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The Necessity of Close Contact Tracing in Combating COVID-19 Infection – A Systemic Study

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Abstract

Many contact tracing solutions developed by countries around the globe in containing the Covid-19 pandemic are in the area of location-based tracing, which does not enable them to identify close contacts accurately. As location-based tracing implementations continuous on, the results have not been as effective as intended. Thus, in providing some closure, this study will dissect the need for close contact tracing solutions for the pandemic by providing a comprehensive contact tracing characteristic framework (CCTCF) for Covid-19, which will help authorities toward better pandemic management. In this study, CCTCF for Covid-19 was constructed by applying several methods. Using Problem, Intervention, Comparison, Outcome (PICO) as the framework, methods conducted were: (1) Case study to analyze the contact tracing systems in 30 countries; (2) Systematic literature review (n=2056) regarding solutions' elements, (3) Thematic analysis for characteristics framework development. A total of 25 items were obtained for CCTCF, along with valuable insights that necessitate close contact tracing for the pandemic. Results from CCTCF have also shown that the best contact tracing solution for Covid-19 is bi-directional human-to-human close contact tracing, which uses a retrospective approach and is able to identify the source as well as groups of infection using a personal area network (PAN).

Keywords:

Close Contact Tracing;
Location-Based Tracing;
Covid-19;
Characteristics Framework;
Contact Tracing.

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1- Introduction

Covid-19 is a virus that has become a pandemic and continues to spread rapidly around the world. Currently, many countries have utilized various contact tracing systems to manage this infectious disease [1]. In the early days of the outbreak, contact tracing for the infected was conducted manually through interviews. Those infected were asked to identify the people they had close contact with in the past for 7 to 14 days [2]. Overall, the process is slow and labor-intensive, without having the ability to recreate close contacts effectively [3].

However, the scenario changed when the number of cases started to rise from the hundreds to the thousands, hence making manual contact tracing an impossible task to execute. As a result, countries started to adopt rigorously smart digital contact tracing solutions to contain the spread [4]. Figure 1 illustrates the world map, highlighting the only few remaining countries that do not adopt contact tracing towards Covid-19 pandemic (as of January 3rd, 2022). These

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solutions are extremely necessary as Covid-19 is a highly infectious virus [5] that spreads mainly through water droplets [6]. Infection can occur simply from breathing, sneezing, and coughing, which makes contact tracing a crucial and critical tool. Apart from that, mathematical models of the pandemic from Feretti et al. (2020) prove that fast, effective contact tracing combined with large-scale virus testing will be an immense help in slowing down the epidemic [7]. Therefore, if there exists a solution that can conduct effective contact tracing, lockdowns and the number of quarantine centers around the globe can be reduced by a sizeable number. Nevertheless, fast and effective contact tracing is only achievable with the help of technology, and using the manual, conventional method will not even be possible to attain [8].

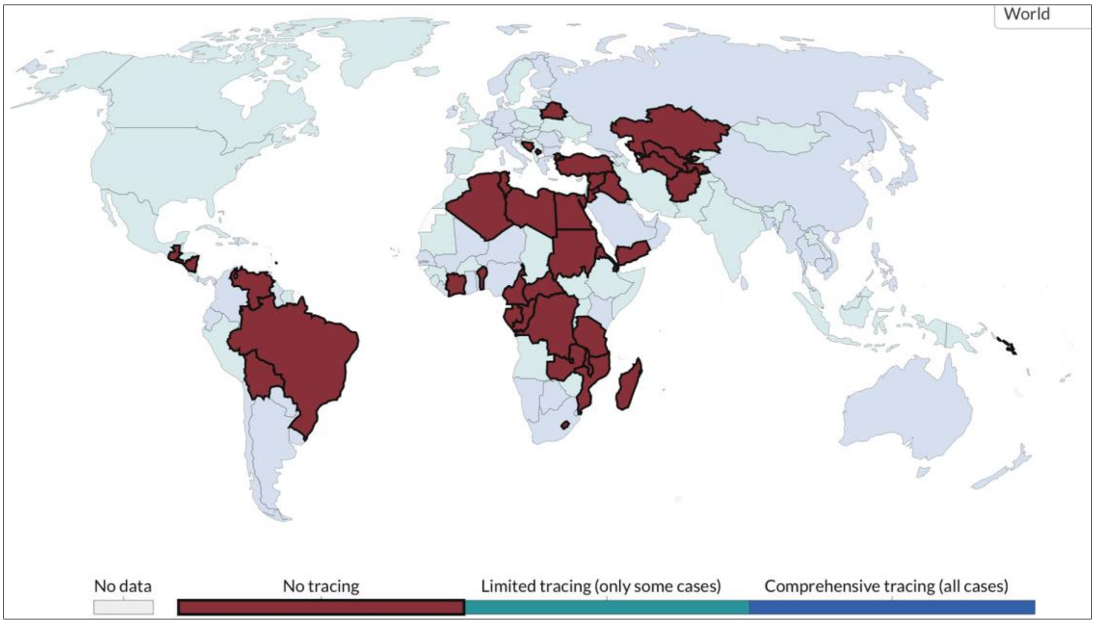

Figure 1. World map indicating countries that does no tracing, limited tracing and comprehensive tracing

From Figure 1, it shows that the majority of the countries have taken initiative towards contact tracing, which indicates that it is one of the key elements in combating the pandemic. Even with a vast number of countries executing contact tracing, many of the solutions adopted are actually in the area of location-based tracing, which does not have the capability to identify exact close contacts during an outbreak [9]. This is proven by a study from Juneau et al. (2020), where the authors examined 32 articles regarding their contact tracing solutions' effectiveness and found out that none of them were able to produce credible evidence on it. While so, eighteen of them rely on assumptions for effectiveness value [10]. The scenario is expected as location-based tracing has low accuracy in identifying close contacts. This is due to the fact that these contact tracing systems are based on the spatial proximity principle, where entities that are close are perceptually grouped with one another. Therefore, location-based tracing identifies individuals who are within a given proximity to those infected [11]. When the actual distance between close contacts cannot be efficiently measured, a lot of false positives are detected [12]. As a result, this system has proven to be less effective, especially when the number of infected individuals sharply increased during the Covid-19 pandemic. The general difference between location-based tracing and close-contact tracing is shown in Figure 2.

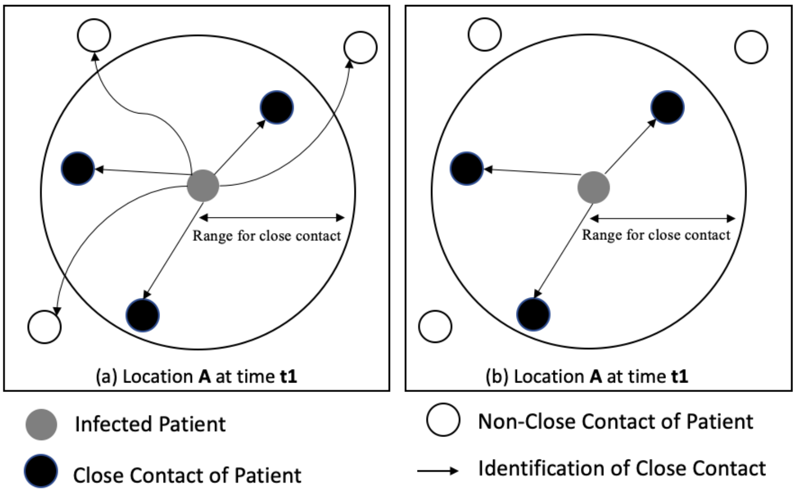

Figure 2. (a) Location-Based Tracing; (b) Close Contact Tracing

Thus, it is important that CCTCF can be developed to help direct contact tracing for Covid-19 in the correct direction. While doing so, CCTCF can also be used as guidance for future similar outbreaks to come and provide an overall picture of what digital contact tracing consists of. Last but not least, the outcomes of the study are intended to increase the efficacy of contact tracing solutions for better Covid-19 pandemic management.

1-1- Defining Close Contact Tracing and Location-Based Tracing

Location-based tracing is used for identifying the groups or individuals that have been at an outbreak location at a particular time [13]. As dimensions of distance between person-to-person are not used, location-based tracing is not able to efficiently detect close contacts but rather utilizes the probability that these groups will be infected due to their close proximity to the scene [14]. In fulfilling the probability, data such as location, time, user ID, and many others are being collected. Thus, technologies such as the Global Positioning System (GPS), QR Code, and cellular network are being utilized in it [15]. While doing so, with many non-close contact individuals being taken as a patient's close contact, as shown in Figure 2, the error gets accumulated over time, especially when the duration is long and the outbreak is severe. Thus, it creates a huge burden for the countries' healthcare systems and makes containment and management of the Covid-19 pandemic difficult. Generally, location-based tracing is mainly used for public masses where coverage for a wide area is required, and adopting close contact tracing is not really an easy task [16]. As for close contact tracing, it is the process of identifying the close contacts of Covid-19 patients who have been exposed to this disease at a person-to-person level rather than an entire group. The requirement from the Centre for Disease Control and Prevention states a distance of less than 6 feet and 15-minute exposure time is used as a requisite for close contact identification [17]. Close contact tracing utilizes distance between users rather than a location, which makes it the only type that has the ability to adhere to the requirements set by the CDC accurately.

With regards to contact tracing, there are four main approaches that have been identified by McLachlan et al. (2020) for infectious deceases and they are: first-order, single-step, iterative, and retrospective [5]. Figure 3 illustrates these different approaches. First-order tracing only identifies the people that an infected person comes in contact with at the first-order. Whether they show any sign of symptoms or none, it does not matter, as it can detect both. This kind of approach nonetheless makes second-order infected groups to be left out. While in single-step tracing, identification of close contacts are conducted towards the people an infected comes contact with, as well as the close contacts of the infected people. However, in single-step, only symptomatic patients are considered for second-order of the infection chain. Thus, one of its weaknesses is that the asymptomatic patients will keep on infecting people until they start to display symptoms [18]. For iterative tracing, it is similar to single-step with the addition that it can recognize or take account of asymptomatic cases as well. Last but not least, a retrospective approach has all the attributes of previous approaches while being able to identify the source of infection (backward tracing). It can be viewed as the most comprehensive approach available for combating infectious outbreaks, especially the Covid-19 pandemic. In the early stage of the Covid-19 pandemic, first-order, single-step, and iterative approaches were adequate. However, as Covid-19 virus was later proven to be quite infectious, the retrospective approach was best suited, as it was able to identify the source and the people that the patient had infected. This approach can do "forward-tracing" which is the identification of people to whom an infected person has contaminated (as well as their close contacts) and "backward-tracing" which is to identify the source of infection [19]. These approaches are not applicable to location-based tracing, as it does not possess the ability to measure or estimate distances between users accurately. Thus, the only solution possible for effective tracing towards retrospective approach is only by close contact tracing.

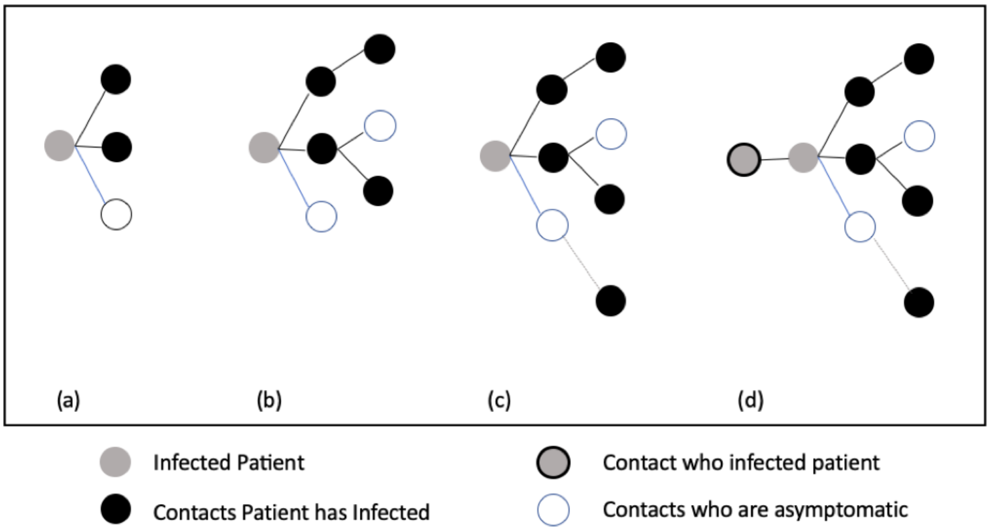

Figure 3. (a) First-order; (b) Single-step; (c) Iterative; (d) Retrospective Contact Tracing by McLachlan et. al [5]

In an another angle, contact tracing for Covid-19 can be classified into three types. They are mass-type, movement-type and individual-type, with each having its own characteristics and objectives. Even though there is another type which is the Group-Type, it has not been widely adopted. Table 1 shows the differences between these three main types of contact tracing for the pandemic. Mass-type of contact tracing is aimed for the public areas such as malls, supermarkets, shop lots and so on where the amount of people visiting the area will be big in number. Thus, it uses location-based tracing where three vital information which are time, date and location will be recorded whenever a person comes to a premise. As for movement-type of contact tracing, it is aimed for people travelling during the lockdown period as what Gerak Malaysia does [20, 21]. For this type of tracing, information such as GPS locations for a duration will be utilized to track the movements of individuals from point A to B. As for the individual-type, it is meant for human-to-human tracing which make it highly efficient to trace close contacts. However, it is not easy to develop it as there are many constraints that comes with it. Thus, from Table 1, location-based tracing utilizes mass-type and movement-type of tracing, while close contact tracing requires individual human-to-human method. In location-based tracing, it is hard to identify close contacts because it uses location as a point of contact. Thus, it makes the tracing accuracy to be low and the efforts to be futile. While for close contact tracing, the accuracy is high because it detects close contacts in both forward and backwards tracing. Table 2 shows the gap analysis from the points discussed indicating the apparent gap of using location-based tracing and why CCTCF is crucial to provide some closure especially for Covid-19 pandemic. From Table 2, it shows that there is a critical gap for all the items discussed as the desired states were not achieved. Thus, it is important to identify the comprehensive characteristics of Covid-19 contact tracing solutions in order to know areas that are lacking, segments that require improvements and elements that needs changes. Last but not least, CCTCF will help to provide a strong insight on why close contact tracing is essential for the pandemic.

Table 1. Types of Digital Contact Tracing with its Characteristics

	Mass-Types	Movement-Type	Individual-Type
Aims	Mass close contact	Mass movement close contact	Individual close contact
Method	Location-based tracing	Location-based tracing	Human-to-human tracing
Concept Used	**Proximity**	**Proximity**	**Close contact**
Possible Approaches	(a) First-order (b) Single-step (c) Iterative	(a) First-order (b) Single-step (c) Iterative	Retrospective
Functionality	Utilizes a location to record the presence of people at a particular point of time.	Utilizes location(s) to record the presence of people at a particular point of time.	Utilizes distance to record close contact.
Accuracy in Contact Tracing	**Low** - due to usage of proximity concept	**Low** - due to usage of proximity concept	**High** – due to usage of close contact concept
Technology Used	GPS, QR Code, Wi-Fi, Cellular Network	GPS, QR Code, Wi-Fi, Cellular Network	Bluetooth, NFC

Table 2. Gap Analysis on Contact Tracing Solutions' Main Requirements for Covid-19 with Respect to Location-Based Approach

Main Requirements	Current State	Desire State	Gap (small, moderate, critical)
Ability to adhere to CDC's requirements for close contact identification	No	Follow the guidelines with high accuracy	Critical
Ability for retrospective tracing	No	Yes, with high accuracy	Critical
Asymptomatic patient tracing	No	Yes, with high accuracy	Critical

1-2- Current Contact Tracing Solutions

Before the deployments in mobile-based smart contact tracing solutions, governments around the globe had relied on the conventional method of interviewing for Covid-19. Figure 4 shows the summary of current contact tracing solutions developed by the selected 30-countries from the case study conducted in this study. It should be noted that all the solutions utilize mobile phones as the means for contact tracing application. Results obtained show that many of the countries still relies on location-based method in conducting contact tracing in their country. Out of the 30-countries studied, fourteen of them are utilizing solely on location-based tracing. This is worrying as almost half of the countries studied are implementing ineffective and low accuracy contact tracing solutions.

It is also a critical problem as Covid-19 has shown to cause damages to many life aspects such as education, entertainment, tourism and manufacturing if it is not contained [22]. While so, it will waste of countries' resources when enormous efforts were exerted to develop those solutions but in return, the results are not as expected as what studies have shown in Juneau et. al [10].

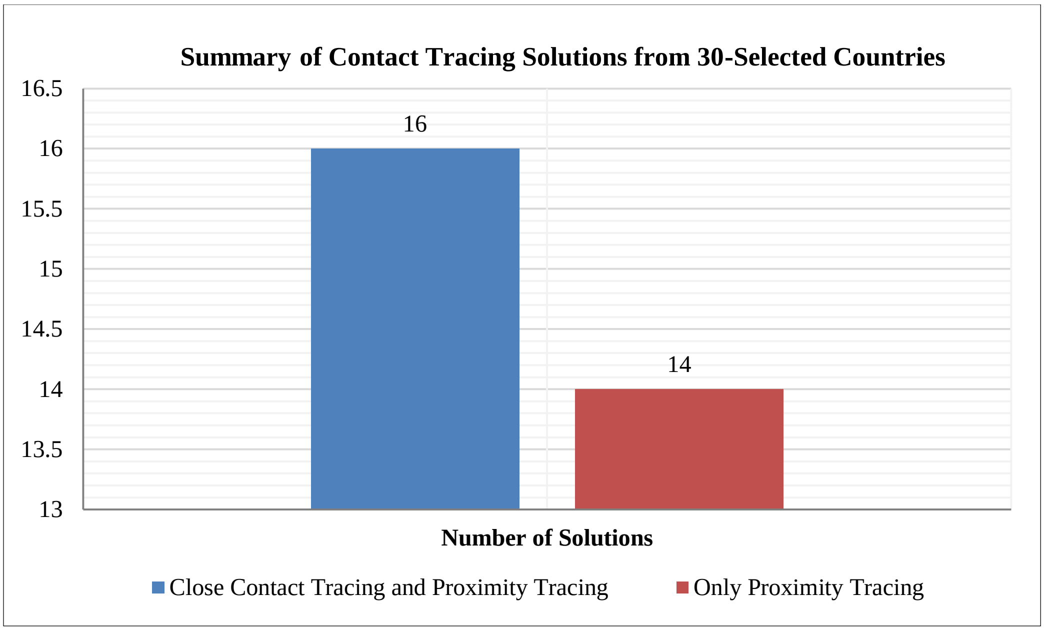

Figure 4. **Summary of Contact Tracing Solutions from thirty selected countries**

2- Methods

This study was conducted using PICO (problem, intervention, comparison, outcome) framework that consists of several methods which are case study, systematic literature review (SLR) and thematic analysis. For the Problem from PICO framework, it was identified from the case study conducted on the thirty countries reviewing in-detail on their contact tracing solutions. Intervention is in the form of the development of the comprehensive framework for contact tracing solutions using thematic analysis and systematic literature review on the characteristics of contact tracing solutions from major journal databases. As for Comparison from PICO, the framework was utilized in order to come out with the Outcome that necessitates the use of close contact tracing for Covid-19 in order to control the pandemic. Table 3 shows the Eligibility Criteria used for the systematic literature review for contact tracing solutions. Data were obtained from a selection of major journals of Emerald Insight, Springer, DOAJ, Science Direct, PudMed, IEEE Explore, SAGE and Wiley.

Table 3. **Eligibility Criteria for Systematic Literature Review**

	Inclusion Criteria	Exclusion Criteria
Language of Publication	English	Languages other than English
Date of Publication	After year 2019 (since Covid-19 started)	Published before the year 2019
Journal	- Peer reviewed - Access to full-text versions	Non peer reviewed
Research Design	- Qualitative Research - Mixed Method research - Pilot research	Observational research
Intervention	Technology-based contact tracing solution	Manual solution
Outcomes	Contact tracing solution for Covid-19	-

The search for contact tracing solutions for SLR was conducted using several keywords. They are: (1) "Contact Tracing" AND "solution", (2) "Contact Tracing" AND "Covid-19", (3) "Proximity Contact Tracing" and (4) "Close Contact tracing". It was initially screened by its title and abstract for relevancy while duplicates were discarded. Afterwards, only the study that fulfils the eligibility criteria were selected with the type of contact tracing solution used was identified from the paper and separated into three different groups which are forward, backward and bi-directional tracing. If the solution type is not clearly stated, then the study will not be eligible nor selected as well. General flowchart of the whole process conducted is shown in Figure 5 below while Figure 6 shows the systematic review process. It should be noted that there was no study risk assessment or effect measures as the study intended to gain as many sources as possible.

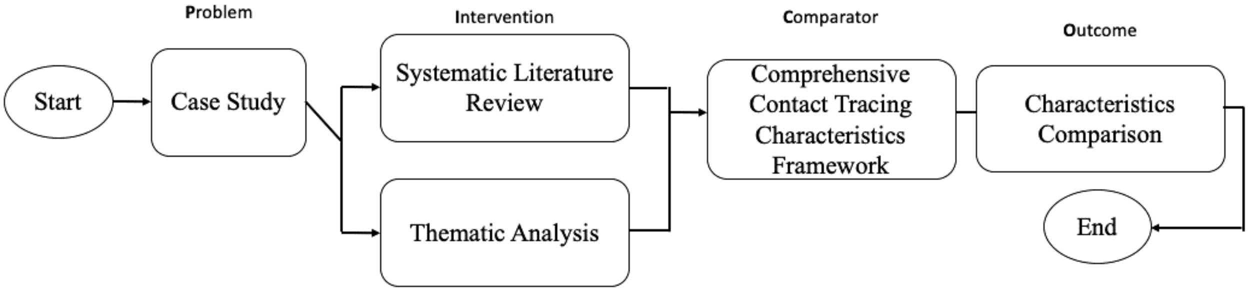

Figure 5. **General Flowchart of Methods Used using PICO Framework**

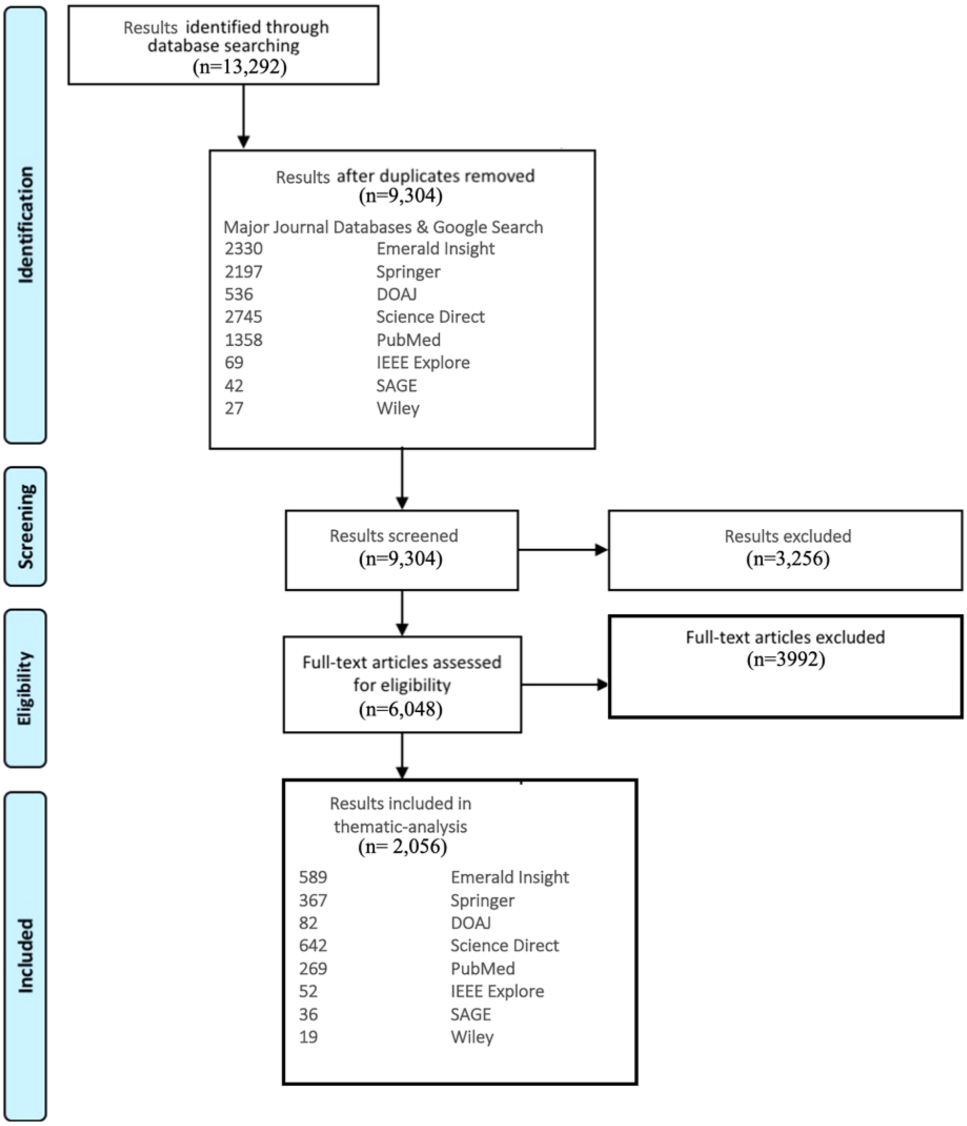

Figure 6. **Systematic Literature Review Process**

3- Results – Comprehensive Contact Tracing Characteristics Framework

From the thematic analysis, CCTCF for Covid-19 was constructed as shown in Table 4 in the last section of the page. It is divided into three main approaches or sections which are Forward, Backward and Bi-directional tracing. The reasoning behind it is because, only these three main approaches keeps on appearing consistently from all the included studies. From Table 4, it shows that a total of 25 items have been obtained in making the characteristics to be comprehensive where it covers wide range of themes. Each of the items has its own attributes that provide its characteristics for each of the sections. For these items, it is divided into five themes using Braun & Clarke (2006) six-phase guidance framework as shown in Figure 7 [23]. These themes are: (i) Classification, (iv) Mechanism, (iii) Technology, (iv) System and (v) Generic that will provide a proper arrangement for all the items. As for location-based tracing, it falls under Forward tracing only while close contact tracing falls under Backward and Bi-directional tracing.

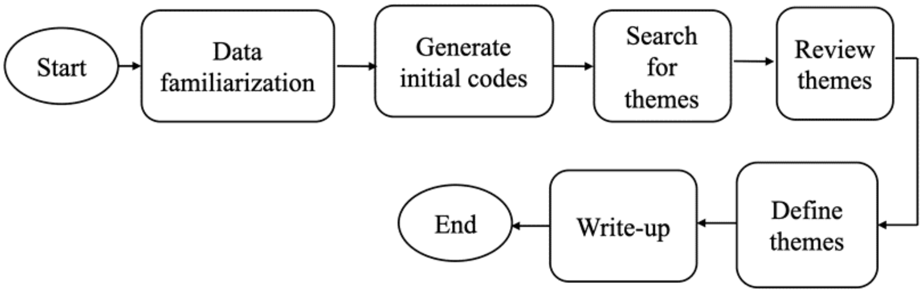

Figure 7. **Thematic Analysis Process Framework by Braun et. al [23]**

Table 4. **Comprehensive Contact Tracing Characteristics Framework for Clovid-19**

	No.	Items	Forward Tracing	Backward Tracing	Bi-directional tracing
Classification	1.	Possible Types	[1]Mass-Type [1]Movement-Type [2]Individual-Type (Manual) Group-Type	Individual-Type Group-Type	Individual-Type Group-Type
	2.	Aims	[1]Mass close contact [2]Individual close contact	Individual close contact	Individual close contact
	3.	Usage of Technology	**Yes** – depending on solution **No** – depending on solution	**Yes** – due to CDC's requirement	**Yes** – due to CDC's requirement
	4.	Method	[1]Location-based tracing [1]Venue-based tracing [2]Interviews	Human-to-human tracing	Human-to-human tracing
		Concept Used	**[1]Proximity**	**[2]Close Contact**	**[2]Close contact**
Mechanism	5.	Approach Options	(a) First-order (b) Single-step (c) Iterative [2]Iterative	Retrospective (limited to source identification)	Retrospective
	6.	Component for Identification	[1]Memory [1]Mathematical Probability [1]Manual Records [1]GPS locations [2]Distance Estimation	Distance Estimation Signal Capture	Distance Estimation Signal Capture
Technology	7.	Accuracy in Contact Tracing	[1]**Low** - due to usage of proximity concept [2]**Medium** – due to usage of close contact concept	**Low** - due to ability to identify source only	**High** – due to usage of close contact concept
	8.	Time Requirement for Contact Tracing	[1]**Medium** - due to technology elements incorporated [2]**Low to High** – Depending on number of cases	**Medium** - due to technology elements incorporated	**Low** – due to autonomous tracing
	9.	Number of Users	**Low to High** – depending on solution	**Low to High** – depending on solution	**Low to High** – depending on solution
	10.	Replicability	**Easy to Hard** – depending on the solution	**Easy to Hard** – depending on the solution	**Easy to Hard** – depending on the solution
	11.	Technology Used	[1]Wide Area Network (WAN), QR Code, others Global Positioning System [2]**None**	Personal Area Network (PAN)	Personal Area Network (PAN)
System	12.	System Architecture	(a) Centralized (b) Decentralized (c) Hybrid	(a) Centralized (b) Decentralized (c) Hybrid	(a) Centralized (b) Decentralized (c) Hybrid
	13.	System Transparency	[1]**Low to High** – depending on country [2]**High**	**Low to High** – depending on country	**Low to High** – depending on country
	14.	System Security	[1]**Medium to High** – due to usage of technology [2]**Low** – due to usage of people	**Medium to High** – due to usage of technology	**Medium to High** – due to usage of technology
	15.	Demand of Resources	**Low to High** – Depending on solution and number cases	**Medium** - due to technology elements incorporated	**Low** – due to autonomous tracing
	16,	Scalability	**[1]Yes** – due to usage of technology **[2]Yes** – demand bigger usage of resources	**Yes** – due to usage of technology	**Yes** – due to usage of technology

	17.	Ability to Identify Symptomatic / Asymptomatic Cases	**Yes** – depending on solution **No** – depending on solution	**Yes** – depending on solution **No** – depending on solution	**Yes** – depending on solution **No** – depending on solution
	18.	Ability to add Exception Cases	**Yes** – depending on solution **No** – depending on solution	**Yes** – depending on solution **No** – depending on solution	**Yes** – depending on solution **No** – depending on solution
	19.	Ability to Identify Clusters	**Yes** – depending on solution **No** – depending on solution	**Yes** – depending on solution **No** – depending on solution	**Yes** – depending on solution **No** – depending on solution
Generic	20.	Essential Information	[1]Location, date and time [2]Individual contact details, location, date, time and duration	Distance and duration	Distance and duration
	21.	Essential Information Reliability	**Low** to **High** – Depending on solution and number cases	**Moderate** to **High** – Depending on solution and number cases	**Moderate** to **High** – Depending on solution and number cases
	22.	Ease of Implementation	[1]Easy to Moderate [2]Easy	Moderate to Hard	Hard
	23.	Accessibility	[1]**Low to High** – depend on country [2]**Moderate to High**	**Low to High** – depend on country	**Low to High** – depend on country
	24.	Voluntariness	[1]**Low to High** – depending on country [2]**Moderate to High**	**Low to High** – depending on country	**Low to High** – depending on country
	25.	Limitations	**Low to High** – Depending on solution	**Low to High** – Depending on solution	**Low to High** – Depending on solution

Nevertheless, CCTCF generally indicates that the implementation and development of a contact tracing solution get harder and more complicated when pursuing backward and bi-directional tracing. For bi-directional tracing, the requirements in terms of technology and systems are not a simple matter. Location-based tracing only resides in forward tracing and does not have the ability to progress further or be in other segments. While so, location-based tracing is not a difficult task, especially with the use of the QR code. Due to this attribute, it may be one of the reasons why many countries have utilised it. Through CCTCF's three sections, it can be considered the current level of a contact tracing solution, where the highest is in bi-directional, where characteristic requirements are stricter.

4- Discussion

In general, the CCTCF for Covid-19 gives an idea of the many ways a contact tracing solution can be implemented. From the choice of technology to the system architecture, there are a lot of options to be chosen from. While so, these choices have their own consequences that affect their implementation, effectiveness, scalability, and sustainability in tackling the pandemic. With the framework in place, countries can utilize it for better pandemic management and adapt necessary changes. Not just that, countries can also identify their weaknesses in their solutions and improve wherever necessary. The limitation of the framework is that it was developed solely in a literature arena and has yet to include insights from the practical scene. Thus, it can be a future direction that can add more solidity to it. Apart from that, another limitation in existence is that only four people are handling the analysis, which may limit the extent of the development. If more people can be utilized, there can be more insights into the framework. Nevertheless, it is still solid and comprehensive enough that countries and implementors can utilize it for their solutions, as many have been using low-accuracy, inefficient solutions. There is also not a single study that examines the comprehensive characteristics needed for contact tracing solutions, but many are reporting on a general basis. For example, Cho et al. (2020) mainly report on privacy concerns for contact tracing solutions [24], and Blasimme et al. (2021) use only a few items for the characteristics [25]. Thus, this study is the pioneer to produce comprehensive characterises for Covid-19 contact tracing solutions. From CCTCF, it shows that in order to achieve high accuracy in contact tracing, a retrospective approach must be adopted utilizing PAN.

High accuracy cannot be achieved using other network technologies such as Wide Area Network (WAN) and Local Area Network (LAN), as these two technologies have low accuracy in estimating distances between users. Not just that, it should also be noted that when a solution is able to identify the source of infection, it has entered an autonomous state when conducting contact tracing. This is because the solution will utilize some important elements such as the time of signal capture in order to determine the source of infection, and it can only be done with a good algorithm that makes it autonomous. While so, due to CDC's requirement, there has to be a technology utilisation in the solution and usage of manual method is not an option. With the choice of technology, comes the component of close contact identification. From CCTCF, it can be observed that components of close contact identification become less strict and have more options for forward tracing rather than backward and bi-directional tracing. Items such as memory and mathematical probability are the ones that make forward tracing less accurate. Overall, the main findings of this study are that location-based tracing has too many disadvantages when compared to close contact tracing from CCTCF. Thus in return, it shows the necessity for the usage of close contact tracing as efforts will be futile and containment of the pandemic will not be effective as intended with location-based tracing. Last but not least, the CCTCF can also be used as guidance for future similar pandemics as the characteristics of a contact tracing solution for infectious diseases have been found.

5- Conclusion

From the study conducted, it appears that many of the contact tracing solutions developed by countries to combating Covid-19 pandemic, fall under location-based tracing rather than close contact tracing. With many limitations and low accuracy of location-based tracing, it is proven that location-based tracing is not the best choice against the pandemic. Thus, the best solution obtained from CCTCF is bi-directional human-to-human close contact tracing which utilises a retrospective approach that it able to identify the source and groups of infection. It uses PAN as the network connectivity, and it is autonomous in detecting close contacts. Nevertheless, it is a tough option as results have shown that it is not easy to develop even though it has high accuracy.

From CCTCF, a total of 25 characteristics have been identified and grouped accordingly that can be used for Covid-19 and similar pandemics to come. It can be concluded that the CCTCF is solid as it carries an adequate number of studies and can be a source of guidance for developers in making sure their solutions are on the right path. Last but not least, CCTCF can also be expanded further by other researchers toward the expansion of the list of items or by developing it into a contact tracing index to measure the smartness of a solution. It is hope that with this study, Covid-19 can be better managed through effective contact tracing and future new outbreaks to be halted before expanding to an epidemic.

6- Declarations

6-1- Author Contributions

Conceptualization, T.O.K.Z. and S.M.; methodology, T.O.K.Z. and K.S.M.A.; validation, S.M., M.T.S.; formal analysis, T.O.K.Z, S.M., B.P and M.J.K.; investigation, T.O.K.Z.; writing—original draft preparation, T.O.K.Z.; writing—review and editing, S.M.; supervision, S.M.; project administration, K.S.M.A.; All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6-3- Funding and Acknowledgements

This study is supported by Faculty of Management (FOM), Multimedia University, Malaysia.

6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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