and specificity relies on minimizing false negatives and false positives, respectively.[4] False positives occur when individuals are tagged as close contacts when there was little or no possibility of transmission – for example, between walls, in different vehicles, wearing personal protective equipment (PPE) – despite satisfying the criteria for duration and distance. False negatives occur when encounters with high risk of transmission – such as a sneeze or cough during a short elevator ride, touching of contaminated buttons or doorknobs – are not tagged as close contacts because they do not satisfy the duration and distance criteria. The trade-off is that reducing false negatives is likely to increase false positives, and vice versa. Adjustments in close contact criteria may therefore be necessary over time to minimize false negatives and false positives to acceptable levels. Alignment with national/local contact tracing guidelines may also be required to harmonize data analysis.

Balancing social acceptability and effectiveness

The decision to select the appropriate digital tool comes down to balancing social acceptability and effectiveness.[4] This presents another trade-off: greater effectiveness often carries a higher risk of privacy infringement and, therefore, lower social acceptability. Countries and populations leaning towards effectiveness can find themselves on a slippery slope: top–down approaches increasingly demand (and attempt to justify) collecting more identifiable data in order to build a complete profile of the population (or clusters, cases and contacts), whereas tools that maximize privacy may be more socially acceptable but restrict the ability of authorities to respond in a timely and precise manner whenever the need arises.[14]

Considering GPS and Bluetooth

GPS

- Location trails (GPS) can never be truly anonymous,[4,8] especially if the places visited are rarely frequented by others.
- GPS signals can be blocked or deflected by buildings or other obstacles and are not precise indoors or underground. Logging location trails would also not be applicable for people in motion (for example, in a car or on public transport).
- GPS is typically accurate to within 5 metres under open sky.[15]
- GPS does not recognize barriers between people such as floors, walls, windows and so on, which means individuals separated by such structures may be recorded as false-positive contacts.

Bluetooth

- A significant proportion of the population must own Bluetooth-compatible phones.
- Bluetooth has an approximate range of 2 to 10 metres indoors.[16]
- Bluetooth can be subject to interference with mobile phones, fluorescent lighting and Bluetooth-connected peripherals, such as headsets and earbuds.
- Bluetooth does not recognize barriers between people such as floors, walls, windows and so on, which means individuals separated by such structures may be recorded as false-positive contacts.
- Some Bluetooth-based tools require the app to be run in the foreground, which means other apps cannot be used in the meantime, a significant barrier to adoption.

6. Advantages and disadvantages of DCTQ tools

Advantages	Disadvantages
Coverage: With high levels of mobile phone ownership and internet connectivity in many countries, the ability to reach a high percentage of populations in near real time via one- or two-way communications is now a reality. With high coverage, more cases can be surveyed, and more contacts can be solicited from cases, when implementing digital tools. This would produce a more complete assessment of the situation on the ground. **Timeliness:** The possibility of near real-time communications speeds up contact identification, listing and follow-up by removing bottlenecks in capacity and overcoming geographical barriers.[13] This is particularly important in outbreaks with a short serial interval, and when there is pre-symptomatic or asymptomatic transmission – as is the case with COVID-19. **Precision:** The level of detail of contacts/encounters and visited locations tracked by DCTQ tools has the potential to increase precise application and fine-tuning of public health measures when compared to generalized and intrusive lockdowns. **Passivity:** Certain digital tools minimally rely on actions on the part of the individuals involved, thereby overcoming psychological and logistical barriers to participation, such as unwillingness, fear, deliberate deception and lack of time or patience. For instance, the locations visited by a case can be automatically logged as long as a mobile application is installed and Bluetooth or GPS is turned on. If telecommunications data are directly obtained and analysed, this step would not even be necessary.	**Risk of privacy/confidentiality compromise/infringement:** Whether "centralized" or "decentralized" DCTQ tools are deployed, enabling data collection en masse opens up opportunities for abuse. For example, such data could be used beyond the time frame of the pandemic or for purposes beyond public health. Data could also be accidentally disclosed or leaked, hacked or sabotaged by third parties. This risk exists even if data are only stored for a limited time (for example, 28 days) on user devices. In addition, the risk of re-identifying anonymous or de-identified data is never zero, whether data are analysed by a central authority or broadcast as alerts to the general population. Individuals as well as businesses (exposed on maps) may be stigmatized, leading to reputational and financial losses. This underlines the crucial need for legal and regulatory data protection/privacy frameworks, data-sharing agreements, and cybersecurity risk analysis and measures (such as encryption). Any tool implemented must comply with data protection and privacy laws and regulations at all levels, as well as emergency measures or exceptions in place during the outbreak. **Risk of low adoption:** It has been estimated that 60% is the approximate level of adoption required for voluntary DCTQ tools to be effective.[17] Furthermore, adoption is not a single step but comprises fulfilment of numerous steps, including download, installation, registration (where applicable), and active and consistent usage.[9] Download metrics cannot be relied upon because apps are often uninstalled or not used. Factors that complicate contact tracing also include the use of a single device by multiple individuals, use of multiple devices by a single individual, and infrequent or erratic carriage of devices.

De-identification: For some digital tools, it may no longer be necessary to recall or know individuals with whom a case has come into contact. This can be facilitated by the exchange of temporary, encrypted and anonymous IDs behind the scenes within a zone of proximity (the Bluetooth route) or through geospatial analysis (the GPS route). **Accuracy:** With the advantages described, the accuracy of contact data obtained can be increased substantially. Mechanisms to authenticate individuals and verify reported data (such as phone numbers and addresses) can also be built into digital tools to enhance accuracy. **Automation:** Certain digital tools may require significantly less manual effort from health authorities, by automating one or more stages of the contact tracing process. This acts as a workforce multiplier because contact tracers may, for instance, require 5 minutes per case instead of 20, thereby quadrupling capacity. Not only would this support contact identification, which is generally a one-off process, but also contact follow-up, which may be required daily for two weeks or longer. In addition to saving human resources, automation can reduce the need for training and conserve precious supplies of PPE. **Consistency:** Traditional, human-led methods can be inconsistent from one individual to another. Automated methods offered by DCTQ tools therefore offer a measure of consistency albeit with the potential cost of adaptability. **Health protection:** By reducing or eliminating face-to-face contact between public health officers and cases, the risk of transmission is significantly lowered. **Integration:** Digital tools provide the opportunity to integrate existing digital systems or platforms, connecting surveillance, contact tracing, screening/triage, testing and other workflows, which reduces duplication and streamlines activities.	**Dependence on infrastructure limitations:** Despite rapid digitization around the world, many areas still face fundamental infrastructure challenges, such as electricity access, mobile phone ownership and internet coverage, especially rural and remote communities, or areas with mobile, disadvantaged or older populations. Through the expected widespread implementation of digital tools, the digital divide may be exposed and exacerbated. **Technical unreliability:** Bluetooth, GPS and other technologies are not always accurate at measuring proximity or location. Factors such as orientation of the device, signal strength, battery life and the presence of other wireless devices can interfere with detection and measurement. **Dependence on literacy and digital literacy:** Digital tools requiring user intervention would have to be adapted to local languages and dialects, literacy and skill levels with digital technologies, in order to facilitate adoption and adherence. **Risk of fragmentation:** The relatively low barriers to set up a digital tool have led to more fragmented efforts in many countries. Simultaneous efforts among many – from government and academia to tech companies and NGOs – without careful coordination can lead to duplication of work, confusion among populations and increased risk of inappropriate data use/leakage. In short, loss of time and opportunity. **Dependence on trust and motivation:** Deriving from the above factors, trust in digital technologies and in the government, personal motivation and peer influence are key considerations that influence societal acceptance, adoption and sustainability of digital tools.[6]

Cost-effectiveness: By conserving resources (compared with traditional contact tracing) and leveraging the scale of digital technologies, the human resources and costs associated with contact tracing can be reduced, perhaps significantly. **Standardization:** Adoption of common frameworks or platforms may facilitate standardization of contact tracing efforts at the national, regional or global level. However, a lack of global standards also risks fragmentation.[8] **Quality assurance:** Storage and manipulation of data digitally (especially in the cloud) means that data are not subject to physical deterioration, space limitations or loss compared to traditional paper records. Furthermore, digitization creates a trail of data that can be analysed to further refine and improve containment measures, both during and after an outbreak.	**Risk of biased data:** Mobility data are dependent on coverage of the population of the particular MNO or mapping service. These data can be skewed towards segments of the population that reside in areas with high service coverage or use particular operating systems, or with certain educational backgrounds or socioeconomic characteristics. **Risk of complacency and non-cooperation:** The use of digital tools can give people a false sense of safety that causes them to neglect basic precautions such as personal hygiene measures and physical distancing.[4] This may be exacerbated by the use of “safe” in the names of many DCTQ tools (see Annex). Further, the use of DCTQ tools may give individuals internal justification to decline involvement in conventional contact tracing efforts. **Risk of deception:** Since individuals can turn off GPS, Bluetooth and Wi-Fi functions and close the app at any time, there is the risk that individuals deliberately do so whenever they are in close contact with certain people or spend longer times at certain locations in order to assure privacy. These are, in fact, often situations with the highest risk of transmission. **Risk of non-reporting:** Given that many DCTQ tools are optional, individuals may use the app for the sole purpose of receiving notifications of cases or accessing maps of hotspots, without necessarily reporting themselves as cases if they are later diagnosed (either intentionally or unintentionally). This “free rider” phenomenon is ultimately self-defeating. **Inflexibility of questioning:** Until more advanced and natural virtual assistants are developed, DCTQ tools will remain relatively fixed in terms of questions and responses. Human contact tracers can dig deeper in ascertaining history and behaviours. They can also personalize and adjust their approach based on individual characteristics and local context.

	Challenges with integration and interoperability of data/systems: For top–down tools, the potential for incompatibilities between information systems, databases and data formats is high. This may restrict data integration (for example, accurate matching of individuals). Common data models and technical standards agreed by stakeholders are important to address potential incompatibilities at the start. For bottom–up tools, interoperability is also a concern on a technical level (with devices, Bluetooth capabilities, operating systems, etc.) as well as at a policy level (for example, with data sharing between national borders or subnational boundaries[4] for tourists, business travellers and migrant populations). **Loss of human connection between the population and authorities:** Increasing reliance on digital tools may disrupt rapport between public health authorities and the population, reducing empathy and trust on both sides.

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Annex. Overview of DCTQ tools

The examples of DCTQ tools in the table below are for illustrative purposes only. They have not been reviewed, recommended or endorsed by WHO or its partners. Many are drawn from the Western Pacific Region and may change quickly, given the rapidly evolving technology. The functions ascribed to these tools constitute one conceptual interpretation as per the Identify–Inform–Quarantine framework (see figure on page 3). No claims or guarantees are made regarding technical accuracy, acceptability or effectiveness.

Examples of DCTQ tools

DCTQ tool	Functions	Link to official website or media article
Apple–Google	1a, 2a	https://www.apple.com/covid19/contacttracing/
Belgium: Romware Covid Radius	3d	https://romware.com/covid-radius/
China: Close contact detector	1d, 2e	https://www.bbc.co.uk/news/technology-51439401
China: Drones	3d	https://abcnews.go.com/international/coronavirus-china-deploys-drones-cameras-loudhailers-chastise-people/story?id=68746989
China: Health code	1b, 1d, 1f, 2d, 3a	https://technode.com/2020/04/07/china-voices-how-alibaba-built-chinas-health-code/
China: Travel card	1d, 3a	http://www.xinhuanet.com/politics/2020-04/09/c_1125832845.htm
Europe: DP-3T	1a, 1b, 2a	https://github.com/DP-3T/documents
France: Permission form	3c	https://www.thelocal.fr/20200406/france-coronavirus-lockdown-this-is-how-frances-new-online-permission-form-works
FLIR	3d	https://www.flir.com/
Google: Community Mobility Reports	3e	https://www.google.com/covid19/mobility/
Hong Kong SAR (China): StayHomeSafe	3b	https://www.coronavirus.gov.hk/eng/stay-home-safe.html
Israel: Shin Bet	1d	https://techcrunch.com/2020/03/18/israel-passes-emergency-law-to-use-mobile-data-for-covid-19-contact-tracing/
Japan: COCOA	1a, 2a	https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/cocoa_00138.html
Landing AI	3d	https://landing.ai/landing-ai-creates-an-ai-tool-to-help-customers-monitor-social-distancing-in-the-workplace/
MIT: Safe Paths	1b, 2f	https://covidsafepaths.org/
New Zealand: COVID Tracer	1c, 2b	https://www.health.govt.nz/our-work/diseases-and-conditions/covid-19-novel-coronavirus/covid-19-health-advice-general-public/contact-tracing-covid-19/nz-covid-tracer-app
New Zealand: Line list	2e	https://www.health.govt.nz/our-work/diseases-and-conditions/covid-19-novel-coronavirus/covid-19-current-situation/covid-19-current-cases/covid-19-current-cases-details
Norway: Telenor	3e	https://www.telenor.com/how-our-mobility-data-can-help-predict-and-prevent-the-spread-of-covid-19/
Philippines: KontraCOVID	1f	https://www.kontracovid.ph/
Republic of Korea: CDC	2e	https://www.nature.com/articles/d41586-020-00740-y

Republic of Korea: Corona 100m	2e	https://www.businessinsider.com/coronavirus-south-korea-photos-apps-location-outbreak-where-2020-3
Republic of Korea: Corona Map	2e	https://coronamap.site
Republic of Korea: Self-quarantine safety protection	3b	https://www.technologyreview.com/2020/03/06/905459/coronavirus-south-korea-smartphone-app-quarantine/
Republic of Korea: SMS Emergency Alerts	2e	https://www.bbc.com/news/world-asia-51733145
Singapore: SafeEntry	1c	https://covid.gobusiness.gov.sg/faq/safeentry
Singapore: SPOT	3d	https://www.tech.gov.sg/media/media-releases/spot-robot-trial-for-safe-distancing-operations
Singapore: TraceTogether	1a	https://www.tracetogether.gov.sg/
Spain: Drones	3d	https://www.bbc.com/news/world-51911340
Thailand: Thai Chana	1c	https://thethaiger.com/coronavirus/thai-chana-app-to-help-track-safe-retailers-in-a-covid-era
United Kingdom: NHS Isolation Note Service	3c	https://digital.nhs.uk/news-and-events/latest-news/isolation-notes
UNTIL: 1point5	3d	https://until.un.org/news/until-released-free-social-distancing-app-1point5
United States of America: CDC Clara Coronavirus Self-Checker	1f	https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html

The following compilations of DCTQ tools from third parties may also serve as additional references:

MIT Technology Review Covid Tracing Tracker
https://docs.google.com/spreadsheets/d/1ATalASO8KtZMx__zJREoOvFh0nmB-sAqJ1-CjVRSCOw/edit#gid=0

Top10VPN COVID-19 Digital Rights Tracker
https://www.top10vpn.com/research/investigations/covid-19-digital-rights-tracker/

WPR/DSE/2020/023