

Multi-mode standardization under extreme time-pressure – the case of COVID-19 contact-tracing apps

Klaus Marhold^{1,*}  and Jan Fell^{1,2} 

¹Institute for Entrepreneurship and Innovation, Vienna University of Economics and Business, Vienna, 1020, Austria. klaus.marhold@wu.ac.at jan.fell@iss.nthu.edu.tw

²Institute of Service Science, National Tsing Hua University, Hsinchu, 300044, Taiwan, R.O.C. jan.fell@iss.nthu.edu.tw

The present study investigates the standardization process of contact tracing apps during the COVID-19 pandemic. Due to the epidemiological urgency, and differing from classical examples in the literature, this process is characterized by a compressed timeframe. In this setting, we investigate the role of different standard-setting modes and their interaction through the lens of multi-mode standardization. We find that the processes of standard setting through market competition or inclusive multi-stakeholder committees proved time-consuming and inefficient in addressing the immediate needs during this major global health crisis. Multi-mode standardization between committees, market players, and governments equally proved unable to coordinate a standard. Ultimately, a so far neglected actor, namely platform owners, proved to be pivotal in coordinating a widely-adopted standard. Our research extends multi-mode standardization with platform owners as a further standardization actor of proliferating importance given the increasing pervasiveness of platforms in numerous contexts. The present article provides implications for the interplay between different modes of standard setting in general, and the setting of technological standards in crises in particular.

1. Introduction

There is a strong interest in the literature about technological standards and the process through which they are created and implemented (Narayanan and Chen, 2012). Prior literature has discussed how standards often exist concurrently in competing relationships for years (Schilling, 2002). Even when multi-stakeholder committees collaborate in the development of a standard to avoid long periods of uncertainty (Gallagher, 2007), it may require years

for a standard to be released (O’Connell, 2013). Increasingly, standards arise out of multi-mode standardization, i.e., through the interaction between different paths to standardization, such as markets, committees, and governments (Wiegmann et al., 2017), adding complexity to already drawn-out processes.

Crises, such as the coronavirus disease 2019 (COVID-19) pandemic, can lead to extreme time pressure to develop, standardize, and roll-out technologies. A recent example of a key technology requiring

standardization are COVID-19 *contact-tracing apps* (Sun and Viboud, 2020; Ting et al., 2020). This technology must be supported by standardization processes faster than the archetypical multi-year processes, given that delays in effectively combating the COVID-19 pandemic could lead to prolonged negative socio-economic consequences (Nicola et al., 2020; Breeze, 2021). Contact-tracing apps automatically record physical proximity between mobile phones (Ferretti et al., 2020), notifying users if they were in close contact with an infected person (McCall, 2020). As network goods, these apps depend heavily on mutual compatibility and thus on standardization. Studies indicate a need for 60%–75% of a population to use mutually compatible apps to achieve epidemiological effectiveness (Hinch et al., 2020; The Straits Times, 2020a). However, while contact-tracing apps had been used in research settings since 2010 (Yoneki and Crowcroft, 2014), no common standard or deployable solution existed at the outbreak of the pandemic in early 2020 (Oliver et al., 2020). This dearth has led diverse actors to rapidly develop apps and work toward their standardization.

Expecting that standard setting under a compressed temporal frame substantially differs from what was investigated by the extant literature, we investigate different approaches to standardize contact-tracing apps. Our analysis, through the lens of the Wiegmann et al. (2017) multi-mode standardization framework, highlights the difficulties of various actors to coordinate standardization within a compressed timeframe. We find that an actor thus far not considered in the standardization literature, namely Apple and Google as mobile operating system *platform owners*, played an important role in setting the eventual contact-tracing standard. An investigation of the role of platform owners, which often exercise absolute power over their platforms (Cutolo and Kenney, 2020), in standard-setting processes is relevant given the continued proliferation of platforms in contexts such as mobile technologies, electric vehicles, software, and multimedia content (Parker et al., 2016; van Dijck et al., 2018). Platforms also play an ever-increasing role in responding to various crises, ranging from health crises (Krausz et al., 2020) to natural disasters (Poblet et al., 2014).

2. Theoretical background

2.1. Standards and standard setting

Standards are rules facilitating compatibility between technological products (Katz and Shapiro, 1985; Gandal, 2002),¹ and thereby complement

dominant designs (Gallagher, 2007), which alone do not imply mutual compatibility (Afuah, 2003). Mutual compatibility reduces uncertainty (Rosenberg, 1976). This is especially relevant for network goods that do not offer benefits in isolation but increase in utility with an increase in the number of adopters (Henderson and Clark, 1990; Shapiro and Varian, 1999; Chen and Forman, 2006). An example of this is the video cassette. By the 1980s, magnetic tapes held in plastic cartridges had evolved as the dominant design in the home video market, though several mutually incompatible standards backed by different market players (e.g., Sony's Betamax and JVC's video home system [VHS]) existed in competition (Cusumano et al., 1992). An increase in the population of VHS adopters led to an increase in the utility of VHS, with the movie industry and rental chains offering a wider selection of titles (Ohashi, 2003). Analogous cases include the DVD, the Blu-ray Disc, online social networks, or peer-to-peer file sharing (Dranove and Gandal, 2003; Lin and Kulatilaka, 2006; Salek et al., 2010; Wang, 2010).

As presented in the preceding examples and mirroring dominant designs, standards can exist concurrently in competition (Schilling, 2002). This is typical for *de facto standards* emerging from market competition (Farrell and Saloner, 1986a; Rada, 1993; Updegrove, 1995; Lee and Mendelson, 2007; Techatassanasoontorn and Suo, 2011; Tamura, 2015). They are unlike *de jure standards* officially approved by a recognized standards developing organization (SDO)² or government agency (Farrell and Saloner, 1986b; Rada, 1993; International Organization for Standardization, 2020b). While generally *de jure standards* embody best practices agreed upon by expert consensus (McCallum, 1996; International Organization for Standardization, 2020a), *de facto standards* do not necessarily embody best practices. VHS is a well-known example of a technologically inferior *de facto* standard emerging from market competition (Higuchi and Troutt, 2008; Barney, 2014).

The binary categorization of standard setting modes into *de jure* and *de facto standards* is pervasive in prior literature (e.g., Farrell and Saloner, 1986a; Rada, 1993; Updegrove, 1993; Olle, 1996; Schilling, 2002; Suárez, 2004; Lee and Mendelson, 2007; Leiponen, 2008; Büthe and Mattli, 2010; Bryer et al., 2011; Narayanan and Chen, 2012). However, for several technologies (e.g., 3G, Java, and FireWire), the standard setting did not occur through an ideal-typical single mode, but materialized when actors coordinated across modes

(e.g., Garud et al., 2002; Gao, 2014; van de Kaa and Vries, 2015).

2.2. Coordination across modes in standard setting

In this vein, the multi-mode standardization view recognizes that whether and at which pace a standard emerges, is implemented and subsequently adopted, depends on the coordination between actors involved in this process (Wiegmann et al., 2017). These actors comprise individual firms, industry consortia, standards organizations, professional associations, and government agencies (Leiponen, 2014; Yates and Murphy, 2019; Conde et al., 2020). In their seminal work on multi-mode standardization, Wiegmann et al. (2017) provide a granular typology of standard-setting modes, where apart from *de-facto standards* (i.e., market-based), they further differentiate *de-jure standards* as either *committee-based* (i.e., set by a standards organization), or *government-based* (i.e., set by a government agency). Table 1 presents these ideal-typical standard-setting modes – market-based, committee-based, and government-based standards – and their characteristics.

Unlike this ideal-typical view, there exist several relationships, interactions, and interdependencies between actors across the ideal-typical standard-setting modes, whereby the setting of a standard becomes multimodal (Wiegmann et al., 2017). These multimodal relationships include committee and market actors (e.g., Funk and Methe, 2001; von Burg, 2001; de Vries et al., 2008; Blind, 2011); government and committee actors (Pelkmans, 2001; Egyedi and Spirco, 2011; Townes, 2012; Gao, 2014); government and market actors (Rosen et al., 1988; Funk and Methe, 2001; Puffert, 2002); or markets, committees, and governments (Abbate, 2001; Büthe and Mattli, 2011; Bakker et al., 2015).

Despite their increasing significance, literature has paid limited attention to multi-mode standardization occurring on platforms (Wiegmann et al., 2017). Here, platforms refer to business models utilizing technology to enable various stakeholders to create and exchange value within an ecosystem (Parker et al., 2016). Real-life ubiquitous examples of organizations subscribed to the platform business model are Amazon, Apple, Facebook, Google, and Microsoft (van Dijck et al., 2018). The governance mechanisms of platforms are defined and established by the platform owner (Ballon, 2009; Hein et al., 2020). This level of control implies a significant influence of platform owners on the standard-setting processes. For instance, platform owners Apple and

Google, which in late 2020 controlled almost 100% of the mobile operating system market (Statista, 2020), actively curate and limit the extent to which stakeholders (e.g., third-party developers) may add their products and services (generally in the form of apps) to the iOS and Android platforms (Hänninen and Paavola, 2020). In summary, multi-mode standardization processes are of high relevance for platforms, which are characterized by often complex interactions between owners and various stakeholders. Given the relevance and increasing prevalence of platforms, it would behoove scholars and practitioners to better understand the multi-mode aspects of standardization and the role platform owners play in the standard-setting processes.

3. Method

3.1. Research approach and context

To investigate the standard-setting process of contact-tracing apps in Europe, we employ a case study approach. While the methodology literature suggests multiple-case study designs (Eisenhardt, 1989, 1991), single-case studies are appropriate ‘where the case represents an extreme case or an unusual case, deviating from theoretical norms or even everyday occurrences’ (Yin, 2014, p. 173). This is also in line with prior empirical research on standardization reporting on single cases (e.g., Blind, 2002; Garud et al., 2002; Büthe and Mattli, 2010; Townes, 2012).


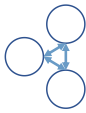
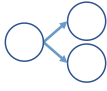
COVID-19 started spreading in Europe in February of 2020, and within less than a month suffused to all European countries (Whitworth, 2020). From March onwards, the increasing number of cases resulted in governments implementing measures ranging from travel restrictions to lockdowns (Cohen and Kupferschmidt, 2020). At the same time, many different organizations were working on supporting health authorities’ contact-tracing efforts through automated solutions. These ranged from commercial companies and startups to multi-national committees formed to develop such solutions, providing opportunities to investigate the different standardization modes (Table 1) and their interactions.

3.2. Data collection and analysis

Our case study on the standardization of contact tracing apps in Europe is based on a variety of primary and secondary research data and has been conducted in three broad phases (Table 2).

The first exploratory phase (March to April 2020) aimed to gain an understanding of the initial

Table 1. Ideal-typical modes of standardization

	Committee-based	Market-based	Government-based
Relationships between actors			
Coordination mechanism	Coordination through cooperation between stakeholders. Standards are developed in committees and only diffused if members agree on a common solution	Solutions intended as a standard can be developed by anyone. Coordination through competition between solutions in the market, leading often (but not always) to one de-facto standard	Solutions intended as a standard can come from various sources. Coordination through governments using their hierarchical position to impose these standards' use on others
Timing of coordination	Coordination takes place during standard development – only one solution is chosen to enter the market	Coordination takes place during diffusion – different standards are developed and compete with each other	Governments can intervene in development or mandate using an already developed standard
Main actors driving the standardization process	Predominantly private: Stakeholders cooperating in committees; SDOs providing a platform for standard development	Predominantly private: Individual market actors influencing the outcome of the market competition with their actions	Predominantly public: Governmental bodies developing standards and/or enforcing their use
Avenues of influence	Participating in committees to influence standards' contents	Engaging in the market to influence battles' outcomes by influencing decisive factors	Influencing government decision-making through lobbying or parliamentary representatives
Inclusiveness in standard development	High, any interested party can join a committee	Varies, some standard development venues are open; access to others is restricted	Medium, lobbying may require high effort

Source: Obtained from Wiegmann et al. (2017).

Table 2. Phases of research and employed research data

Phase	Focus	Data and examples
Phase 1: Initial observations	<ul style="list-style-type: none"> Overall picture and timeline of the initial development process of contact tracing solutions from the perspective of one of the many startup actors involved in this effort 	<ul style="list-style-type: none"> Primary data <ul style="list-style-type: none"> Participation in more than 50 online meetings of Novid20 Internal documents of Novid20 <ul style="list-style-type: none"> Overview document of contact tracing solutions 8 pitch decks for various national and international potential users 2 diaries of key decisions taken by the founder and the HR manager Access to more than 10,000 internal messages on the organization's Slack messenger account Access to more than 200 emails between Novid20 and external contacts
Phase 2: Dominant design and standards	<ul style="list-style-type: none"> Emergence of a dominant design Early attempts at setting a European standard through the committee-based mode 	<ul style="list-style-type: none"> Primary data <ul style="list-style-type: none"> Interviews with Novid20 leading members Secondary data <ul style="list-style-type: none"> News reports (e.g., BBC, 2020b; Financial Times, 2020b; Reuters, 2020d) Medical and epidemiological research articles (e.g., Hellewell et al., 2020; Wang et al., 2020) Research articles on contact tracing solutions (e.g., Abeler et al., 2020; Vaughan, 2020)
Phase 3: Multi-mode standardization	<ul style="list-style-type: none"> Multi-mode standardization Analysis of the resultant standard and how it arose with the involvement of a new type of actor (i.e., platform owners) 	<ul style="list-style-type: none"> Primary data <ul style="list-style-type: none"> Interviews with DP-3T co-initiators EU documents (e.g., eHealth Network, 2020a; European Commission, 2020a) National government documents (e.g., French Government, 2020; German Federal Government, 2020; Swiss Federal Council, 2020) Information released by committees (e.g., DP-3T, 2020c; PEPP-PT, 2020b) Secondary data <ul style="list-style-type: none"> News reports (e.g., Bloomberg, 2020; The Guardian, 2020) Research articles on contact tracing solutions (e.g., Ahmed et al., 2020; Shubina et al., 2020)

Modelled after the matrix data display for qualitative research in Verdinelli and Scagnoli (2013).

development process of contact-tracing solutions in Europe. In this phase, a key source of primary information was Novid20, an Austrian social startup founded to develop an app-based contact-tracing solution. Novid20 was considered a suitable data source for three reasons. First, the authors were granted access to various internal Novid20 meetings and documents. These documents contained information on other solutions, actors, marketing documents, pitch decks, app specifications, and meeting minutes.

Second, Novid20 is representative of organizations that undertook the development of contact-tracing apps in Europe in the spring of 2020. Third, Novid20 was a member of *Pan-European Privacy-Preserving Proximity Tracing* (PEPP-PT), one of the two committees aiming to implement a common standard across Europe.

In the second phase (May 2020), based on our understanding of the initial development process of contact-tracing apps, we focused on the

standard-setting process. To this end, we conducted a series of formal interviews with key personnel of Novid20. All interview participants (Table 3) provided information on Novid20's development and diffusion efforts and the activities of PEPP-PT. We augmented this information using publicly accessible secondary data.

In the third phase (October to December 2020), heeding to comments received on an earlier version of this work, we examined the standardization process through the lens of multi-mode standardization. Hence, in this phase, the supplementary data collection focused on the various actors – market participants, committees, and government agencies – and their interactions. We gained key insights through formal interviews with co-initiators of the *Decentralized Privacy-Preserving Proximity Tracing* (DP-3T) committee. DP-3T was initiated by researchers at the Swiss Federal Institute of Technology in Lausanne (EPFL); it developed the specifications and protocols that eventually served as the basis for the Apple/Google contact-tracing standard (The New York Times, 2020a).

We conducted semi-structured interviews lasting for 20 to 40 min (Table 3). The interview questions (Appendices A and B) aimed to collect general information about the interviewees – their organizational role and experience with standards during the development process – and the collaboration between different actors. We collected additional primary data from committees, Apple/Google, and the European Union (EU) by accessing their websites and the code repository GitHub. The collection of secondary data throughout Phases 2 and 3 was conducted with the broad selection criteria of source credibility and expected contribution to our understanding of the case. We used Web of Science to identify relevant academic literature and Factiva and Pressreader to locate news articles.

The various data sources allowed us to apply triangulation (Amaratunga and Baldry, 2001; Maxwell and Reibold, 2015) to corroborate information and fill in gaps in our understanding of the case. In the first phase of the research, we employed inductive coding.

The second phase relied on a blended approach (Skjott Linneberg and Korsgaard, 2019) that mixed certain deductive categories resulting from the research in Phase 1 with inductive coding, especially in such interviews revealing new information to us. For the third phase of the research, which was closer aligned with the Wiegmann et al. (2017) multi-mode standardization framework, we employed a deductive coding scheme. Table 4 provides an overview of the coding schemes and key categories.

4. Findings

4.1. The emergence of a dominant design

Actors in Europe had a variety of options when considering technical solutions for contact-tracing. Countries and territories in East and Southeast Asia, which were the first to be affected by COVID-19, developed and employed different technological approaches to contact-tracing. In Mainland China, the government rolled out a QR code-based solution (Kamel Boulos and Geraghty, 2020; Mozur et al., 2020), while Taiwan employed analysis of mobile phone location data (Chen et al., 2020). In South Korea, *behavioral big data* (Shmueli, 2017) was pooled and provided to the authorities (Park et al., 2020).

However, it became apparent that while effective in their home markets, these solutions would not work in Europe due to differences in data availability, as well as data privacy laws and norms (Klonowska, 2020). Instead, the focus quickly shifted to Bluetooth-based contact-tracing apps. This was also inspired by Singapore launching the Bluetooth-based *TraceTogether* app in mid-March (Bay et al., 2020; McCall, 2020).

If you consider digital contact tracing, it was clear to us that Bluetooth was the way to go. And all other proposed solutions in Europe were using Bluetooth, too.

DP-3T Co-Initiator 1

Table 3. Overview of formal interviews

Organization	Role within the organization	Interview date
DP-3T	Co-Initiator 1	2020-11-25
DP-3T	Co-Initiator 2	2020-11-25
Novid20	Founder	2020-05-04
Novid20	Managing Director	2020-05-05
Novid20	Chief Technology Officer	2020-05-06
Novid20	Stakeholder Relations Officer	2020-05-06
Novid20	Security and Privacy Lead	2020-05-09

Table 4. Data analysis approach

Phase	Approach	Key themes/categories
Phase 1: Initial observations	Inductive	Background, solutions, motivations, actors
Phase 2: Dominant design and standards	Blended	Dominant design, standards, competition, collaboration, data privacy, ethics
Phase 3: Multi-mode standardization	Deductive	<ul style="list-style-type: none"> • Ideal-typical Modes of standardization <ul style="list-style-type: none"> ○Committee-based ○Market-based ○Government-based • Multi-mode standardization <ul style="list-style-type: none"> ○Government- and market-based ○Committee- and market-based ○Government- and committee-based • Platform owners in the standardization process <ul style="list-style-type: none"> ○Platform owners as a new type of actor ○Multi-mode standardization efforts

The emergence of Bluetooth-based contact-tracing apps as the dominant design did by itself not ensure interoperability. Subsequent standardization processes focused on the underlying data architecture and protocols.

4.2. Single mode attempts at setting a standard

Initial efforts at setting a standard for contact-tracing apps predominantly took place within one of the ideal-typical standardization modes, that is, market-based, committee-based, and government-based.

4.2.1. Market-based

The market mode of standard setting highlights that solutions can be developed by anyone and that coordination happens as the various solutions compete in the market (Wiegmann et al., 2017).

Indeed, in March and April 2020, a large number of different solutions were developed by firms, startups and non-profit organizations, e.g., *Novid20*, *CoEpi*, *COVID Community Alert*, *COVID19 Alert*, and *COVID Safe Paths* (eHealth Network, 2020b). A review of contact-tracing apps identified more than 50 apps in use worldwide (Shubina et al., 2020). The emergence of different solutions might also be explained by the fact that some of the early solutions were not immediately released as open source, as the process of documenting the protocol and providing reference implementations takes some time (ComputerWeekly.com, 2020). As the CTO of *Novid20* mentioned, the time pressure to release a functional contact-tracing app prompted them to develop their own solution, rather than wait for other developers' open-source documentation:

We were operating under time pressure. Nobody could know how the COVID-19 crises would develop.

For us, waiting for a standard was not a scenario that we considered. Rather, we built something based on our existing technological capabilities while ensuring the flexibility to adopt future standards.

Novid20 CTO

An interesting situation occurred in Austria, where under normal market-based standardization, competition between the two local market actors *Novid20* and *Red Cross* would have eventually resulted in a *de-facto* standard. However, realizing the harmful effects of competing to become the national standard, *Novid20* decided not to release its app:

Under normal circumstances, we should have released our app and let the market decide. We acted in the interest of the greater good, since two apps would have confused the Austrian population and negatively impacted public health.

Novid20 CTO

4.2.2. Committee-based

Standardization through committees refers to a cooperative mode of coordination involving a wide array of stakeholders, such as SDOs, industry consortia, as well as professional and trade associations. These stakeholders cooperate to define a standard before its subsequent diffusion, which aids the standard's legitimacy and reduces uncertainty (Wiegmann et al., 2017).

Two committees aiming to coordinate and diffuse a contact-tracing standard utilizing Bluetooth were formed in Europe in the first week of April 2020, namely *PEPP-PT* (TechCrunch, 2020a), and *DP-3T* (2020b).

The key question was what kind of protocol to run on top of Bluetooth. We started collaborating with a lot of scientists to come up with a very efficient

and privacy-preserving protocol that satisfies all the needs of the epidemiologists. This was a goal-driven design, not just a random walk in the solution space.

DP-3T Co-Initiator 1

These two committees proposed diametrically opposed approaches, specifically *centralized* versus *de-centralized* contact-tracing (Langheinrich, 2020). In the centralized approach, all apps are connected to a central authority. The central authority stores all contact-tracing data, and determines their further use and disclosure. Conversely, in the decentralized approach, no entity is a sole authority or has control over the whole network and generated data (Dar et al., 2020). Participation in either of the two committees thus largely reflected support for either of these approaches. While hailed by some to represent a superior means to coordinate a quick and coordinated epidemiological response (White and Basshuysen, 2020), the centralized approach provoked fears of mass surveillance and malicious use of the contact-tracing data (Sweeney, 2020; Vaudenay, 2020). The ensuing discussion led to a rift, with proponents for both solutions openly criticizing the other solution while advocating for their own (Reuters, 2020d). For instance, when on April 18th PEPP-PT released a document illustrating their proposed security and data protection specifications on GitHub, DP-3T responded a day later with a detailed critique (DP-3T, 2020c). DP-3T has since then been backed by several actors formerly participating in PEPP-PT (Bloomberg, 2020; Fortune, 2020; Reuters, 2020c). Ultimately, neither PEPP-PT nor DP-3T were able to on their own diffuse a widely adopted standard between March and June of 2020 (Politico, 2020).

4.2.3. Government-based

Governments can also play an important role by using a hierarchical position to coordinate and impose standards. They can either develop these standards themselves or mandate the use of an existing standard (Wiegmann et al., 2017).

Given the importance of contact-tracing in augmenting public health efforts, national governments got involved in the standard-setting process. France, for example, pushed for a domestic, centralized solution. To succeed, however, it had to solve a technical issue that had plagued contact-tracing apps on Apple's iOS devices since the launch of the first apps in Singapore, Australia, and Canada (ABC News, 2020; Global News, 2020; The Straits Times, 2020b). Specifically, certain Bluetooth functions are limited when the app is not active or the device is in standby mode. Hence, for full operability, on iPhones the app has to be running in the foreground, limiting

the use of the device for other tasks. This issue constrained the functionality of the apps, and because of negative user experiences, threatened the widespread adoption of such apps. France demanded that Apple solve this issue to ensure full operability of its national contact-tracing solution (BBC, 2020b). This request was denied, leading to perpetual inoperability of the standard released by the French government (Reuters, 2020b). A similar case unfolded in the United Kingdom (UK), where the government had decided to develop a national centralized solution. Citing issues of operating this solution on Apple devices, in June 2020, the UK government decided to switch to the Apple/Google standard, which did not face such limitations (Financial Times, 2020c; The Guardian, 2020).

In Europe, the cross-country functionality of contact-tracing apps played a large role in plans to ensure a safe re-opening of internal borders. The EU, a supranational institution with quasi-governmental qualities, did not push for a specific standard, but took a different role. In early April, it published a recommendation (European Commission, 2020a) on the use of contact-tracing apps in Europe, pointing towards 'interoperability and promotion of common solutions' as an important factor (European Commission, 2020b). This was followed by the release of more detailed interoperability guidelines (eHealth Network, 2020a, 2020b). This focus became more apparent, when in June member states agreed on interoperability for their decentralized contact-tracing apps (European Commission, 2020d). The required infrastructure was set up by two commercial companies, with the data being hosted by the European Commission's data center. It became operational on the 19th of October of 2020, when the Apple/Google-based contact-tracing apps of Germany, Italy, and Ireland were linked to the system (European Commission, 2020c).

4.3. Multi-mode standardization

Actors not only engaged in developing solutions and propagating standards on their own (and thus within the ideal-typical standardization modes), but also, sometimes concurrently, in various collaborative configurations across modes.

4.3.1. Government- and market-based

When governments and markets interact, governments may use their hierarchical powers to directly influence a national standard, thereby preventing the prolonged period of competition between market actors innate to the ideal-typical market-based standardization. Beyond the national level, governments

usually do not possess the hierarchical means to directly influence the standardization process. Nevertheless, their backing and support can send strong signals to the market (Wiegmann et al., 2017).

European governments engaged in various standardization efforts with market players. The German government joined SAP and Deutsche Telekom in the development of a national contact-tracing solution (Bloomberg, 2020), and the Austrian government joined the Austrian Red Cross and Accenture in the development of a national solution (Accenture, 2020). What these examples have in common is that governments picked a single solution from the many under development in their respective country, thus aiming to avoid the usual period of competition for dominance among market actors.

While governments used their hierarchical means to influence the standardization process on the national level by involving themselves in the competition between market actors, two important shortcomings remained. First, national governments and market actors were unable to compel Apple to allow the required Bluetooth functionality on iOS devices, thus rendering any coordinated standard epidemiologically useless. Second, the coordinated standards were proprietary and not interoperable. Recalling the country-like qualities of the EU – namely the freedom of movement of citizens, goods, and services – interoperability was a crucial design requirement from an epidemiological point of view. And while the ability of national governments to shorten standard battles was limited to national markets, the EU also proved unable to hierarchically, or otherwise, coordinate a pan-European standard among the different market players in the member states (Kask, 2020).

4.3.2. Committee- and market-based

Elements of competition and cooperation are combined when committee- and market-based standardization jointly drive the standardization process (Wiegmann et al., 2017).

In the early weeks of the pandemic, various start-ups and initiatives had commenced working on app-based Bluetooth contact-tracing solutions (eHealth Network, 2020b). While these actors competed for being the first to deploy or enjoy widespread adoption – behaviors characteristics of market-based standardization (Farrell and Saloner, 1986a; Updegrove, 1995) – a number of them (e.g., *Heartbeat Labs*, *Novid20*, and *Tourmaline Labs*) also joined the PEPP-PT committee (PEPP-PT, 2020b). Thus, PEPP-PT as a committee differed from DP-3T in that it not only invited universities and research institutes, but also market actors already in the process of developing contact-tracing apps (PEPP-PT, 2020a). As the

Novid20 CTO remarked during the interview, market actors saw the committee as means to coordination and exchange, and to gain information on approaches being deliberated and developed. Nevertheless, at the same time they continued pursuing the diffusion and adoption of their own standards. He attributed this dual-pronged approach to the impression that coordination within the committee resulted in a slower speed of development than in smaller, more agile organizations.

Despite the inclusion of numerous market actors, the PEPP-PT committee was unable to transform its proposed standard into a widely adopted contact-tracing app between April and June of 2020 (Politico, 2020), and by November 2020 the committee's website was unreachable.³ It thus appears that market actors involved in PEPP-PT could not benefit from the usual advantage associated with combined committee- and market-based standardization, i.e., the faster coordination of a standard through rounds of negotiations between the market-actor stakeholders of the committee with the aim of reducing rivaling solutions (Farrell and Saloner, 1988).

4.3.3. Government- and committee-based

In some cases, a standard is the product of interplay between government and a committee. In this deviation from ideal-typical modes, governments either use hierarchical means to direct the outcomes of committee-based standardization, or enter the committee as a powerful actor (Wiegmann et al., 2017).

Several European countries directly influenced or actively campaigned for either of the two committees, namely PEPP-PT and DP-3T. Initially, governments supported whichever of these two committees included actors from their respective country. The German government supported the PEPP-PT committee, which featured research units of the public Fraunhofer Institute, the government-operated Robert Koch Institute, and a number of public research universities among its stakeholders (NPR, 2020; PEPP-PT, 2020b). Germany's support included advocacy and involvement of national research institutes, as well as publicly hinting at adopting the PEPP-PT standard for the national contact-tracing app (German Federal Government, 2020). Conversely, the Swiss government advocated for the DP-3T committee, initiated by Swiss universities, and ultimately implemented their solution in the Swiss contact-tracing app (SwissInfo, 2020). Thus, in the present case, governments were involved as powerful actors in both committees either through national research organizations, or as ardent promoters of a standard developed by committees in their respective countries. In this vein, Germany's

health minister Jens Spahn characterized the rivalry between PEPP-PT and DP-3T as ‘a war of religion’ (Reuters, 2020a).

In April 2020, the centralized approach became the focus of serious criticism due to privacy and data protection concerns. The significant impact of government involvement in the committees was illustrated by national governments switching support from PEPP-PT to DP-3T (TechCrunch, 2020b). In late April, the German government abandoned the centralized approach, and instead switched support to the decentralized approach proposed by the DP-3T committee (Bavarian Broadcasting Corporation, 2020; Foreign Policy, 2020). Without government support, the departure of public research institutes, as well as government agencies, the PEPP-PT committee soon faltered. Yet, it was not the support by an increasing number of national governments that majorly benefited the adoption of DP-3T’s solution, but, as presented in the following section, the involvement of a new type of actor in the standard-setting process.

4.4. A new type of actor transcending standardization modes

Despite the various single- and multi-modal attempts at standardization, in Spring of 2020, the market was in a heterogeneous state and characterized by an abundance of non-interoperable solutions (European Commission, 2020e). A major development in April of 2020 was the announcement of a partnership between Apple and Google to work on an interoperable Bluetooth contact-tracing standard (Apple, 2020a). In the midst of a global health crisis, Apple and Google recognized the urgent need for a contact-tracing standard, and decided to jointly allocate their immense resources to this task (Apple, 2020c):

All of us at Apple and Google believe there has never been a more important moment to work together to solve one of the world’s most pressing problems. Through close cooperation and collaboration with developers, governments, and public health providers, we hope to harness the power of technology to help countries around the world slow the spread of COVID-19 and accelerate the return of everyday life.

The *Google Apple Exposure Notification* solution provides a standard protocol for Bluetooth contact-tracing apps on mobile devices running iOS and Android (TechCrunch, 2020c). A major technical challenge experienced by committees, governments, and firms engaged in standardization efforts was overcome as Apple’s restrictions on the use

of Bluetooth in standby mode were lifted for contact tracing apps adopting the Apple/Google standard (BBC, 2020a). Additionally, apps utilizing the Apple/Google solution became in principle interoperable, thus laying the foundation for EU-wide roaming (European Commission, 2020e). While France continued to resist the quasi-hierarchical imposition of a standard by platform owners Apple and Google (BBC, 2020b), within weeks of its release, the vast majority of EU member states had adopted this standard (The New York Times, 2020b; Reuters, 2020c).

[...] once a standard has been developed by the two players that control the platform, which is what Apple and Google do in mobile phones, then it doesn’t really matter what you want, it only matters what they want. France hasn’t yet conceded that, but that is the reality.

DP-3T Co-Initiator 2

The abrupt end of solution heterogeneity in Europe resulting from Apple and Google coordinating an interoperable standard highlights the government-like qualities innate to platform owners. Further, France’s futile attempts to impose its own standard on Apple (Financial Times, 2020a) and the UK’s departure from its own solution in favor of Apple and Google (Financial Times, 2020c), reveal qualities that go beyond the hierarchical means of governments, which are typically limited to their territories (Wiegmann et al., 2017).

You could not build a contact tracing app on iOS without Apple’s involvement, because of the security and privacy features of the system.

DP-3T Co-Initiator 2

A specific diversion from extant descriptions of the government-based standardization mode pertains the ability of platform owners acting as quasi-governments on their platforms, and thus exercising powers over actual national governments. For instance, in its contact-tracing terms of service, Apple and Google place restrictions on any repurposing of data by national governments beyond the use scope unilaterally permitted by the two platform owners in the first place (Apple, 2020b; Google, 2020).

4.4.1. Multi-mode standardization between platform and committee

Apple and Google did not develop the contact-tracing standard on their own. Rather, it was DP-3T, which laid the foundations and approached Apple and Google with the aim of jointly coordinating a standard:

We approached Apple and Google through our contacts, and send them a message – which was really a redundant message – that the two of them would have to work together so that there would be a solution that worked for all phones. We pushed our solution, which was at that point developed and published. And it turns out that because of Apple’s fairly strong position in favor of privacy, this was the more favored solution to them than the centralized protocol. They evaluated the two approaches and decided that they would go with the DP-3T solution.

DP-3T Co-Initiator 2

This resulting standard is the product of collaboration between DP-3T and Apple and Google, who worked together on integrating their proposed decentralized standard into an earlier unreleased version of the Apple/Google standard (DP-3T, 2020a).

The original Apple/Google solution had some differences we did not consider as advantageous. And we worked with them and pushed them to implement a few other things.

DP-3T Co-Initiator 2

The decision-making processes within Apple and Google are not publicly disclosed, and neither is there a formal and transparent process by which other actors (i.e., market players, committees, or governments) can participate in the standard-setting process. While in this specific case, DP-3T was able to convince Apple and Google of their solution from a technological and epidemiological standpoint, no formal mechanism of coordination existed, pointing to limited avenues of influence and low inclusiveness.

5. Discussion

During the early phase of the COVID-19 outbreak in Asia, different approaches to contact-tracing were pursued. These ranged from GPS tracking, QR Codes, and big data analytics, to Bluetooth-based apps. When COVID-19 reached Europe, Bluetooth-based contact-tracing apps quickly emerged as the dominant design. The time pressure to release a working contact-tracing solution caused market actors to commence immediate, and at the same time uncoordinated, development. This led to the creation of a multitude of similar, yet mutually incompatible solutions. Our observations in this initial phase concur with characterizations of the market-based standardization mode in prior literature: standardization requires long periods of time, resulting in major uncertainty over which solution to back. In

the pandemic, prolonged standard-setting processes and technological uncertainty would have had negative epidemiological and socioeconomic effects. Ultimately, the market did not have the opportunity to coordinate a standard, as market actors were outpaced by Apple’s and Google’s sudden entrance to the standardization process.

In prior examples, such as USB (O’Connell, 2013), wireless LAN (Hayes, 1991), and JPEG (Graham et al., 2018), committees played an important role. These commonly involve competing firms and techno-scientific organizations coordinating standards before products are developed and marketed (Jakobs et al., 2001; Gallagher, 2007). While the setting of standards through this mode benefits from legitimacy and network effects through the involvement of multiple stakeholders (Koppell, 2010), efforts can take years to result in a standard. In the case of contact-tracing apps in Europe, this slower speed of coordination caused market actors (e.g., app startups) to continue promoting their own solutions rather than rally behind a committee. Eventually, and analogous to the market mode, committees did not have the opportunity to coordinate a standard. The sudden entrance of Apple and Google to the standardization process simply outpaced committee efforts to coordinate a standard. Beyond these time-related obstacles, conflict between two committees, PEPP-PT and DP-3T, and varying support of governments also contributed to a failure to set a standard through the committee-based mode. This is noteworthy, as these two committees were seen by many to possess more legitimacy due to their wide representation and were expected to raise fewer concerns regarding data protection and privacy than commercial actors.

Governments can impose newly developed or existing standards by virtue of their hierarchical position (Wiegmann et al., 2017). In the present case, countries such as the UK and France developed their own proprietary solutions, while other governments, sometimes in addition to their own developments, backed the emerging committees. Ultimately, the involvement of governments was not substantial in the setting of a common standard, as they were constrained by technical limitations and outpaced by Apple and Google entering the process. Their role on both national and supra-national levels became crucial only once a standard had been set by platform owners Apple and Google. Specifically, the EU and national authorities then focused on linking individual apps to national health infrastructure and across member states.

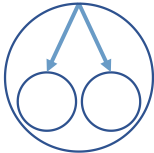
Prior literature on standard setting shows that often standards are not set through a single mode,

but through the interaction of multiple actors and mechanisms (e.g., Blind, 2002; Townes, 2012). The present case also highlights such avenues of collaboration and interplay between different modes. In the initial phase, it was especially the interaction between governments and the market, as individual governments either pushed for their own solutions or backed, mostly local, market players. The market-based actors in some cases collaborated with the emerging committees in order to gain insights and affect the development of a standard. However, ultimately these efforts at multi-mode standardization by known actors (Table 1) were not successful. Rather, they were outpaced by the speed with which platform owners Apple and Google collaborated on and ultimately set a standard with the DP-3T committee. This immediately solved prior technical limitations and resulted in a standard widely adopted by the various developers of contact-tracing apps throughout Europe.

When comparing the role Apple and Google played in this process to ideal-typical actors (Table 1), they do not appear to fit in any of the established categories. As we show in Table 5, as private companies they align with the market-based mode of standardization. Yet, in terms of the coordination mechanism, the standard was neither reached through market competition, nor through the consensus characteristic of the committee-based mode. Rather the standard was ‘forced’ upon the public and private developers of contact-tracing apps by the platform owners. This is highlighted by the example of Apple refusing to

accommodate the French government’s solution, and making it clear that only the Apple/Google standard can be used. This is clearly in line with how governments are setting standards hierarchically. What grants Apple and Google this power is their absolute control over the platform. In this case, iOS and Android jointly hold an almost 100% market share. Within their platforms, the owners act as quasi-governments. However, unlike the government-based mode of standardization, inclusiveness in the standard setting process is low and there typically exist no formal avenues of influence. The observed characteristics of platform owners in the present case, as well as their behavior in the standard-setting process, clearly deviate from all actors and modes described in the extant literature. This highlights that platform owners should be seen as a distinct standardization actor. Moreover, platform owner-based standardization should be considered as a fourth major mode of standardization. We also show that in this case multi-mode standardization played a major role as the platform owners cooperated with a committee, and that especially in complex cases of standardizations, a single mode of standardization is often not feasible. And while time pressure was not causal in the ultimate success of platform owner-based standardization, it was time pressure from the perspective of epidemiological urgency during a public health crisis with its ancillary negative socioeconomic effect that was causal in the entry of Apple and Google to the standardization process in the first place (Apple, 2020c).

Table 5. Characteristics of a platform owner-based mode of standardization

	Platform owner-based
Relationships between actors	
Coordination mechanism	Solutions intended as a standard can come from various sources. Coordination through platform owners using their hierarchical position to impose these standards’ use on others
Timing of coordination	Coordination takes place at either or a combination of standard development, diffusion, or when a standard has already been developed by another party
Main actors driving the standardization process	Predominantly private: Individual platform owners developing standards and/or supporting and then enforcing their use
Avenues of influence	Extremely limited, anti-trust laws and regulations
Inclusiveness in standard development	Low, typically internal decision-making processes of platform owners

Authors’ own work, characteristics obtained from Wiegmann et al. (2017).

6. Conclusion

6.1. Contributions

We investigated a unique case of standardization, in which a technology with wide-reaching consequences was developed, and a standard was set in the extremely compressed timeframe of a few months. This setting adds to the literature on standardization, which typically has focused on cases with longer timeframes (e.g., von Burg, 2001; Funk and Methe, 2001; Blind, 2011). We show that under time pressure, market-based standardization was not an effective mode of standardization. And while prior literature has indicated that in the given circumstances, committees with their inclusive development process should have had major advantages in terms of legitimacy (Tamm Hallström and Boström, 2010; Botzem and Dobusch, 2012), the present case is atypical in that neither of the involved committees was able to independently coordinate a standard.

We also contribute to recent literature on multi-mode standardization (Wiegmann et al., 2017). Specifically, we identified a case allowing for the observation of numerous configurations of multi-mode standardization in a single, time-compressed case. We highlight the efforts and failures of these multi-mode attempts, and point to the important role of platform owners in the outcome of this standardization process. Platform owners fall outside of the previously discussed actors and modes of standardization, and represent a completely new category, that given their increasing prevalence, will rise in importance.

6.2. Policy implications

Concerning future crises, decision-makers in governments must embrace technology as a central tool. This technology should include mobile and wearable devices of citizens to leveraging ubiquitous and pervasive computing resources. Our research shows that, under time pressure, the market cannot solve standardization-related issues. Hence, governments must devise a policy for standard-setting for future crisis situations. This policy should clarify the following questions: Who sets the standards? Which parties are invited to provide technological solutions? Whom does the government endorse and by which process? Governments should embrace regional exchanges on their standard-setting policies to ensure mutual compatibility during crises. This is relevant for single market entities, such as the EU, and other regional blocs, such as the Association of Southeast Asian Nations or the African Union. Regarding the increasing importance of mobile operating platforms

in disaster and crisis response (Manso and Manso, 2013; Tan et al., 2017), our results should prompt governments to involve platform owners as central actors in the standardization process.

In the context of COVID-19, the standardization of technological responses remains crucial. For example, electronic vaccination certificates, an important tool in the post-vaccination phase of the pandemic, pose standardization challenges analogous to contact tracing apps (Marhold and Fell, 2021).

6.3. Limitations and directions for further research

Our research is focused on time pressure during a crisis acting on the involved entities and the coordination of a standard. Within the stream of standardization literature, our case is atypical as it unfolded in the course of only months, rather than years. We expect future research to investigate other cases in which the timeframe differs from established literature to provide additional insights into standard setting in crises and other situations characterized by a high level of time pressure. Beyond that, time and temporal aspects provide a number of perspectives for future research. For instance, the startups and committees in our case study could be investigated from the perspective of temporary organizing (see Bakker et al., 2016). In this vein, we envision future research addressing how the work of the diverse ad-hoc organizations not part of the eventual Apple/Google standard – likely in the tens of thousands of staff hours – can be captured beyond these organizations' eventual temporal demise for both future crisis preparedness and utilization in analogous markets.

Given the nature of the crisis and response, some of the insights may not be generalized. Unlike other technologies, contact-tracing apps, as a software, can be updated to accommodate new standards. To generalize the results, we expect future research to investigate the role of platform owners in the standardization process in various settings and from various perspectives, such as the avenues of influence for the platform users and how this role could affect innovation (Eaton, 2016).

Ethics statement

The present research has received approval through an ethics review process by the University Senate Research Committee at the first author's institution of affiliation. No conflicting interests were reported by the authors.

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References

- Abbate, J. (2001) Government, business, and the making of the Internet. *Business History Review*, **75**, 1, 147–176. <https://doi.org/10.2307/3116559>
- ABC News. (2020, April 26) *COVIDSafe's Effectiveness on iPhone in Question as Government Releases Coronavirus Contact Tracing App*. Retrieved from <https://www.abc.net.au/news/2020-04-26/coronavirus-tracing-app-covidsafe-apple-iphone-covid-19/12187448>
- Abeler, J., Bäcker, M., Buermeyer, U., and Zillesen, H. (2020) COVID-19 contact tracing and data protection can go together. *JMIR Mhealth Uhealth*, **8**, 4, e19359. <https://doi.org/10.2196/19359>
- Accenture. (2020) “*Stopp Corona*” App. Retrieved from <https://www.accenture.com/us-en/case-studies/public-service/stopp-corona-app>
- Afuah, A. (2003) *Innovation Management*. Oxford: Oxford University Press.
- Ahmed, N., Michelin, R.A., Xue, W., Ruj, S., Malaney, R., Kanhere, S.S., Seneviratne, A., Hu, W., Janicke, H., and Jha, S.K. (2020) A survey of COVID-19 contact tracing apps. *IEEE Access*, **8**, 134577–134601. <https://doi.org/10.1109/ACCESS.2020.3010226>
- Amaratunga, D. and Baldry, D. (2001) Case study methodology as a means of theory building: performance measurement in facilities management organisations. *Work Study*, **50**, 3, 95–105. <https://doi.org/10.1108/00438020110389227>
- Apple. (2020a) *Apple and Google Partner on COVID-19 Contact Tracing Technology*. Retrieved from <https://web.archive.org/web/20200414004834/https://www.apple.com/newsroom/2020/04/apple-and-google-partner-on-covid-19-contact-tracing-technology/>
- Apple. (2020b) *Exposure Notification APIs Addendum*. Retrieved from https://developer.apple.com/contact/request/download/Exposure_Notification_Addendum.pdf
- Apple. (2020c) *Privacy-Preserving Contact Tracing*. Retrieved from <https://web.archive.org/web/20200609160509/https://covid19.apple.com/contacttracing>
- Bakker, R.M., DeFillippi, R.J., Schwab, A., and Sydow, J. (2016) Temporary organizing: promises, processes, problems. *Organization Studies*, **37**, 12, 1703–1719. <https://doi.org/10.1177/0170840616655982>
- Bakker, S., Leguijt, P., and van Lente, H. (2015) Niche accumulation and standardization – the case of electric vehicle recharging plugs. *Journal of Cleaner Production*, **94**, 155–164. <https://doi.org/10.1016/j.jclepro.2015.01.069>
- Ballon, P. (2009) The platformisation of the European mobile industry. *Communications & Strategies*, **1**, 75, 15–34 Retrieved from <https://EconPapers.repec.org/RePEc:idt:journl:cs7501>
- Barney, J. (2014) *Gaining and Sustaining Competitive Advantage*. Harlow: Pearson.
- Bavarian Broadcasting Corporation. (2020) Retrieved from <https://www.br.de/nachrichten/deutschland-welt/corona-app-bundesregierung-doch-fuer-dezentrale-datenspeicherung,RxEI42Q>
- Bay, J., Kek, J., Tan, A., Hau, C.S., Yongquan, L., Tan, J., and Quy, T.A. (2020) *BlueTrace: A Privacy-Preserving Protocol Forcommunity-Driven Contact Tracing across Borders*. Government Technology Agency. Retrieved from https://bluetrace.io/static/bluetrace_whitepaper-938063656596c104632def383eb33b3c.pdf
- BBC. (2020a) *Apple and Google Accelerate Coronavirus Contact Tracing Apps Plan*. Retrieved from <https://web.archive.org/web/20201203050833/https://www.bbc.com/news/technology-52415593>
- BBC. (2020b) *Coronavirus: Apple and France in Stand-Off Over Contact-Tracing App*. Retrieved from <https://www.bbc.com/news/technology-52366129>
- Blind, K. (2002) Driving forces for standardization at standardization development organizations. *Applied Economics*, **34**, 16, 1985–1998. <https://doi.org/10.1080/00036840110111158>
- Blind, K. (2011) An economic analysis of standards competition: the example of the ISO ODF and OOXML standards. *Telecommunications Policy*, **35**, 4, 373–381. <https://doi.org/10.1016/j.telpol.2011.02.007>
- Bloomberg. (2020) *Germany Taps SAP, Deutsche Telekom for Contact Tracing App*. Retrieved from <https://www.bloomberg.com/news/articles/2020-04-27/germany-taps-sap-deutsche-telekom-for-contact-tracing-app>
- Botzem, S. and Dobusch, L. (2012) Standardization cycles: a process perspective on the formation and diffusion of transnational standards. *Organization Studies*, **33**, 5–6, 737–762. <https://doi.org/10.1177/0170840612443626>
- Breeze, E. (2021) Inequalities persist in Europe – and COVID-19 does not help. *Journal of Epidemiology and Community Health*, **75**, 8, 710–711. <https://doi.org/10.1136/jech-2021-216796>
- Bryer, L.G., Lebson, S.J., and Asbell, M.D. (2011) *Intellectual Property Strategies for the 21st Century Corporation: A Shift in Strategic and Financial Management*. Hoboken, NJ: Wiley.
- von Burg, U. (2001) *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard*. Stanford, CA: Stanford University Press.
- Büthe, T. and Mattli, W. (2010) International standards and standard-setting bodies. In: Coen, D., Grant, W. and Wilson, G. (eds), *The Oxford Handbook of Business and Government*. New York, NY: Oxford University Press, pp. 440–471.
- Büthe, T. and Mattli, W. (2011) *The New Global Rulers: The Privatization of Regulation in the World Economy*. Princeton, NJ: Princeton University Press.

- Chen, C.-M., Jyan, H.-W., Chien, S.-C., Jen, H.-H., Hsu, C.-Y., Lee, P.-C., Lee, C.-F., Yang, Y.-T., Chen, M.-Y., Chen, L.-S., Chen, H.-H., and Chan, C.-C. (2020) Containing COVID-19 among 627,386 persons in contact with the diamond princess cruise ship passengers who disembarked in Taiwan: big data analytics. *Journal of Medical Internet Research*, **22**, 5, e19540. <https://doi.org/10.2196/19540>
- Chen, P.-Y. and Forman, C. (2006) Can vendors influence switching costs and compatibility in an environment with open standards? *MIS Quarterly*, **30**, 541–562. <https://doi.org/10.2307/25148772>
- Cohen, J. and Kupferschmidt, K. (2020) Countries test tactics in ‘war’ against COVID-19. *Science*, **367**, 6484, 1287. <https://doi.org/10.1126/science.367.6484.1287>
- ComputerWeekly.com. (2020, March 24) *Singapore Government to Open Source Contact-Tracing Protocol*. Retrieved from <https://www.computerweekly.com/news/252480501/Singapore-government-to-open-source-contact-tracing-protocol>
- Conde, F., Li, L., and Huang, C. (2020) Standard setting organizations, standard essential patents and FRAND terms. In: Liu, K.-C. and Hilty, R.M. (eds), *SEPs, SSOs and FRAND: Asian and Global Perspectives on Fostering Innovation in Interconnectivity*. Oxon: Routledge, pp. 62–85.
- Cusumano, M.A., Mylonadis, Y., and Rosenbloom, R.S. (1992) Strategic maneuvering and mass-market dynamics: the triumph of VHS over beta. *Business History Review*, **66**, 1, 51–94. <https://doi.org/10.2307/3117053>
- Cutolo, D. and Kenney, M. (2020) Platform-dependent entrepreneurs: power asymmetries, risks, and strategies in the platform economy. *Academy of Management Perspectives*. <https://doi.org/10.5465/amp.2019.0103>
- Dar, A.B., Lone, A.H., Zahoor, S., Khan, A.A., and Naaz, R. (2020) Applicability of mobile contact tracing in fighting pandemic (COVID-19): issues, challenges and solutions. *Computer Science Review*, **38**, 100307. <https://doi.org/10.1016/j.cosrev.2020.100307>
- van Dijck, J., Poell, T., and de Waal, M. (2018) *The Platform Society: Public Values in a Connective World*. New York, NY: Oxford University Press.
- DP-3T. (2020a) *Apple/Google Exposure Notification*. Retrieved from <https://github.com/DP-3T/documents#apple-google-exposure-notification>
- DP-3T. (2020b) *DP-3T Documents*. Retrieved from <https://github.com/DP-3T/documents/commit/3b6024918f8980d2be10eeaf7a43d6d52b64a38>
- DP-3T. (2020c) *Security and Privacy Analysis of the Document ‘PEPP-PT: Data Protection and Information Security Architecture’*. Retrieved from https://github.com/DP-3T/documents/blob/master/Security%20analysis/PEPP-PT_%20Data%20Protection%20Architecture%20-%20Security%20and%20privacy%20analysis.pdf
- Dranove, D. and Gandal, N. (2003) The Dvd-vs.-Divx standard war: empirical evidence of network effects and preannouncement effects. *Journal of Economics & Management Strategy*, **12**, 3, 363–386. <https://doi.org/10.1111/j.1430-9134.2003.00363.x>
- Eaton, B. (2016, January 5–8) The dynamics of digital platform innovation: Apple’s strategy to control modular and architectural innovation in iOS. Paper presented at the 2016 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA.
- Egyedi, T. and Spirco, J. (2011) Standards in transitions: catalyzing infrastructure change. *Futures*, **43**, 9, 947–960. <https://doi.org/10.1016/j.futures.2011.06.004>
- eHealth Network. (2020a) *Interoperability Guidelines for Approved Contact Tracing Mobile Applications in the EU*. Retrieved from https://ec.europa.eu/health/sites/health/files/ehealth/docs/covid-19_apps_en.pdf
- eHealth Network. (2020b) *Mobile Applications to Support Contact Tracing in the EU’s Fight Against COVID-19 – Common EU Toolbox for Member States*. European Commission. Retrieved from https://ec.europa.eu/health/sites/health/files/ehealth/docs/covid-19_apps_en.pdf
- Eisenhardt, K.M. (1989) Building theories from case study research. *Academy of Management Review*, **14**, 4, 532–550. <https://doi.org/10.5465/amr.1989.4308385>
- Eisenhardt, K.M. (1991) Better stories and better constructs: the case for rigor and comparative logic. *Academy of Management Review*, **16**, 3, 620–627. <https://doi.org/10.5465/amr.1991.4279496>
- European Commission. (2020a) *Commission Recommendation (EU) 2020/518 of 8 April 2020 on a Common Union Toolbox for the Use of Technology and Data to Combat and Exit from the COVID-19 Crisis, in Particular Concerning Mobile Applications and the Use of Anonymised Mobility Data*. Retrieved from <https://eur-lex.europa.eu/eli/recol/2020/518/oj>
- European Commission. (2020b) *Coronavirus: Commission Adopts Recommendation to Support Exit Strategies through Mobile Data and Apps* [Press release]. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_20_626
- European Commission. (2020c) *Coronavirus: EU Interoperability Gateway Goes Live, First Contact Tracing and Warning Apps Linked to the System* [Press release]. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1904
- European Commission. (2020d) *Coronavirus: Member States Agree on an Interoperability Solution for Mobile Tracing and Warning Apps* [Press release]. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1043
- European Commission. (2020e) *Mobile Contact Tracing Apps in EU Member States*. Retrieved from https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/travel-during-coronavirus-pandemic/mobile-contact-tracing-apps-eu-member-states_en
- Farrell, J. and Saloner, G. (1986a) Economic issues in standardization. In: Miller, J. (ed.), *Telecommunications and Equity: Policy Research Issues*. New York, NY: Columbia University Press. pp. 165–179.
- Farrell, J. and Saloner, G. (1986b) Installed base and compatibility: innovation, product preannouncements, and predation. *The American Economic Review*, **76**, 5, 940–955. Retrieved from <http://www.jstor.org/stable/1816461>

- Farrell, J. and Saloner, G. (1988) Coordination through committees and markets. *The RAND Journal of Economics*, **19**, 2, 235–252. <https://doi.org/10.2307/2555702>
- Ferretti, L., Wymant, C., Kendall, M., Zhao, L., Nurtay, A., Abeler-Dörner, L., Parker, M., Bonsall, D., and Fraser, C. (2020) Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. *Science*, **368**(6491), eabb6936. <https://doi.org/10.1126/science.abb6936>
- Financial Times. (2020a) *EU Contact Tracing Scheme will not Include French App*. Retrieved from <https://web.archive.org/web/20200807112154/https://www.ft.com/content/6f9845e2-4c1f-48a2-be98-357809168aeb>
- Financial Times. (2020b) *How Europe Splintered Over Contact Tracing Apps*. Retrieved from <https://www.ft.com/content/7416269b-0477-4a29-815d-7e4ee8100c10>
- Financial Times. (2020c) *UK to Replace Contact-Tracing App with Apple and Google Model*. Retrieved from <https://www.ft.com/content/819ff491-0ae9-4359-b3db-ed8de48330d7>
- Foreign Policy. (2020) *Germany's Angst is Killing its Coronavirus Tracing App*. Retrieved from <https://foreignpolicy.com/2020/05/08/germany-coronavirus-contact-tracing-pandemic-app/>
- Fortune. (2020) *Controversy around Privacy Splits Europe's Push to Build COVID-19 Contact-Tracing Apps*. Retrieved from <https://fortune.com/2020/04/20/coronavirus-contact-tracing-privacy-europe-pepp-pt-dp3t-covid-19-tracking/>
- French Government. (2020) *Application TousAntiCovid*. Retrieved from <https://www.gouvernement.fr/info-coronavirus/tousanticovid>
- Funk, J.L. and Methe, D.T. (2001) Market- and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication. *Research Policy*, **30**, 4, 589–610. [https://doi.org/10.1016/S0048-7333\(00\)00095-0](https://doi.org/10.1016/S0048-7333(00)00095-0)
- Gallagher, S. (2007) The complementary role of dominant designs and industry standards. *IEEE Transactions on Engineering Management*, **54**, 2, 371–379. <https://doi.org/10.1109/TEM.2007.893991>
- Gandal, N. (2002) Compatibility, standardization, and network effects: some policy implications. *Oxford Review of Economic Policy*, **18**, 1, 80–91. <https://doi.org/10.1093/oxrep/18.1.80>
- Gao, X. (2014) A latecomer's strategy to promote a technology standard: the case of Datang and TD-SCDMA. *Research Policy*, **43**, 3, 597–607. <https://doi.org/10.1016/j.respol.2013.09.003>
- Garud, R., Jain, S., and Kumaraswamy, A. (2002) Institutional entrepreneurship in the sponsorship of common technological standards: the case of Sun Microsystems and Java. *Academy of Management Journal*, **45**, 1, 196–214. <https://doi.org/10.5465/3069292>
- German Federal Government. (2020) *Kontaktketten digital identifizieren*. Retrieved from <https://web.archive.org/web/20200407193127/https://www.bundesregierung.de/breg-de/themen/coronavirus/corona-app-1738516>
- Global News. (2020, May 05) *Alberta's Contact-Tracing App Only Works on iOS When Phone is Unlocked, App Running in Foreground*. Retrieved from <https://globalnews.ca/news/6898691/ab-trace-together-contact-app-alberta-covid-ios/>
- Google. (2020) *Google COVID-19 Exposure Notification Service Additional Terms*. Retrieved from https://blog.google/documents/72/Exposure_Notifications_Service_Additional_Terms.pdf
- Graham, H., Alain, L., Birger, N., István, S., and Jørgen, V. (2018) JPEG-1 standard 25 years: past, present, and future reasons for a success. *Journal of Electronic Imaging*, **27**, 4, 1–19. <https://doi.org/10.1117/1.JEI.27.4.040901>
- Grindley, P. (1995) *Standards, Strategy and Policy: Cases and Stories*. Oxford: Oxford University Press.
- Hänninen, M. and Paavola, L. (2020) Digital platforms and industry change. In: Lehtimäki, H., Uusikylä, P., and Smedlund, A. (eds), *Society as an Interaction Space: A Systemic Approach*. Singapore: Springer. pp. 213–226.
- Hayes, V. (1991) Standardization efforts for wireless LANs. *IEEE Network*, **5**, 6, 19–20. <https://doi.org/10.1109/65.103805>
- Hein, A., Schrieck, M., Riasanow, T., Setzke, D.S., Wiesche, M., Böhm, M., and Krcmar, H. (2020) Digital platform ecosystems. *Electronic Markets*, **30**, 1, 87–98. <https://doi.org/10.1007/s12525-019-00377-4>
- Hellewell, J., Abbott, S., Gimma, A., Bosse, N.I., Jarvis, C.I., Russell, T.W., Munday, J.D., Kucharski, A.J., Edmunds, W.J., Funk, S., Eggo, R.M., Sun, F., Flasche, S., Quilty, B.J., Davies, N., Liu, Y., Clifford, S., Klepac, P., Jit, M., Diamond, C., Gibbs, H., and van Zandvoort, K. (2020) Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. *The Lancet Global Health*, **8**, 4, e488–e496. [https://doi.org/10.1016/S2214-109X\(20\)30074-7](https://doi.org/10.1016/S2214-109X(20)30074-7)
- Henderson, R.M. and Clark, K.B. (1990) Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, **35**, 1, 9–30. <https://doi.org/10.2307/2393549>
- Higuchi, T. and Troutt, M. (2008) *Life Cycle Management in Supply Chains: Identifying Innovations Through the Case of the VCR*. Hershey, NY: IGI Publishing.
- Hinch, R., Probert, W., Nurtay, A., Kendall, M., Wymant, C., Hall, M., ... Fraser, C. (2020) *A Report to NHSX: Effective Configurations of a Digital Contact Tracing App*. Retrieved from <https://045.medsci.ox.ac.uk/files/files/report-effective-app-configurations.pdf>
- International Organization for Standardization. (2020a) *Developing Standards*. Retrieved from <https://www.iso.org/developing-standards.html>
- International Organization for Standardization. (2020b) *Standards in Our World*. Retrieved from https://www.iso.org/sites/ConsumersStandards/1_standards.html
- Jain, S. (2012) Pragmatic agency in technology standards setting: the case of Ethernet. *Research Policy*, **41**, 9, 1643–1654. <https://doi.org/10.1016/j.respol.2012.03.025>
- Jakobs, K., Procter, R., and Williams, R. (2001) The making of standards: looking inside the work groups. *IEEE*

- Communications Magazine*, **39**, 4, 102–107. <https://doi.org/10.1109/35.917511>
- van de Kaa, G. and de Vries, H.J. (2015) Factors for winning format battles: a comparative case study. *Technological Forecasting and Social Change*, **91**, 222–235. <https://doi.org/10.1016/j.techfore.2014.02.019>
- Kamel Boulos, M.N. and Geraghty, E.M. (2020) Geographical tracking and mapping of coronavirus disease COVID-19/severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) epidemic and associated events around the world: how 21st century GIS technologies are supporting the global fight against outbreaks and epidemics. *International Journal of Health Geographics*, **19**, 1, 8. <https://doi.org/10.1186/s12942-020-00202-8>
- Kask, M. (2020) *Contact Tracing Apps in Europe: When One is Better Than Many*. Retrieved from https://web.archive.org/web/20200727100030/https://www.bertheismann-stiftung.de/fileadmin/files/BSst/Publikationen/GrauePublikationen/202000616_Contact_Tracing_Apps_Kask.pdf
- Katz, M.L. and Shapiro, C. (1985) Network externalities, competition, and compatibility. *The American Economic Review*, **75**, 3, 424–440. Retrieved from <http://www.jstor.org/stable/1814809>
- Klonowska, K. (2020) *The COVID-19 Pandemic: Two Waves of Technological Responses in the European Union*. The Hague: The Hague Centre for Strategic Studies. Retrieved from <https://hcss.nl/report/covid-19-pandemic-two-waves-technological-responses-european-union>
- Koppell, J.G. (2010) *World Rule: Accountability, Legitimacy, and the Design of Global Governance*. Chicago, IL: University of Chicago Press.
- Krausz, M., Westenberg, J.N., Vigo, D., Spence, R.T., and Ramsey, D. (2020) Emergency response to COVID-19 in Canada: platform development and implementation for eHealth in crisis management. *JMIR Public Health and Surveillance*, **6**, 2, e18995. <https://doi.org/10.2196/18995>
- Langheinrich, M. (2020) First contact! *IEEE Pervasive Computing*, **19**, 3, 4–9. <https://doi.org/10.1109/MPRV.2020.3002116>
- Lee, D. and Mendelson, H. (2007) Adoption of information technology under network effects. *Information Systems Research*, **18**, 4, 395–413. <https://doi.org/10.1287/isre.1070.0138>
- Leiponen, A.E. (2008) Competing through cooperation: the organization of standard setting in wireless telecommunications. *Management Science*, **54**, 11, 1904–1919. <https://doi.org/10.1287/mnsc.1080.0912>
- Leiponen, A.E. (2014) Intellectual property rights, standards, and the management of innovation. In: Dodgson, M., Gann, D.M., and Phillips, N. (eds), *The Oxford Handbook of Innovation Management*. Oxford: Oxford University Press. pp. 559–578.
- Lin, L. and Kulatilaka, N. (2006) Network effects and technology licensing with fixed fee, royalty, and hybrid contracts. *Journal of Management Information Systems*, **23**, 2, 91–118. <https://doi.org/10.2753/MIS0742-1222230205>
- Manso, M. and Manso, B. (2013) The role of social media in crisis: a European holistic approach to the adoption of online and mobile communications in crisis response and search and rescue efforts. In: Akhgar, B. and Yates, S. (eds), *Strategic Intelligence Management*. Waltham, MA: Butterworth-Heinemann. pp. 93–107.
- Marhold, K. and Fell, J. (2021) Electronic vaccination certificates: avoiding a repeat of the contact-tracing ‘format wars’. *Nature Medicine*, **27**, 5, 738–739. <https://doi.org/10.1038/s41591-021-01286-w>
- Maxwell, J.A. and Reybold, L.E. (2015) Qualitative research. In: Wright, J.D. (ed.), *International Encyclopedia of the Social & Behavioral Sciences*, 2nd edn. Oxford: Elsevier. pp. 685–689.
- McCall, B. (2020) Shut down and reboot – preparing to minimise infection in a post-COVID-19 era. *The Lancet Digital Health*, **2**, 6, e293–e294. [https://doi.org/10.1016/S2589-7500\(20\)30103-5](https://doi.org/10.1016/S2589-7500(20)30103-5)
- McCallum, S. (1996) What makes a standard? *Cataloging & Classification Quarterly*, **21**, 3–4, 5–15. https://doi.org/10.1300/J104v21n03_02
- Mozur, P., Zhong, R., and Krolik, A. (2020) In coronavirus fight, China gives citizens a color code, with red flags. *New York Times*. Retrieved from www.nytimes.com/2020/03/01/business/china-coronavirus-surveillance.html
- Narayanan, V.K. and Chen, T. (2012) Research on technology standards: accomplishment and challenges. *Research Policy*, **41**, 8, 1375–1406. <https://doi.org/10.1016/j.respol.2012.02.006>
- Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, M., and Agha, R. (2020) The socio-economic implications of the coronavirus pandemic (COVID-19): a review. *International Journal of Surgery*, **78**, 185–193. <https://doi.org/10.1016/j.ijssu.2020.04.018>
- NPR. (2020) *In Germany, High Hopes For New COVID-19 Contact Tracing App That Protects Privacy*. Retrieved from <https://www.npr.org/sections/coronavirus-live-updates/2020/04/02/825860406/in-germany-high-hopes-for-new-covid-19-contact-tracing-app-that-protects-privacy?t=1608364258056>
- O’Connell, J. (2013) An IT perspective on standards, service architectures and platforms. In: Bertin, E., Crespi, N., and Magedanz, T. (eds), *Evolution of Telecommunication Services: The Convergence of Telecom and Internet: Technologies and Ecosystems*. Heidelberg: Springer. pp. 118–137.
- Ohashi, H. (2003) The role of network effects in the US VCR market, 1978–1986. *Journal of Economics & Management Strategy*, **12**, 4, 447–494. <https://doi.org/10.1111/j.1430-9134.2003.00447.x>
- Oliver, N., Lepri, B., Sterly, H., Lambiotte, R., Deletaille, S., De Nadai, M., Letouzé, E., Salah, A.A., Benjamins, R., Cattuto, C., Colizza, V., de Cordes, N., Fraiberger, S.P., Koebe, T., Lehmann, S., Murillo, J., Pentland, A., Pham, P.N., Pivetta, F., Saramäki, J., Scarpino, S.V.,

- Tizzoni, M., Verhulst, S., and Vinck, P. (2020) Mobile phone data for informing public health actions across the COVID-19 pandemic life cycle. *Science Advances*, **6**, 23, eabc0764. <https://doi.org/10.1126/sciadv.abc0764>
- Olle, T.W. (1996) Impact of standardization work on the future of information technology. In: Terashima, N. and Altman, E. (eds), *Advanced IT Tools: IFIP World Conference on IT Tools 2–6 September 1996, Canberra, Australia*. Boston, MA: Springer. pp. 97–105.
- Park, S., Choi, G.J., and Ko, H. (2020) Information technology-based tracing strategy in response to COVID-19 in South Korea – privacy controversies. *JAMA*, **323**, 21, 2129–2130. <https://doi.org/10.1001/jama.2020.6602>
- Parker, G.G., Van Alstyne, M.W., and Choudary, S.P. (2016) *Platform Revolution: How Networked Markets Are Transforming the Economy – And How to Make Them Work for You*. New York, NY: W. W. Norton & Company.
- Pelkmans, J. (2001) The GSM standard: explaining a success story. *Journal of European Public Policy*, **8**, 3, 432–453. <https://doi.org/10.1080/13501760110056059>
- PEPP-PT. (2020a) *Join us*. Retrieved from <https://web.archive.org/web/20200504182655/https://pipedrivewebforms.com/form/2e4a150c2debcc22bd6d5354de166e277476810>
- PEPP-PT. (2020b) *Members*. Retrieved from <https://web.archive.org/web/20200424174257/https://www.pepp-pt.org/>
- Poblet, M., García-Cuesta, E., and Casanovas, P. (2014) Crowdsourcing tools for disaster management: a review of platforms and methods. Paper presented at the AI Approaches to the Complexity of Legal Systems, Berlin.
- Politico. (2020) *Tech Feud Complicates EU Search for Coronavirus Tracking App*. Retrieved from <https://www.politico.eu/article/tech-feud-complicates-eu-search-for-coronavirus-tracking-app/>
- Puffert, D.J. (2002) Path dependence in spatial networks: the standardization of railway track gauge. *Explorations in Economic History*, **39**, 3, 282–314. <https://doi.org/10.1006/exeh.2002.0786>
- Rada, R. (1993) Standards: the language for success. *Communications of the ACM*, **36**, 12, 17–18. <https://doi.org/10.1145/163298.163351>
- Reuters. (2020a) *European Coalition Takes Shape on Coronavirus Contact Tracing*. Retrieved from <https://www.reuters.com/article/us-health-coronavirus-europe-tech-idUSKBN22J1N8>
- Reuters. (2020) *France Accuses Apple of Refusing Help with 'StopCovid' App*. Retrieved from <https://www.reuters.com/article/us-health-coronavirus-france-tech-idUSKBN22HOLX>
- Reuters. (2020c) *Germany Flips to Apple-Google Approach on Smartphone Contact Tracing*. Retrieved from <https://www.reuters.com/article/us-health-coronavirus-europe-tech-idUSKCN22807J>
- Reuters. (2020d) *Rift Opens Over European Coronavirus Contact Tracing Apps*. Retrieved from <https://www.reuters.com/article/us-health-coronavirus-europe-tech/rift-opens-over-european-coronavirus-contact-tracing-apps-idUSKBN2221U0>
- Rosen, B.N., Schnaars, S.P., and Shani, D. (1988) A comparison of approaches for setting standards for technological products. *Journal of Product Innovation Management*, **5**, 2, 129–139. <https://doi.org/10.1111/1540-5885.520129>
- Rosenberg, N. (1976) *Perspectives on Technology*. Cambridge: Cambridge University Press.
- Salek, M., Shayandeh, S., and Kempe, D. (2010) You share, I share: network effects and economic incentives in P2P file-sharing systems. In: Saberi, A. (ed.), *Internet and Network Economics*. Heidelberg: Springer. pp. 354–365.
- Schilling, M.A. (2002) Technology success and failure in winner-take-all markets: the impact of learning orientation, timing, and network externalities. *Academy of Management Journal*, **45**, 2, 387–398. <https://doi.org/10.5465/3069353>
- Shapiro, C. and Varian, H.R. (1999) *Information Rules: a Strategic Guide to the Network Economy*. Boston, MA: Harvard Business School Press.
- Shmueli, G. (2017) Analyzing behavioral big data: methodological, practical, ethical, and moral issues. *Quality Engineering*, **29**, 1, 57–74. <https://doi.org/10.1080/08982112.2016.1210979>
- Shubina, V., Holcer, S., Gould, M., and Lohan, E.S. (2020) Survey of decentralized solutions with mobile devices for user location tracking, proximity detection, and contact tracing in the COVID-19 era. *Data*, **5**, 4, 87. <https://doi.org/10.3390/data5040087>
- Skjott Linneberg, M. and Korsgaard, S. (2019) Coding qualitative data: a synthesis guiding the novice. *Qualitative Research Journal*, **19**, 3, 259–270. <https://doi.org/10.1108/QRJ-12-2018-0012>
- Srinivasan, R., Lilien, G.L., and Rangaswamy, A. (2006) The emergence of dominant designs. *Journal of Marketing*, **70**, 2, 1–17. <https://doi.org/10.1509/jmkg.70.2.001>
- Statista. (2020) *Mobile Operating Systems' Market Share Worldwide from January 2012 to October 2020*. Retrieved from <https://www.statista.com/statistics/272698/global-market-share-held-by-mobile-operating-systems-since-2009/>
- Suárez, F.F. (2004) Battles for technological dominance: an integrative framework. *Research Policy*, **33**, 2, 271–286. <https://doi.org/10.1016/j.respol.2003.07.001>
- Sun, K. and Viboud, C. (2020) Impact of contact tracing on SARS-CoV-2 transmission. *The Lancet Infectious Diseases*, **20**, 8, 876–877. [https://doi.org/10.1016/S1473-3099\(20\)30357-1](https://doi.org/10.1016/S1473-3099(20)30357-1)
- Sweeney, Y. (2020) Tracking the debate on COVID-19 surveillance tools. *Nature Machine Intelligence*, **2**, 6, 301–304. <https://doi.org/10.1038/s42256-020-0194-1>
- Swiss Federal Council. (2020) *Public Security Test Swiss Covid Proximity Tracing System*. Retrieved from <https://www.melani.admin.ch/melani/en/home/public-security-test/infos.html>
- SwissInfo. (2020) *Swiss Covid-19 Contact Tracing App Ready for Privacy Testing*. Retrieved from https://www.swissinfo.ch/eng/public-scrutiny_swiss-covid-19-contact-tracing-app-ready-for-privacy-testing/45792632
- Tamm Hallström, K. and Boström, M. (2010) *Transnational Multi-Stakeholder Standardization: Organizing Fragile*

- Non-State Authority. Cheltenham, UK: Edward Elgar Publishing.
- Tamura, S. (2015) Who participates in de jure standard setting in Japan? The analysis of participation costs and benefits. *Innovation*, **17**, 3, 400–415. <https://doi.org/10.1080/14479338.2015.1054604>
- Tan, M.L., Prasanna, R., Stock, K., Hudson-Doyle, E., Leonard, G., and Johnston, D. (2017) Mobile applications in crisis informatics literature: a systematic review. *International Journal of Disaster Risk Reduction*, **24**, 297–311. <https://doi.org/10.1016/j.ijdr.2017.06.009>
- Techatassanasoontorn, A.A. and Suo, S. (2011) Influences on standards adoption in de facto standardization. *Information Technology and Management*, **12**, 4, 357–385. <https://doi.org/10.1007/s10799-011-0089-2>
- TechCrunch. (2020a) *An EU Coalition of Techies is Backing a 'Privacy-Preserving' Standard for COVID-19 Contacts Tracing*. TechCrunch. Retrieved from <https://techcrunch.com/2020/04/01/an-eu-coalition-of-techies-is-backing-a-privacy-preserving-standard-for-covid-19-contacts-tracing/>
- TechCrunch. (2020b) *Germany Ditches Centralized Approach to App for COVID-19 Contacts Tracing*. Retrieved from https://techcrunch.com/2020/04/27/germany-ditches-centralized-approach-to-app-for-covid-19-contacts-tracing/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2x1LmNvbS8&guce_referrer_sig=AQAAAL3qngkr58f0IY2dcete0ASwNrr_eh3dxPliKpgzGtqGCJWWPCWE_W-PbkDTJ38TvQLL8mjA4ksC6GWzBxDY5ZkUE41WhEoV31r5_hSkBYr3w8CChZyX7mJ_eQxw5zX_AcESXh0tqXd3_AnfiBiZM_eUuxT-x13cTqn4L_s9TuAR
- TechCrunch. (2020c) *Q&A: Apple and Google Discuss their Coronavirus Tracing Efforts*. Retrieved from <https://techcrunch.com/2020/04/13/apple-google-coronavirus-tracing/>
- The Guardian. (2020) *UK Abandons Contact-Tracing App for Apple and Google Model*. Retrieved from <https://www.theguardian.com/world/2020/jun/18/uk-poised-to-abandon-coronavirus-app-in-favour-of-apple-and-google-models>
- The New York Times. (2020a) *Coronavirus Apps Show Promise but Prove a Tough Sell*. Retrieved from <https://www.nytimes.com/2020/12/07/technology/coronavirus-exposure-alert-apps.html>
- The New York Times. (2020b) *Europe Rolls Out Contact Tracing Apps, With Hope and Trepidation*. Retrieved from <https://www.nytimes.com/2020/06/16/world/europe/contact-tracing-apps-europe-coronavirus.html>
- The Straits Times. (2020a, April 6) *Coronavirus: Google Launches New Tool to Help Public Health Officials Plan Social Distancing Measures*. Retrieved from <https://www.straitstimes.com/tech/google-launches-new-tool-to-help-public-health-officials-plan-social-distancing-measures>
- The Straits Times. (2020b, November 12) *Wearable Device for Covid-19 Contact Tracing to be Rolled Out Soon, May be Issued to Everyone in Singapore*. Retrieved from https://www.straitstimes.com/politics/parliament-wearable-device-for-contact-tracing-set-to-be-issued-trace-together-does-not-work?utm_medium=Social&utm_campaign=STFB&utm_source=Facebook#Echobox=1591331720
- Ting, D.S.W., Carin, L., Dzau, V., and Wong, T.Y. (2020) Digital technology and COVID-19. *Nature Medicine*, **26**, 4, 459–461. <https://doi.org/10.1038/s41591-020-0824-5>
- Townes, M. (2012) The spread of TCP/IP: how the Internet became the Internet. *Millennium*, **41**, 1, 43–64. <https://doi.org/10.1177/0305829812449195>
- Updegrove, A. (1993) Forming, funding, and operating standard-setting consortia. *IEEE Micro*, **13**, 6, 52–61. <https://doi.org/10.1109/40.248055>
- Updegrove, A. (1995) Consortia and the role of government in standard setting. In: Kahin, B. and Abbate, J. (eds), *Standards Policy for Information Infrastructure*. Cambridge, MA: MIT Press. pp. 321–348.
- Vaudenay, S. (2020) *Centralized or Decentralized? The Contact Tracing Dilemma*. Retrieved from <https://eprint.iacr.org/2020/531>
- Vaughan, A. (2020) The problems with contact-tracing apps. *New Scientist*, **246**, 3279, 9. [https://doi.org/10.1016/S0262-4079\(20\)30787-9](https://doi.org/10.1016/S0262-4079(20)30787-9)
- Verdinelli, S. and Scagnoli, N.I. (2013) Data display in qualitative research. *International Journal of Qualitative Methods*, **12**, 1, 359–381. <https://doi.org/10.1177/160940691301200117>
- de Vries, H., de Vries, H.J., and Oshri, I. (2008) *Standards Battles in Open Source Software: The Case of Firefox*. New York, NY: Palgrave Macmillan.
- Wang, B. (2010) Survival and competition among social networking websites: a research commentary on “Critical Mass and Willingness to Pay for Social Networks” by J. Christopher Westland. *Electronic Commerce Research and Applications*, **9**, 1, 20–22. <https://doi.org/10.1016/j.eelerap.2009.08.002>
- Wang, C.J., Ng, C.Y., and Brook, R.H. (2020) Response to COVID-19 in Taiwan: big data analytics, new technology, and proactive testing. *JAMA*, **323**, 14, 1341–1342. <https://doi.org/10.1001/jama.2020.3151>
- White, L. and van Basshuysen, P. (2020) How to overcome lockdown: selective isolation versus contact tracing. *Journal of Medical Ethics*, **46**, 11, 724. <https://doi.org/10.1136/medethics-2020-106680>
- Whitworth, J. (2020) COVID-19: a fast evolving pandemic. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **114**, 4, 241–248. <https://doi.org/10.1093/trstmh/traa025>
- Wiegmann, P.M., de Vries, H.J., and Blind, K. (2017) Multi-mode standardisation: a critical review and a research agenda. *Research Policy*, **46**, 8, 1370–1386. <https://doi.org/10.1016/j.respol.2017.06.002>
- Yates, J. and Murphy, C.N. (2019) *Engineering Rules: Global Standard Setting Since 1880*. Baltimore, MD: Johns Hopkins University Press.
- Yin, R.K. (2014) *Case Study Research: Design and Methods*, 5th edn. Thousand Oaks, CA: Sage Publications.
- Yoneki, E. and Crowcroft, J. (2014) EpiMap: towards quantifying contact networks for understanding epidemiology in developing countries. *Ad Hoc Networks*, **13**, 83–93. <https://doi.org/10.1016/j.adhoc.2012.06.003>

Notes

¹ We follow earlier examples (e.g., Grindley, 1995; Srinivasan et al., 2006; Jain, 2012) and understand that “standards” represent technical specifications for quality, compatibility, and connectivity. In our case, standards refer to the underlying protocols influencing and governing the detection and reporting of contacts, and not the app-specific localized graphical user interface.

² Examples of major SDOs are the *International Organization for Standardization* (ISO), the *Institute of Electrical and Electronics Engineers* (IEEE), and the *International Telecommunication Union* (ITU).

³ <https://web.archive.org/web/20201106053030/https://www.pepp-pt.org/>

Klaus Marhold is Assistant Professor at the Institute for Entrepreneurship and Innovation at Vienna University of Economics and Business. He obtained his Ph.D. degree in Technology Management from Seoul National University. His research focuses on open innovation and entrepreneurship.

Jan Fell is a concurrently a Ph.D. candidate at the Institute for Entrepreneurship and Innovation at Vienna University of Economics and Business, and at the Institute of Service Science at National Tsing Hua University.

APPENDIX A

Semi-structured interview outline (translated from German)

1. Please describe your role within Novid20 and tell us about the organization.
2. Can you describe the initial process that led to the decision to develop a Bluetooth-based contact-tracing app?
3. In the beginning, were there any established standards or other solutions that you could build up on?
4. How did a lack of standards affect the development of Novid20's contact-tracing solution?
5. What is the current situation with respect to established designs and standards for contact-tracing apps?
6. How is Novid20 affected by standards and consortia? Can you describe positive or negative influences?
7. Within Austria, there is more than one organization developing contact-tracing solutions. How would you describe Novid20's relationship to other organizations developing and deploying similar apps (e.g., the Red Cross in Austria)?

8. More recently, major tech firms Apple and Google have entered the scene and are developing a reference solution. How does this affect Novid20, and how was this news received within your organization?
9. Are Apple and Google considered ‘competition’ or a useful complement to existing initiatives?
10. Can you tell us about the collaboration between different initiatives in Europe?

APPENDIX B

Semi-structured interview outline for founding members of DP-3T

Background

1. Please describe your role within DP-3T and tell us about the organization.
2. Can you describe the genesis of DP-3T? How did the various members and individuals involved come together?

Dominant design and standards

3. Can you describe the process that led you to focus on a Bluetooth-based standard? Why not a QR code or phone-based location tracking?
4. Did you take any particular country's solution as a role model?
5. In the beginning, were there any existing formal standards or *de-facto* standards that you could build upon?
6. What is the current situation with respect to established designs and standards for contact-tracing apps? To what extent is the work of DP-3T still part of rolled-out solutions/solutions currently under development?

Actors

7. How would you describe the roles of consortia (such as DP-3T) in the standard-setting process for contact-tracing apps?
8. Do any other important actors in this process come to your mind?
9. Can you tell us about the collaboration and/or competition between different initiatives in Europe?
10. How do you perceive the role of European governments and the European Union?
11. More recently, major tech firms Apple and Google have entered the scene and developed a reference solution. How did this affect DP-3T, and how was this news received within your organization?
12. Do you consider Apple and Google as ‘competition’ or a useful complement to existing initiatives?