2024 IEEE International Conference on Systems, Man, and Cybernetics (SMC)
October 6-10, 2024. Sarawak, Malaysia

2024 IEEE International Conference on Systems, Man, and Cybernetics (SMC) | 978-1-6654-1020-5/24/$31.00 ©2024 IEEE | DOI: 10.1109/SMC54092.2024.10831636

# A New Transmission Cause and Effect Analysis (TCEA) Approach to Risk Management for non-healthcare context: A Case Study on COVID-19

Yi Wen Kerk, Kai Meng Tay, Chian Haur Jong, Chee Shee Chai, Chee Peng Lim

***Abstract*—Leveraging the concept of Failure Mode and Effect Analysis (FMEA), we propose a simple and systematic approach, namely *Transmission Cause and Effect Analysis* (TCEA), to achieve a defined goal of reducing transmission risk through effective preventive and control actions in real-world environments. Specifically, the *transmission risk* of an infectious disease (e.g., COVID-19) is perceived as a combination of the presence of a transmission agent (e.g., SARS-CoV-2 virus or its variants) and the requisite factors that lead to infection of humans and the associated aftermath of infection. TCEA adopts a causal map to represent all possible transmission risks via a brainstorming process. Next, appropriate preventive and control actions associated with each transmission risk are identified. Similar to FMEA, a Risk Priority Number model with Severity, Occurrence, and Detection ratings is adopted for analysis, prioritization, and decision-making. To demonstrate the usefulness of TCEA, a real-world case study on COVID-19 is conducted. The empirical results indicate that TCEA provide a simple, systematic and easy-to-implement approach to effectively analyze and manage transmission risks of COVID-19 in non-healthcare workplaces.**

## I. Introduction

COVID-19 (an infectious disease caused by a recently discovered coronavirus) has been a global burden in healthcare [1-3]. A variety of preventive measures that aim to reduce or prevent transmission of the coronavirus, such as social distancing and isolation [4-5], wearing mask and/or personal protective equipment (PPE) [4], maintaining personal hygiene [4], and lockdown [5] have been practiced worldwide. In this paper, the *transmission risk* of an infectious disease is perceived (could be defined) as a combination of the presence of a harmful pathogen (i.e., a microorganism, e.g., a SARS-CoV-2) with the requisite factors that lead to infection of a human (e.g., COVID-19) and the aftermath of infection [6] (e.g., health and socio-economy impact). Factors such as human population, population activities, and population immunity are considered to be modifiers of the basic distribution of the pathogen leading to disease transmission [6].

Y. W. Kerk is with Faculty of Information Science & Technology, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia (e-mail: ykerk@ukm.edu.my).

K. M. Tay is with Faculty of Engineering, Universiti Kebangsaan Malaysia, Kota Samarahan 94300, Malaysia. (e-mail: kmtay@unimas.edu.my).

C. H. Jong is with School of Engineering & Technology, Universty of Technology Sarawak, Sibu 96000, Malaysia (e-mail: chian.haur@uts.edu.my).

C. H. Chai is with Faculty of Medicine & Health Sciences, Universiti Malaysia Sarawak, Kota Samarahan 94300, Malaysia (e-mail: cschai@unimas.my).

C. P. Lim is with Institute for Intelligent Systems Research and Innovation, Deakin University, Geelong VIC 3216, Australia (e-mail: chee.lim@deakin.edu.au)

Leveraging on the principle of *systems engineering* [7], a fundamental challenge is to understand the transmission risk of an infectious disease (e.g., COVID-19) in a real-world environment, and transfer such understanding toward utilising practical systems engineering tools and methods to tackle the problem. This paper considers two challenges: 1) how can we (medical experts and/or stakeholders) better understand the transmission risk of an infectious disease (e.g., COVID-19) in a real-world environment? 2) how can we utilize the learned knowledge for reducing the transmission risk of an infectious disease in a real-world environment through a systematic methodology? According to [8], even though real-world environments are dynamic and non-stationary, a systematic approach can be an efficient means to achieve clearly defined goals. In this respect, the importance of leveraging a systematic approach to contain COVID-19 was discussed in [9].

Stemming from the concept of *systems thinking* [8], a systematic methodology is proposed in this paper, namely *Transmission Cause and Effect Analysis* (TCEA) with a well-defined set of goals pertaining to reducing the transmission risk of infectious diseases (i.e., COVID-19) in a real-world environment. As depicted in Fig. 1, TCEA aims to undertake the above-mentioned two challenges. In formulating an effective solution for undertaking the first challenge, a proposed causal map (Section II.A) is adopted to represent the possible transmission scenarios within a real-world environment in a form of transmission causes (TCs), possible transmission potentials (TPs), transmission effects (TEs), preventive and control actions as well as their associated severity (Sev), occurrence (Occ), and detection (Det) ratings. The Sev, Occ, and Det scale tables are defined for evaluating the severity of TEs, the likelihood of TCs, and the effectiveness of relevant prevention and control actions, respectively.

To tackle the second challenge, the Risk Priority Number (RPN) model in Failure Mode and Effect Analysis [10-11] is exploited. A systematic procedure that involves a task force is established. The focus is on continuous brainstorming for better understanding and documentation of possible transmission scenarios and ratings of Sev, Occ and Det, as well as prioritization of the TPs and preventive and control actions with the RPN model, in order to achieve the goal of transmission risk reduction of an infectious disease (e.g., COVID-19). To evaluate the usefulness of TCEA, a real case study on reducing the transmission risks of COVID-19 in an office is conducted. The outcomes positively indicate the effectiveness of the proposed TCEA methodology for achieving the goals.

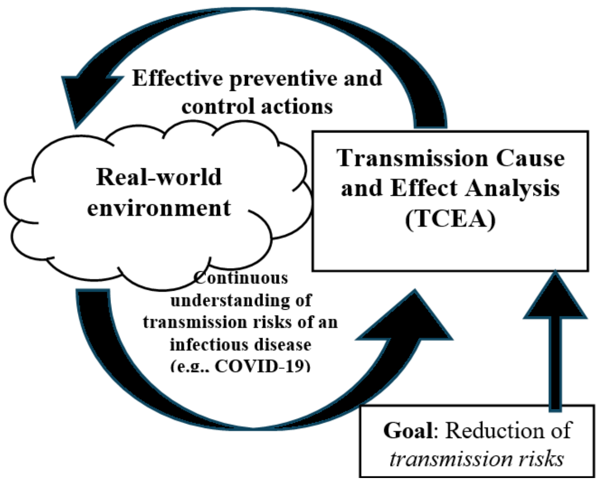


*Fig.1. Transmission Cause and Effect Analysis (TCEA) for reduction of transmission risks*

TCEA, if successfully implemented, is expected to serve as a systematic approach to implementing useful decisions [12], which include preventive strategies [13], during the design or planning stage of a new product/process/service or for improving an existing product/process/service. In this respect, studies on prevention of infectious diseases with systematic methodologies are available in the literature, e.g., using the Hidden Markov Model for prediction of epidemic alert levels [14]. Besides, an artificial intelligence-driven system (i.e., α-Satellite) for tracking the emerging dynamics of COVID-19 [15], and a web-based infectious disease informatics system to support information sharing, analysis and visualization [16] were proposed.

## II. REPRESENTATION OF TRANSMISSION RISKS

### *A. A proposed causal map*

A causal map is a concept representation to capture causality or influence relationships [17]. It has been widely employed in structuring intervention related problems [18-19], serving as an effective tool to represent subjective knowledge about a phenomenon, a discourse on perceived causes and effects [18]. The proposed causal map is depicted in Fig.2. In practice, it is important to consider the possible transmission modes [20] during the brainstorming session for TPs. This is particularly crucial when it is difficult to identify the transmission modes of an infectious disease ([21]) and [22]). In addition, the transmission modes of an infectious disease can be dynamic, due to evolutionary mechanism of the disease [23]. The same arguments apply to TCs.

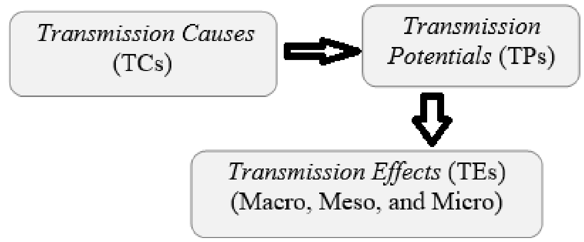


Fig. 2. The proposed causal map

Three types of TEs are available, i.e., micro (direct), meso (indirect), and macro (indirect and global). In this paper, the micro TEs covers the direct effects of disease transmission to human health. Meso TEs are indirect effects of disease transmission to the operations of an organisation, while macro TEs cover potential global effects to the social, economic, political and other concerns.

#### *A.1. Remarks*

The use of causal representations together with reasoning and inferencing methods in infection diseases modeling is not new. As an example, a causal diagram [24-25] was constructed to represent the phenomenon of small-pox and its vaccination. Instead of representing a scientific phenomenon, in this paper, a causal map is employed to represent qualitative and subjective knowledge for allowing TCs, TPs, and TEs to be identified by a taskforce involved in making decision. In this respect, the use of Ishikawa diagram or fishbone diagram together with 5Ms, 8Ps, and 4Ss principles to identify TCs constitutes an interesting direction.

### *B. Severity (Sev), Occurrence (Occ), and Detection (Det) scales*

Tables 1 to 3 show an example of the Sev, Occ, Det scales for our case study, respectively, following the general practices of FMEA. Sev is a rating of how severe an TE is; Occ is a rating of the occurrence of an TC; while Det is a rating of how effective a preventive action is. Each scale table consists of three columns, i.e., "Ranking", "Linguistic term", and "Descriptions", while the score intervals (from 1 to 10) are shown in "Ranking".

The Sev scale table is designed to rate the TEs pertaining to a susceptible host. For simplicity, Table 1 is designed based on a risk stratification method with respect to vital health indicators, lifestyle and medical history of interest. In accordance with [26], the possible risk factors of morbidity and mortality caused by COVID-19 can be divided into five categories, i.e., lifestyle factors, demographic factors, pre-existing comorbidities, developed comorbidities, and clinical factors.

The scale table of Occ is developed to rate the likelihood of TC occurrences. Table 2 is designed with two considerations: (i) the confidence level to prevent humans/objects/surfaces infected or contaminated by the COVID-19 virus from entering to a company premise; and (ii) the judgement of the likelihood for humans/objects to transmit the COVID-19 virus to other humans/objects, considering the nature of daily work activities and social interactions.

Table 3 is formulated to evaluate the effectiveness of the proposed preventive strategy, as detection ratings. Factors that influence the effectiveness are (i) screening protocols of risks and symptoms [27], (ii) cleaning and disinfection protocols [28], and (iii) PPE [29].

**Table 1** Scale table for Severity ratings

| Ranking | Linguistic term | Descriptions |
|---|---|---|
| 1-3 | Low | • Young workers maintain health practices and standard precautions<br>➢ Non-smoker, no excessive alcohol intake<br>➢ Regular contact with healthcare providers, maintain healthy routines<br>➢ Good public hygiene<br>• Young workers clean and disinfect frequently touched objects and surfaces |
| 4-7 | Medium | • Workers without health issues<br>• Potential objects susceptible to contamination |
| 8-9 | High | • Senior age group (e.g.,>60 years old), regardless of any medical conditions<br>• Pregnant women<br>• Worker with health issues (e.g., diabetic, hypertension. cardiovascular diseases, chronic lung diseases, cerebrovascular disease, chronic liver diseases. chronic kidney disease, malignancy) |
| 10 | Very High | • Senior age group with health conditions issues<br>• Pregnant women with health issues |

**Table 2** Scale table for Occurrence ratings

| Ranking | Linguistic term | Descriptions |
|---|---|---|
| 1-3 | Low | • High confidence that all humans are not infected<br>• High confidence that objects /surfaces are not contaminated<br>• Close communication can be avoided. |
| 4-6 | Moderate | • High confidence that all humans are not infected<br>• High confidence that objects /surfaces are not contaminated<br>• Close communication can be hardly avoided. |
| 7-8 | High | • Low confidence that all humans are not infected.<br>• Objects/surfaces contamination can hardly be avoided<br>• Close communication can hardly be avoided |
| 9-10 | Very High | • Low confidence that all humans are not infected<br>• Objects/surfaces contamination can hardly be avoided<br>• Confined spaces, crowded places, and close communication |

**Table 3** Scale table for Detection ratings (Prevention strategy)

| Ranking | Linguistic term | Descriptions |
|---|---|---|
| 1 | Very High | Prevention is very good<br>• Single-use objects/surfaces<br>• Traveling to high risk geography location can be totally avoided.<br>• Face-to-face interaction and communication can be totally avoided. |
| 2-3 | High | Prevention is good<br>• Objects/ Surfaces which can be effectively cleaned, disposed, or replaced without special handling<br>• Travelling staff members aware of exposure risk, within Sarawak.<br>• Face-to-face interaction and communication cannot be totally avoided, but social distancing with preventive protocols (e.g. face shield/mask) can be implemented. |
| 4-7 | Moderate | Manageable Prevention<br>• Disposable objects that need special handling (e.g., hand gloves)<br>• Travelling staff members aware of exposure risk, within the nation |
| 8-9 | Low | Hard to prevent<br>• Non-disposable objects that cannot be disinfected<br>• International travelling staff members aware of exposure risk. |
| 10 | Very low | Prevention is almost impossible<br>• Non-disposable objects that cannot be disinfected, special handling needed.<br>• International travelling staff with regular employee travel members aware of exposure risk. |

## III. The TCEA Procedure and Case Study

### A. The TCEA Procedure

The TCEA procedure in Fig. 3 can be modified for other processes, designs, or services to suit the nature of industry and business. The priorities are given to TPs or control and/or prevention actions associated with high RPN scores.

### B. Background of Case Study

To evaluate the usefulness of TCEA, a real-world case study with information collected from an IT (information technology) company is conducted. The summary of company information is shown below in Table 4. The company employs a total of 10 staff members, i.e., 9 male and 1 female, ranging from 21 to 33 years old. The company office occupies a total of 1920ft$^2$. As depicted in Fig. 4, it consists of a computer lab (Lab 1), a system integration lab (Lab 2), office of the Chief Technical Officer (CTO) (i.e., CTO Office), a discussion room, a server room, a pantry, a restroom, and a document room.

In this case study, four possible transmission modes are identified for COVID-19 prevention, i.e., contact, droplet, and fomite, as well as, airborne, transmission modes. Tables

1, 2 and 3 are the scale tables for Sev, Occ, and Det ratings. Similar to FMEA, the TCEA spreadsheet consists of 11 columns, i.e., “Area/Room”, “Function and Description”, “ID”, “Transmissions Potentials (TPs)”, “Transmission Effects (TEs)”, “Transmission Causes (TCs)”, “Control/prevention action”, and Sev, Occ, Det ratings as well as RPN score. To have a better understanding, a summary of the TCEA spreadsheet are presented in Table 5. Table 5 covers the key workspaces, i.e., Lab 1/ Lab 2, Discussion Room, Server Room and CTO Office.

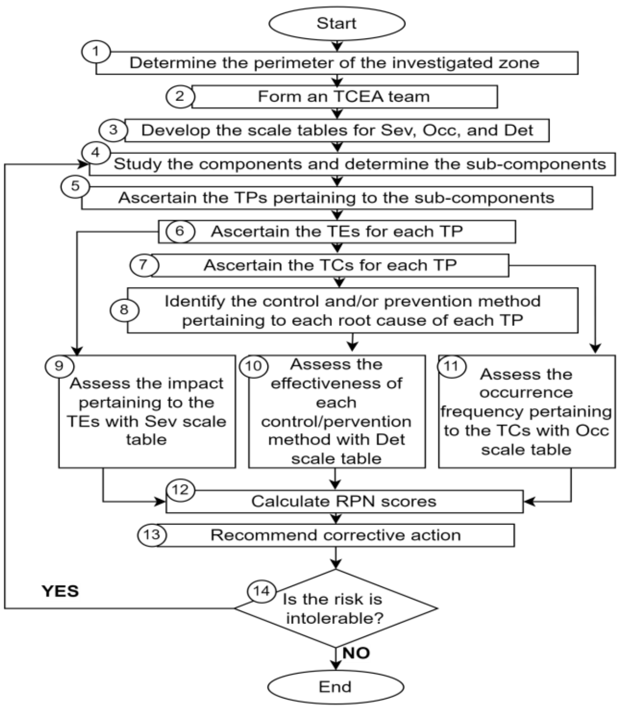


Fig. 3. The TCEA procedure

**Table 4** Summary of Company Information

| Parameter | Details |
|---|---|
| Total Staff | 10 |
| Gender Distribution | 9 Male, 1 Female |
| Age Range | 21-33 years |
| Office Space (Total Area) | 1920 ft² |
| Key Workspaces | Lab 1, Lab 2, Discussion Room, Server Room, CTO Office |
| Other Rooms | Lift, Main Entrance, Pantry, Restroom, Document Room |

*C. The TCEA spreadsheet*

A total of 26 TPs are identified, together with the corresponding TEs (tagged with Sev ratings), TCs (tagged with Occ ratings), and control or prevention actions (tagged with Det ratings). Fig. 5 summarizes the Sev, Occ, and Det ratings for all TPs. From Fig. 5, there are 16 TEs with Sev rating of 1, 4 TEs with Sev rating of 2, and 6 TEs with Sev rating of 3. The Sev ratings are low (from 1 to 3) because all staff members are from the low-risk group, i.e., young and non-smokers.

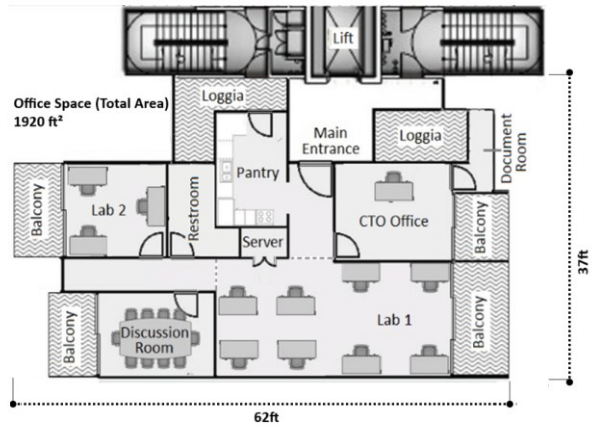


Fig. 4. The floorplan of the ICT company

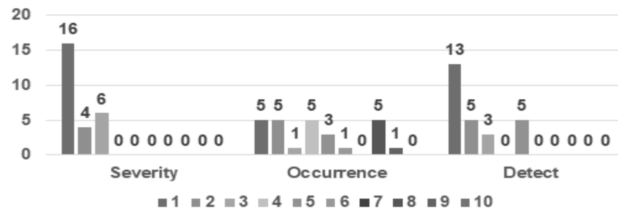


Fig. 5. Distributions of S, O, and D ratings

Besides that, the most frequent Occ ratings are 1, 2, 4 and 8, each with 5 TCs. This is followed by Occ ratings of 5 for 3 TCs, and of 3, 6 and 9 (each with 1 TC). High Occ ratings indicate that not all TCs for COVID-19 can be prevented with the standard measures if the company is operating during the pandemic period. As such, additional transmission-based control and preventive actions are necessary. From Fig. 5, a total of 21 control and preventive actions are associated with Det ratings from 1 to 3. However, there are 5 control and prevention actions associated with high Det rating of 8.

*D. Analysis of transmission risks*

Figure 6 depicts qualitative analysis of transmission risks for all TPs pertaining to Sev and Occ. A matrix of Sev versus Occ is established, which can be divided into five categories, i.e., very low risk, low risk, acceptable risk, high risk, and very high risk. There are total of 19 TPs associated with the risk level of “Very Low”, 1 TP with the risk level of “Low”, and 6 TPs with the risk level of “Acceptable”. This analysis indicates that TP with the highest risk (which is still acceptable) appears at the shared lift, which is used by outsiders.

| Sev \ Occ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Color | Risk Level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 5 | 1 | 1 | 3 | 1 | - | - | - | - | | Very Low |
| 2 | - | - | - | 4 | - | - | - | - | - | - | | |
| 3 | - | - | - | - | - | - | - | 5 | 1 | - | | Low |
| 4 | - | - | - | - | - | - | - | - | - | - | | |
| 5 | - | - | - | - | - | - | - | - | - | - | | Acceptable |
| 6 | - | - | - | - | - | - | - | - | - | - | | |
| 7 | - | - | - | - | - | - | - | - | - | - | | High |
| 8 | - | - | - | - | - | - | - | - | - | - | | |
| 9 | - | - | - | - | - | - | - | - | - | - | | Very High |
| 10 | - | - | - | - | - | - | - | - | - | - | | |

Fig. 6 A risk matrix of Sev and Occ ratings

### E. Prioritization of TPs using RPN Scores

Prioritization of TPs, covers Lab 1/ Lab 2, Discussion Room, Server Room and CTO Office, in the TCEA spreadsheet is summarized, as presented in Table 5, respectively, in a descending order. Column "Transmission Potentials" explains TPs; column "Area/Room" explains the location in which TPs occur; while columns "Sev", "Occ", "Det" and "RPN" are the Sev, Occ and R ratings as well as the RPN scores, respectively.

From Table 5, TP1.5, TP1.10 and TP1.14 are related to "*necessary entry of contactors to the premise for facilities and utilities maintenance*"/. They have the highest RPN score (i.e., RPN=120), which cover Labs 1 and 2, CTO Office, and the Discussion room. One solution is to conduct the maintenance work after office hours or weekend to prevent or minimize contacts between staff members and contactors. This is followed by TP1.1, TP1.11, TP1.4, and TP1.13, with the RPN scores between 10 and 30. The remaining TPs are associated with low RPN scores (<10). TPs associated with the Server room has the lowest RPN, as it is a restricted area, and only authorized technical staff can access the Server room. In addition, server maintenance tasks are usually conducted via a local area network.

**Table 5** A summary of the TCEA spreadsheet from covers the key workspaces, i.e., Lab 1/ Lab 2, Discussion Room, Server Room and CTO Office

| ID | *Transmission Potentials* (TPs) | *Area/ Room* | Sev | Occ | Det | RPN |
|---|---|---|---|---|---|---|
| TP1.5 | Necessary entry of contactors to the premise for facilities and utilities maintenance | Lab 1/ Lab 2 | 3 | 8 | 5 | 120 |
| TP1.10 | Necessary entry of contactors to the premise for facilities and utilities maintenance | Discussion Room | 3 | 8 | 5 | 120 |
| TP1.14 | Necessary entry of contactors to the premise for facilities and utilities maintenance | CTO Office | 3 | 8 | 5 | 120 |
| TP1.1 | Close distance social interaction which involve 2 and more staff. | Lab 1/ Lab 2 | 2 | 4 | 3 | 24 |
| TP1.11 | Close distance social interaction which involve 2 and more staff. | CTO Office | 2 | 4 | 2 | 16 |
| TP1.4 | Room and office furniture contamination with infectious agents (e.g., office table and chair) | Lab 1/ Lab 2 | 1 | 5 | 2 | 10 |
| TP1.9 | Room and office furniture contamination with infectious agents (E.g., door handle, floor, meeting table and chair) | Discussion Room | 1 | 5 | 2 | 10 |
| TP1.13 | Room and office furniture contamination with infectious agents (E.g., door handle office desk and chair) | CTO Office | 1 | 5 | 2 | 10 |
| TP1.6 | Close distance social interaction which involve 2 and more staff. | Discussion Room | 2 | 4 | 1 | 8 |
| TP1.2 | Sharing of office stationery | Lab 1/ Lab 2 | 1 | 2 | 1 | 2 |
| TP1.3 | Passing papers and document between staffs | Lab 1/ Lab 2 | 1 | 2 | 1 | 2 |
| TP1.7 | Sharing of office stationery | Discussion Room | 1 | 2 | 1 | 2 |
| TP1.8 | Passing paper and document between staff | Discussion Room | 1 | 2 | 1 | 2 |
| TP1.12 | Passing paper and document between staff | CTO Office | 1 | 2 | 1 | 2 |
| TP1.15 | Potential of server room contamination with infectious agents. | Server Room | 1 | 1 | 1 | 1 |
| TP1.16 | Potential of repair tools and equipment contamination with infectious agents. | Server Room | 1 | 1 | 1 | 1 |

### F. Discussion

As demonstrated in the case study, TCEA considers TPs for risk assessment and decision making of COVID-19 management. The study is important, as quoted from [30], "*During the rapid rise in COVID-19 illnesses and deaths globally, and not withstanding recommended precautions, questions are voiced about routes of transmission for this pandemic disease*". All qualitative and subjective knowledge and information related to COVID-19 prevention are successfully modeled through TPs, TCs and TEs with the casual map. The Sev, Occ, and Det scales, which correspond to the TCs, TEs and control and/or prevention actions, respectively, can be rated and compared using a scheme from 1 to 10, as shown in Table 5. Then, the RPN model, in accord to TCEA procedure presented in Fig. 3, allows all TPs to be prioritized for decision-making purposes. The outcomes, as discussed in Section IV-D, indicate that TCEA serves as a useful risk analysis and management tool for prevention of COVID-19 [31].

The case study highlights important potential risks for COVID-19 transmission in real-world environments. As an example, from the results, i.e., prioritization of TPs in the TCEA spreadsheet, as summarized in Table 5, "*Necessary entry of contactors to the premise for facilities and utilities maintenance*" due to "*Failure of basic utilities*" appears to be an important TP for the ICT company. The TCEA outcome is in line with the suggestions on high exposure risks associated with workplaces [32], as quoted: "*Jobs that may fall under this category include domestic workers, social care workers, personal transport and home delivery providers and home repair technicians (plumbers, electricians) who have to provide services in the homes of people with COVID-19.*"

Using the proposed TCEA approach, the respective control and preventive actions can be established. Importantly, TCEA is relatively simple to use, which requires minimal time and training, facilitating its implementation in real-world environments.

## IV. Conclusion

Inspired by FMEA, we have proposed a new TCEA methodology, for management of transmission risks in this study. A case study on an infectious disease, i.e., COVID-19, in real-world environments has been conducted. TCEA adopts a systematic and easy-to-implement procedure that incorporates a casual map, a set of Sev, Occ, and Det ratings and their scales, and an RPN model. It is useful for risk analysis and management of infection diseases in dynamic situations. From the case study on COVID-19 management, the results indicate the effectiveness of the proposed TCEA methodology in understanding and analyzing transmission risks for achieving the goals.

For future work, the use of TCEA in more complex and dynamic environments will be evaluated. In addition, further investigations from the perspective of systems sciences e.g., soft systems methodologies [7-8], and information sciences, e.g., incorporating fuzzy set theories [33] [34] [35] [36], adaptive neural networks, and probabilistic techniques to TCEA, will be carried out.

## Acknowledgment

The authors acknowledge the Fundamental Research Grant Scheme (FRGS), grant number FRGS/1/2021/ICT02/UKM/03/1 by the Ministry of Higher Education (MOHE), Malaysia, and the strong support of Neuon AI (https://neuon.ai/) in this research.

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