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Study of SARS-CoV-2 transmission in urban environment by questionnaire and modeling for sustainable risk control

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1. Introduction

In the 21st century, several epidemic diseases and their outbreak have severely threatened global society development and human health, such as Severe Acute Respiratory Syndrome (SARS), the Middle Eastern Respiratory Syndrome (MERS), and the Ebola Hemorrhagic Fever (EHF) (Gola et al., 2020). They can be considered as both epidemics and hazardous events. From the end of 2019, caused by SARS-COV-2 virus, COVID-19 pandemic has become a major health crisis for human beings (Allen et al., 2020), especially for those with higher ages (over 65 years old, for instance) and underlying conditions (Munoz-Fontela et al., 2020). More than 120 million people have been confirmed infected with over 2.6 million reported death in global (WHO, 2021). Since its spreading through environmental media and damage to human’s health, SARS-COV-2 is also regarded as a hazardous material, with its transmission risk considered also as severe environmental issue and risk. Accordingly, the interaction between environment and SARS-COV-2 transformation showed the necessity for investigation and drew researchers’ attention (Sunyer et al., 2021). Studies have shown the strong correlation and interaction between sustainable development, temperature, radiation, humidity, air pollution etc. and epidemic spreading (Coccia, 2020a; Srivastava, 2021; Sarkodie and Owusu, 2020; Shen et al., 2021; Rosario et al., 2020). Integrated index containing environmental, demographic, climatological and health risk factors to describe the environmental risk of exposure to future epidemic of COVID-19 was also studied (Coccia, 2020b).

Urban environment is the natural hardest hit due to its dense population, frequent activities and the transportation of people, especially in big cities (Wang et al., 2021). With the SARS-COV-2 spreading in urban area becoming a long-term issue, a sustainable epidemic and...
environmental risk control (SEERC) in urban area is urgently needed. For the prevention of virus spreading and human’s well-being in long term, SEERC should efficiently slow the infection and ensure the social/economic functioning. The SEERC can be beneficial in economy, society and environment terms in the sustainability. For instance, the negative influence on the GDP by lockdown is inevitable (Coccia, 2021a), but without a lockdown, the long-term economic functioning can’t be expected. This requires a well management of relationship between economy and epidemic control to retain the strength of both, which will be beneficial to the other in return. For instance, the higher level of healthcare spending has been confirmed to reduce the fatality ratio of COVID-19 patients (Coccia, 2021b), and impoverished regions tend to own higher transmission risk (Yechezkel et al., 2021). Similarly, the healthy functioning and development of society also own the same influence. With the assistance from economy and society, the long-term controlling of SARS-COV-2 transmission as a virus and hazardous material can be achieved.

However, the development of SEERC requires the detailed determination of virus transmission risk through various routes from environmental media to human-to-human pathways in various detailed urban functional areas. This goal meets difficulties to be achieved.

Firstly, the massive ingredients in urban area not only include the daily functional regions like school, working place, business district, residence zone and hospitals, etc. but also contain pollution control system like waste transportation, deposit, wastewater discharge, transportation and treatment plants, which are the natural risk carrier for epidemic spreading. When comes to the concrete ingredient in these regions, the situation can be more diversified and complicated. This enhances the difficulty for the detailed study.

Secondly, in terms of transmission routes, the possible ways for SARS-COV-2 remaining and transmission retain diverse and unclear. Besides the suggested infection corresponding to wide animals (Rothan and Byrareddy, 2020), the human-to-human transmission was also determined (Zhou et al., 2020). In the air phase, the virus-containing spray from coughs and sneeze is considered as a critical infection route, the direct contact to solid materials with active virus was also reported risky (Lotfi et al., 2020). Moreover, the air pollution was suggested as another transmission source, which causes airborne transmission. The faster spreading of the virus was associated with lower wind speed and higher frequency of heavy air pollution (Coccia, 2021c, 2021d, 2021e). The risk may derive from the particulate matter (PM) like PM10 and PM 2.5 (Coccia, 2021c, 2021d; Bashir et al., 2020). The reduction of airborne transmission shows significant value to the controlling of infectious respiratory diseases (Zhang et al., 2021). In terms of water, aerosol from water flushing may contain virus and cause its shedding (McDermott et al., 2020). In urban water system, the SARS-COV-2 RNA concentration tested in sludge can be 6–8 days ahead by the case reporting date, indicating a remaining risk from sewage until the end of water treatment process (Peccia et al., 2020). Meanwhile, transmission risk changes due to the difference between environments, where nosocomial transmission may perform more severely than the that in community (Rivett et al., 2020). The massive cross infection in hospitals indicated the risk of transmission in various areas therein (Wu et al., 2020). The diverse SARS-COV-2 transmission ways not only accelerate the virus spreading and the subsequent infections, but also lifted the difficulty of SEERC.

Moreover, the direct PCR test of virus is one of the most common ways for epidemiology study, while the distribution of COVID-19 from seasonal influenza based on only clinic presentation is challenging (Sieber et al., 2021). However, due to the great error of detection, the heterogeneous distribution of virus in environment/materials and the risky operation, the lab experiment may not be suitable for the detailed transmission risk in various routes and areas. The mathematic models for SARS-COV-2 studies and predictions in various aspects were then conducted, including diagnosis and prognostic models, etc. (Dirggin et al., 2020; Wynants et al., 2020). For instance, numbers of predictions on future cases and mortality by different methods have been conducted and provided help (Fanelli and Piazza, 2020; Mousavi et al., 2020; Ruan et al., 2020; Dairi et al., 2021). Framework for identification of virus spreading cluster was also carried out (Rossman et al., 2020). Moreover, spatial analysis in the 2D level has successfully determined the linkage between characteristic in urban region and the virus transmission degree (Kwok et al., 2021). However, data involved in modeling can hardly tell some of the significant information (in detail how, when and where the infection occurs) and the number of data may be also limited. Especially for the pure prediction of the number of infection, due to the different results (for instance, fatality ratio) in infection in various regions and conditions (Russell et al., 2020), the meaning of study is limited. Besides, the valuable information like frontline medical staff’s experience and opinions can be hardly quantified and will be ignored in the analysis. However, experience accumulation has shown great importance during the epidemic control work. For instance, a report in Italy suggested the experience learned from the first wave of COVID-19 epidemic reduce fatality ratio against confirmed cases during the second wave (Coccia, 2021).

Overall, alternative methods for transmission risk assessment in detailed transmission routes and risky areas are the urgent need. Therein, valuable experience from specialists involved in COVID-19 epidemic controlling should be considered as critical information source. This is for the illustration of degree of risk in detail and guide the establishment of SEERC.

Therefore, in this work, we introduced a new-perspective questionnaire survey with statistical and modeling analysis to address transmission risk assessment for SARS-COV-2 as a virus and hazardous material in urban area. Subsequently, the virus transmission can be investigated in detail, SEERC planning can be guided. The valuable experience from specialists involved in COVID-19 epidemic controlling can be counted in analysis and the efficient data collection can be achieved. To ensure the high quality of the research, the inclusion standard of respondents required doctors and nurses who treated confirmed cases in the frontline, the CDC staffs served epidemic control in frontline and environmental engineers with the background of epidemiological study. A synthetical index method was employed to calculate the degree of risk and the corresponding weights with 5 possible virus transmission routes in 28 typical areas in urban area involved. Subsequently, a modeling developed on Simulink platform to describe the virus quantity variation in different conditions and the effectiveness of various epidemic controlling measures. Based on these results, a new SEERC plan was initially discussed and established.

2. Method

2.1. Critical factors in the study of SARS-COV-2 transmission

The critical factors affecting the degree of SARS-COV-2 transmission risk were distributed according to two dimensions, transmission routes and functional areas in urban region in the questionnaire. 5 possible routes included breath, intake, contact to human, contact to object and unknown route. Totally 28 functional areas in the urban region were considered where the 5 transmission routes may take place. A total 140 scenarios (5 routes × 28 areas) were designed in the questionnaire. All functional areas were distributed into 4 big functional parts, infectious hospital, general hospital, urban district and pollution control system, as shown in Table 1.

In the transmission routes, breathing was regarded as one of the main routes for the virus transmission. This should be corresponding to the existence of viral particles in the air, which would be even prolonged by heavier air pollution (Coccia, 2021d, 2020c; Bashir et al., 2020). Therein, PM10, PM2.5 and droplet particles (bio-aerosol) with diameter < 5 μm were confirmed to play significant roles (Coccia, 2021c; Bashir et al., 2020; Tabatabaeizadeh, 2021). Due to the existence of breath route, the contact-to-human route here mainly derive from the touching
route. It can be associated to direct contact like shaking hands or indirect contact to the patients’ infectious secretions (Vella et al., 2020). Similarly, contact-to-object route performed when touching the contaminated surfaces such as various plastic and metal materials, the danger of this route was also suggested (Choi et al., 2021). Intake route is usually un-focused, a research in Thailand suggested lower awareness of aerosol, food and drink as possible transmission source than other obvious routes (Maude et al., 2021). But intake route also represented a significant potential transmission risk, which may connect to touching contaminated wrapper, food and using contaminated tableware. Infections from contact-to-human, contact-to-object and intake routes may finally conduct through the subsequent touching to noise, eyes and oral, etc. Li et al. (2020). Moreover, there may be other un-defined routes which also represent severe danger. The unknown route in this work left the space for further study and discussion.

The functional areas included (1) ICU, medical imaging room, inpatient department, etc. in infectious hospital; (2) medical imaging room, inpatient department, etc. in general hospital; (3) school/working places, residential area, square, etc. in urban district; (4) Wastewater treatment plant, sludge disposal, refuse burning systems, etc. in pollution control system, as shown in Table 1. Because of the generality of SARS-CoV-2 transformation globally and the wide range of regions and companies where the respondents in this work attached to, the study tended to reflect the new general information, rather than for a specific place.

In the modeling, the purpose to include these routes and areas was to simulate the epidemic spreading of the whole urban region, where healthcare, business, residence, job/work and pollution control system should be all considered as important chains. Subsequently, the degree of virus transmission risk can be determined in all routes and areas, the corresponding transmission kinetics can be also studied. Finally, the modeling of epidemic spreading of the urban region can be conducted.

### 2.2. Sample and data

Each of the functional part (Infectious hospital, general hospital, urban district and pollution control system owned a questionnaire form (totally 4 forms) in the questionnaire. Notably, the definition of infectious hospital also included epidemic treatment area in general hospital.

In each functional part, degree of transmission risk in each scenario (route × area) formatted a question. For instance, the number of questions in infectious hospital was 5 transmission routes × 9 detailed functional areas, equaled to 45 questions. In each question, the degree of risk was scored between 0 and 10 by the respondents of the questionnaire. Notably, the definition of infection probably occurred without self-protection measures, whereas, “0” referred to the minimum risk where the infection was unlike to occur even without self-protection measures.

Specialists invited to score the questionnaire included doctors, nurses, CDC employees and environmental engineers. The admittance criterion required that doctors and nurses involved must have worked in frontline and contacted with confirmed patients during the outbreak. The CDC employees should have participated in anti-epidemic work and management during the outbreak. The inclusive environmental engineers should own the background of epidemiological study. As a result, totally 207 specialists were selected, containing 107 doctors, 62 nurses, 12 CDC employees and 26 environmental engineers. All doctors and nurses worked in infectious hospital or epidemic treatment area in general hospital during the outbreak of the epidemic. The total number of COVID-19 patients contacted/treated by these medical staffs are 9426.

Besides the scoring in the questionnaire, for a scientific analysis of obtained data, the finished questionnaires by various specialists were weighted. The scoring was according to the professions and positions of the respondents during the epidemic control work, ranging from 0 to 10. The weighting was completed by 10 senior specialists: 4 clinicians, 3 specialists in epidemic study and 3 senior environmental engineers.

Therefore, the specialists invited in the study included two groups, A and B. Group A including 10 senior specialists assessed the weight of questionnaire from each kind of profession with various positions in group B. Group B referred to the professional respondents for questionnaire, including doctors, nurses and environmental engineers with treatment experience for confirmed cases and epidemic controlling.

Both results from the questionnaire and the weighting were well preserved and digitalized for the further statistical analysis and modeling.

#### 2.3. Data analysis procedure

The data analysis in this work included statistical and modeling parts. The statistical analysis aimed to evaluate the degree of transmission risk of various routes in different areas according to the scoring of questions in questionnaire. The modeling was to analyze the spreading of epidemic and the growth of virus quantity based on the statistic result, providing conclusions and suggestions to guide the SEERC.

##### 2.3.1. Statistical analysis

Firstly, to comprehensively reflect the overall level of weight and avoid the impact to accuracy by individual extreme values. The weight of questionnaire from each kind of profession in the corresponding position in group B was determined by a comprehensive evaluation index method, where the maximum and average values from the scoring by specialists in group A were considered:

\[
I = \sqrt{\frac{(I^e_{max} + I^e_{ave})}{2}}
\]  

(1)

Where \(I\) refers to the index value of the weight of one kind of profession in the certain position in group B, while \(I^e_{max}\) and \(I^e_{ave}\) are the
corresponding maximum and average values from the scoring by specialists in group A. The various professions in different positions were distinguished by i. Therefore, the final weight index of a certain kind of profession can be then determined as follow:

$$Q_i = \frac{I_i}{\sum_{r_i=1}^{r_i}}$$ (2)

Where $Q_i$ reflected the final weight index of a questionnaire from a certain kind of profession with a certain position. $r_i$ referred to the total number of professions with various positions.

The weight for a certain respondent was defined as:

$$W_p = \frac{Q_i}{(\sum_{r_i=1}^{r_i} Q_i \times n_i)}$$ (3)

Where $W_p$ represented the weight of one certain respondent. $n_i$ referred to number of respondents with the same profession and position i. $p$ referred to the corresponding respondent.

Secondly, in the evaluation of degree of risk, to utilize the valuable opinions from group B, consider the value of each questionnaire and avoid the influence from extremum, the weighted average after crossing extremum was applied. The extremum was deleted in this work by a 3 $\sigma$ standard deviation method:

$$X_{pjk} = X_{pjk}, \text{ if } X - 3\sigma < X_{pjk} < X + 3\sigma$$ (4)

$$X_{pjk} \rightarrow \text{ignored}, \text{ if } X - 3\sigma > X_{pjk} \text{ or } X_{pjk} > X + 3\sigma$$ (5)

Where $X_{pjk}$ referred to the degree of risk of a certain route (j) with one area (k) marked by a certain respondent (p) in group B. While $\sigma$ represented the standard deviation.

The degree of risk of one transmission route in one area (for instance, the breath route in ICU in infectious hospital) can be express as follow:

$$R_{jk} = \frac{\sum_{p=1}^{n} (W_p \times X_{pjk})}{a}$$ (6)

Where a referred to the total number of transmission routes in considered in one area k (for instance, ICU, impatient, clinic, emergency areas in infectious hospital), which was 5. Integrated degree of risk of one transmission route was determined in the same way as in Eq. (8). After the calculation, the degree of risk in all scenarios were further distributed into 4 levels, high risk, mid-high risk, mid-low risk, low risk, by cluster analysis.

2.3.2. Modeling

The modeling in this work aimed to describe the SARS-COV-2 developing in an urban area and deliver meaningful information to SEERC. The modeling was established and processed on the Simulink platform in MATLAB 2020b. In this model, the whole urban region was distributed into 5 main functional regions, hospital, pollution control, business district, residential area and school/working place, as shown in Fig. 1. The direct target of the model was to describe the increasing of SARS-COV-2 quantity in various functional regions in the urban region. The virus quantity in this work was represented by a dimensionless number, rather than the real gene copies, which was named as "equivalent SARS-COV-2 virus quantity (ESVQ)". Therefore, the virus
quantities showed their meaning during the comparing between different conditions, they were not used for reflecting the real numbers or their trends.

2.3.2.1. Theory. Similar to chemical reactions, the increasing speed of ESVQ depended on the original ESVQ, the transmission kinetic coefficient \( k \), and the amount/density of receptor. Because the degree of risk calculated in this work represented the chances of transmission, the integrated degree of risk in the functional regions involved in this model was used as \( k \) values. Due to the consideration of population density in the scoring of questionnaire, the amount/density of receptor was not included in the main equation in this model, this equation was as shown below:

\[
ESVQ_{n+1} = (k_n + 1) \times ESVQ_n
\]

(9)

Where ESVQ referred to the equivalent SARS-COV-2 virus quantity, with \( k_n \) as the corresponding transmission kinetic coefficient in the functional region “n”. \( t \) was the real time point during the epidemic spreading. The step length in this case is settled as 1 h, therefore, \( t + 1 \) indicated a time point+ 1 h.

2.3.2.2. Determination of \( k_n \) values. The \( k_n \) values were determined by integrating the \( R \) values (degree of risk) to represent large functional regions, including: \( k_1 \), hospital area; \( k_2 \), pollution control system; \( k_3 \), business district; \( k_4 \), residential area and \( k_5 \), school/working. The determination of \( k_n \) (Eq. 10) followed the similar method as in Eq. (8).

\[
k_n = \left( \sum_{m=1}^{n} R_{nm} \right)/x
\]

(10)

Where \( n \) represented the certain functional region, \( x \) was the total number of areas including in this functional region. \( R_{nm} \) referred to the degree of transmission risk in an area which was included in the functional region “n”, with \( m \) as the corresponding sequence.

In this case, to simplify the modeling system, the hospital area \( (k_1) \) was from the combination of infectious and general hospital, the corresponding degree of risk in the specific areas in the two units were involved. Pollution control \( (k_2) \) included areas in both waste transportation and pollution deposit processes, also included the pollution control areas hospital systems. Business district contained businesses from fresh market, supermarket to restaurant and hotels, etc. while in residential area region, the garden, square and residential area were considered. Due to their similarity in terms of crowdfunding and transportation of people, the school/working place was regraded as one functional area, where \( k_5 \) was represented by 1 degree of risk.

Before the utilization, the \( k_n \) were standardized between 0 and 1, as shown follow:

\[
k_{n,s} = k_n/k_{n,max}
\]

(11)

Where \( k_{n,s} \) referred to the standardized \( k_n \), \( k_{n,max} \) was the maximum value among \( k_n \) values.

2.3.2.3. Running of the model. The five functional regions were linked by the transportation of people and matter between each other. The ESVQ appeared and developed in various regions and transported to other regions through the traffic line according to the timing of human activity during day and night. According to the average life expectancy, retirement age, school age (including kid garden) and unemployment rate in 2020 in United State as an example, the average population ratio

\[Fig. 2. The degree of risk in all parts included in this study in the urban region. (a) Infectious hospital; (b) General hospital; (c) Urban district; (d) Pollution control; ICU=ICU/Operation room; Clinic=Clinic/Emergency; Lab=Laboratory room; Imaging=Medical imaging room; Inpatient=Inpatient department; SP=Sewage pipe; WW=Wastewater treatment station; Gar/Garbage=Garbage storage/transportation station; AS=Air conditioning system; Con-object=Contact to object; Con-human=Contact to human; Residence=Residential area; Fre-m=Fresh market; Sup-m=Supermarket; Ref-b=Refuse burning; Ref-t=Refuse transport.)\]
of schooling/working was estimated as 0.70. To further simplify the model, the average time spending in business district was settled as 1 h per day, with the average schooling/working time as 8 h per day. According to the high infection risk (Gola et al., 2020; Tiao et al., 2021) in hospital region, this work assumed one initial infection source in hospital and studied the spreading of virus during outbreak.

After modeling, the ESVQ development in original condition without any epidemic control measures and in other conditions with various measures was compared and analyzed for the establishment of SEERC.

3. Result and discussion

3.1. Degree of risk in detailed scenarios

The degree of SARS-COV-2 transmission risk in all 140 scenarios was displayed in Fig. 2, with the degree value classified into 4 levels, high risk, mid-high risk, mid-low risk and low risk. The highest degree of risk of breath route in ICU in infectious hospital was regarded as “1”, providing a reference for the comparison of the degree of risk in various scenarios.

Infection hospital (Fig. 2(a)), with large number of confirmed patients and high concentration of infection source, was one of the most risky area during COVID-19 outbreak. Breath route in ICU/operation room, clinic/emergency, laboratory, inpatient department and medical imaging room expressed high risk, higher than other areas and routes (Fig. 2(a)). This was attributed to the long-time exposure in these closed areas with high content of infection sources in the air phase, like droplet, aerosol and other polluted particulate matter, etc.

The degree of risk in general hospital (Fig. (b)) showed similar trend to that of infectious hospital in terms of areas and routes. However, the patients tested COVID-19 positive in general hospitals would be transported to infectious hospitals for further treatment and quarantine. Therefore, the ICU/operation area was ignored from risk assessment in general hospital. For the same reason, Due to lower density of infection source, the danger of area in the breath route like laboratory, inpatient department and clinic in general hospitals was lower than those in infectious hospitals. However, the difference of degree of risk shrank between each scenario here, compared to that of infectious hospitals. Moreover, 85.7% of scenarios in general hospital still retained degree of risk equals to or higher than mid-low level. Therefore, the efficient control of epidemic in general hospital may require broad focus of all routes and areas involved in the system. In general, the high evaluation of the risk in general hospital should be mainly due to the unknown SARS-COV-2 carriers. The transmission may occur when they accepted testing and treatment in clinic or lived in hospital for other reasons. Compared to infectious hospitals, the general hospitals may focus less on testing of virus and personal protection.

Besides hospitals, the urban district (Fig. 2(c)) retained as another risky area for the outbreak of epidemics. This is due to the high concentration of population and frequent traffic, activities and contact of people, especially in population centers. Compared to hospitals, lower risk levels were obtained in urban district, with only one scenario determined as high risk. The highest degree of risk was found in breath route in fresh market. This was due to (1) the easy preservation of virus in fresh meat/living creatures and (2) the prior transmission risk of breath route.

The pollution control system (Fig. 2(d)) should also draw attention. This was attributed to the involved environmental medias which can be the virus carrier in this system, like garbage and wastewater. The lower degree of risk evaluated here should be due to the consideration of indirect contact between receptor and the source of infection, where the SARS-COV-2 needed the transmission by environmental medias. For instance, the aerosol created during the waterflow in sewer can be a carrier of SARS-COV-2 and caused infection. Despite the relative lower degrees, risk in pollution control system should be still focused on. This was due to the massive waste transported and treated per day that generated large scale of medias which were able to become SARS-COV-2 carrier. Besides, as necessary system for daily use, the pollution control system can be hardly banned or limited, this required the well protection and disinfection to materials, equipment and staffs involved to limit the epidemic spreading.

3.2. Integrated degree of risk in routes and areas

Integrated degree of risk in various routes and areas was displayed in Fig. 3(a) and (b), respectively. In general, the degree of risk of various transmission routes was in the order of breath-contact to object->contact to human->intake->unknown (Fig. 3(a)). The breath route was determined as prior risk, the direct droplet from infected people and the particular matters carrying SARS-COV-2 would cause wide scale of further infection without the use of personal protective equipment (PPE). The slight higher evaluated degree of risk in contact-to-object route, compared to that of contact-to-human route, may derive from the concern that contact-to-object was more inconspicuous. Moreover, the fast, large-scale and frequent material flow may enhance the transmission risk in this route. Intake route retained risky, the relative lower degree of risk was because the low frequency of eating and drinking in many areas. For instance, in ICU, clinic areas in hospitals, the eating and drinking were less frequent than in residential area and restaurant/hotels. The certain values of degree of risk in the unknown route indicated that the existence of unknown/usual routes were still considered as potential risk by specialists.

In terms of various areas (Fig. 3(b)), areas with severe risk were mostly concentrated in medical district in infectious and general hospitals. This should be due to the closed environment and high concentration of SARS-COV-2 in every phase, which may cause fast and frequent infection. The comparable degree of risk was found in the areas in urban district with intensive population and/or fast population flowing. These led to more chances of contact which lifted the degree of risk. The fresh market should be highlighted as its highest value. In this case, the risk should be corresponding to the preservation of virus in food by in cold-chain transportation. The initial infection may derive from the SARS-COV-2 transmission by the continuous touching the food and touching the face. Breathing in the virus diffused into the air phase.
may represent another possibility. After the initial infection, the human- to-human route can also take place. The lower degree of risk in pollution control areas should derive from the consideration of indirect contact and limited number of staffs involved in pollution control system compared to the whole population. However, waste was also regarded as significant carrier with high quantity and manifold sources. The risk from pollution control system should also draw attention.

3.3. Modeling

The modeling was to investigate the COVID-19 epidemic spreading in the urban region, with equivalent SARS-COV-2 virus quantity (ESVQ) as indicator. The influence of common epidemic controlling measures, like source control, activity limitation, homeworking and mask wearing to the variation of ESVQ was also studied. The ratios of these control measures were defined as below:

1. Source control ratio (S): ranging from 0 to 1, described the ratio of infection sources that was controlled from the beginning, without affecting other people or polluted environmental medias.
2. Activity limitation ratio (A): ranging from 0 to 1. This referred to the ratio of interactive activity that was banned in the residential area. 0 mean no limitation, 1 indicated the absolute banning of

Fig. 4. The ESVQ variation (SARS-CoV-2 spreading) with the time length of 10 days after the first infection source appeared. (a), (b) ESVQ variation in 4 functional regions with no epidemic control measures; (b) ESVQ variation in residential area with source control measure, ratio from 0 to 1; (c) ESVQ variation in residential area with activity limitation measure, ratio from 0 to 1; (d) ESVQ variation in residential area with homeworking measure, ratio from 0 to 1; (e) ESVQ variation in residential area with mask wearing measure, ratio from 0 to 1.)
daily activities like parties, dinners together, shopping and sports in group or in public. 
(3) Homeworking ratio (H): ranging from 0 to 1. This represented the ratio of people switching from working/learning in public places to working/learning from home.
(4) Mask wearing ratio (M): ranging from 0 to 1. This described the percentage of people wearing mask during the interaction with people and public environment.

The quantified efficiency of mask wearing retained as a question for the COVID-19 infection prevention. To avoid overconfident evaluation, here we applied 40% of infection prevention from corresponding risk by mask wearing in the modeling. This was from the reported 40–60% aerosol filtration by cotton mask (Rengasamy et al., 2010). And the higher efficiency of medical mask commonly used can be expected.

The ESVQ variation resulted from the modeling was as shown in Fig. 4, with the time length of 10 days after the first infection source appeared. The condition with no epidemic controlling measures was firstly carried out in Fig. 4(a). The residential area showed the highest ESVQ value, 10.0%, 22.5% and 631% higher than that in business district, school/working places and hospital, respectively. The highest value in residential area was due to its hub-role of population flow. Most people entered, stayed and exited residential area every day. Especially when after work, the population flowing back participated in the dinner, parties, sports and family activities. The ESVQ value in residential can be, therefore, an integrated indicator of the severity of epidemic, which was discussed in Fig. 4(b)-(e) with in the influence of epidemic controlling measures. Notably, with the highest infection kinetic coefficient k1, hospital region contributed less ESVQ than other sources. This was due to its limited scale and involved population.

The ESVQ reduced in the residential area with the intervention of all 4 epidemic control measures (Fig. 4(b)-(e)). The ESVQ reduction of 20.0–100% by source control, 24.1–70.9% by activity limitation, 2.3–9.4% by homeworking and 16.7–57.4% by mask wearing were achieved, with the ratios ranging from 0 to 1. Source control owned the highest performance (Fig. 4(b)), this derived from the direct control of infection source at the beginning, slowing down subsequent spreading by the small-scale smart moves. This highlighted the effectiveness of the idea of source controlling. Therefore, this measure should be considered as one of prior actions during SEERC. Activity limitation and mask wearing expressed remarkable but much lower influence to the epidemic spreading (Fig. 4(c) and (e)). This was because of (1) the other infection sources not included in the residential area and the not-absolute preventing of infection by wearing mask. Moreover, very limited ESVQ reduction was obtained by the single homeworking (Fig. 4(d)). This was due to the infection kinetics in other areas, which were at least comparable or even higher than that in school/working places. Hence, even with homeworking, if the activity of this group of people was not further guided, they would also own the infection risk in other areas, rather than in schooling/working places.

Besides the application of individual measures, the cooperation of them was also focused on, as shown in Fig. 5. This matched the epidemic control policies with combined measures in most of countries/regions. Because of the difficulty for the absolute application of any control measures involved in this work, the maximum ratio of all measures was settled as 0.8 in the discussion. Starting with the single homeworking with a ratio of 0.8 (H0.8), a phenomenal lifting of ESVQ reduction ratio by 383% was achieved when combined with activity limitation in residential area with ratio of only 0.2. The number was also 57.7% higher than that with only activity limitation. This was consistent to the discussion in the last paragraph, homeworking policy need the assistance of activity limitation to maximize its efficiency. The synergistic effect of the two measures would contribute significantly to the epidemic control. A notable but not remarkable improvement was achieved when mask wearing was added (purple part). Mask wearing is, of course, one of the most efficient way to avoid COVID-19 infection. However, the limitation of activity and homeworking policy lightened its burden in the epidemic control.

Another combination of source control and mask wearing was also interesting to study, as shown in yellow and blue part of Fig. 5. This was due to the similar idea of source controlling in both measures. Besides source control, mask wearing also aimed to directly limited the transmission from infection source and lower the transmission kinetics. With medium ratio of 0.6 for both measures, the performance was already comparable to the combination of activity limitation, homeworking and mask wearing with high ratios of 0.8. This highlighted the importance of infection sources controlling. The maximum performance of source control-mask wearing combination reached 90.0%, slightly lower than 95.6% with all measures functioned together with maximum ratios.

3.4. Discussion

The risk assessment of SARS-CoV-2 transmission was completed in various routes and areas. In terms of transmission routes, the risk was in the order of breath—contact to object—contact to human—intake—unknown. On the other hand, when comes to various areas in hospital, the degree of risk decreased from the “upstream” ICU/operation room to the “downstream” like sewer and water treatment plants. In urban area, the more population intensive areas with more closed environment showed significant higher risk than the less concentrated areas with opener space. The mechanisms of these difference included the intensity of risk source, the concentration of population, the contact time, the time flow and material flow. For instance, the priority of ICU/operation room was due to the long time contact with patients in a narrow and closed space for a long time. This indicated a high intensity of risk source from the short distance between medical staffs and the patients as well as the accumulated risk source on the human body, materials and in the air. Besides, the operation length and frequency also prolong the contact time. Whereas, the “downstream” sewer and water treatment plants showed a safer condition. In the time flow, with a longer time from the generation of risk sources, less ratio of active virus retained. Simultaneously, the virus-containing materials were diffused and diluted during the material flow, leading to less transmission risk in per space per time range compared to the “upstream” areas.

According to the information obtained from statistical analysis and modeling, the suggestion to SEERC should be further discussed and analyzed, the results was in Fig. 6. This was discussed according to the epidemic control efficiency and the influence on sustainability. In this case, because that society aspect of sustainability is a relative broad concept which showed difficulty to be quantified, and economic condition is able to partly descrit the social condition, economy would represent the integrated economy/society aspects here.

Source control was determined as the primary task in SEERC, this was due to its high efficiency of epidemic control to slow down the
spreading from the beginning. Moreover, due to the limited scale of work required in the source control, the negative effect of it on economy was not comparable to the large-scale activity limitation or homeworking. The combination of source control and mask wearing was also highlighted. Because of the normal production of facemask has been resumed after the outbreak of COVID-19 epidemic, the price has returned to normal and become affordable again. Besides, the medium ratio of mask wearing and source control already owned comparable performance to the combination of activity limitation, homeworking and mask wearing. Therefore, the importance of the combination of source control and mask wearing was confirmed in the SEERC.

Despite the significant negative influence on economy, the combination of activity limitation and homeworking showed significant contribution to epidemic control, it should be still implemented when necessary. Moreover, supported by the application of smart community and remote communication (Doyle et al., 2021), the negative effect to economy and normal human activities can be decreased. However, the single homeworking was not highly recommended, this was due to the limited contribution to the epidemic control and the apparent high influence on economy. As discussed in Section 3.3, to maximize its performance, cooperating with activity control was necessary. Meanwhile, as the easy application, low cost and considerable epidemic control efficiency of social distance and hand washing, they should be always couple to other measures.

After the discussion of the importance of various measure in the SEERS aspect, three possibly SEERC levels are carried out (Fig. 6). Considering the spreading rate coefficient of SARS-COV-2 as $k_s$, the spreading rate $SR$ can be described as $SR = k_s \times t$. Correspondingly, the reduction rate $RR = k_t \times t$, where $k_t$ referred to the reduction rate coefficient by epidemic control measures. In the first level, $(k_t - k_s)$ should equals to a low stable value which allowed the stepwise increasing of treatment capacity in different countries/regions. Therefore, the number of patients needed treatment retained within the treatment capacity in hospitals. In the second level, $(k_t - k_s)$ retains vibrate around zero, which keeps active infected numbers and integrated infection risk from further growing. This stopped the epidemic from spreading in the large scale, the treatment and epidemic control capacity can be remained in a fixed scale without and significantly reduces the numbers of influenced population. To completely end the epidemic in an urban area, the $(k_t - k_s)$ should be remained as long-term minus value. The active confirmed cases can return to zero with only controllable imported cases. The safety can be remained against COVID-19 epidemic in the national/region level.

The discussion of epidemic control measures and levels for SEERC levels aimed to guide dynamic SEERC planning by decision makers and researchers according to their specific capacity and conditions. In general, the sustainable epidemic control planning guides the balance between the normal functioning in society and the epidemic control. The economic, society and environmental aspects of sustainability were involved. In terms of economy, SEERC (1) guides the efficient utilization of resources within the countries/regions capacity and (2) limits the influence of epidemic spreading to the normal economic chain. Subsequently, a health economy supplies strong power to epidemic controlling work in return. When comes to the society aspect, due to this long-term “battle” against COVID-19, SEERC should aim to retain the relative normal human activity, communication and development with a low level of threaten to human health, which can be controlled and solved. The final goal is to maximize the integrated benefit to life equality, human health, personal and society development during the epidemic period. With the support from healthy economy and society, the SARS-COV-2 as virus and environmental hazardous material can be controlled and treated efficiently in long period.

Finally, it’s necessary to declare that the human life should be ahead of any other issues. The higher level of protection should be always encouraged when it’s possible.

4. Conclusions

With the lab-experiment independent questionnaire survey, statistical and modeling analysis, the transmission risks of SARS-COV-2 as a virus and hazardous material in various routes and areas were efficiently studied for the SEERC in urban area. The quantification of valuable experience from frontline medical staffs offers an alternative significant aspect to investigate the COVID-19 pandemic. In terms of transmission route, the breath route was determined as most risky, followed by contact to object, contact to human, intake and unknown routes. When comes to different areas, the degree of risk decreased from closed environments for patient treatment in hospitals to places with opener environment and less concentrated crowd in urban districts.

In the SEERC point of view, it was suggested source control as the prior measure for epidemic control. The combination of source control &

![Diagram of Epidemic Control Measures](image-url)
masking showed by other studies as high-efficient epidemic control measure. The accompanying policy needs to cooperate with other measures like activity control to maximum its performance. In this case, the big influence to economy showed draw attention. New techniques like smart community and remote communication may provide help to solve the issue. Subsequently, three levels of SEERC were summarized for the SEERC planning. The corrected choice of the suitable measures, their degrees and SEERC levels according to the countries/regions capacity would help to protect the health of human, society, economy and environment. The SARS-CoV-2 transmission as a virus and a hazardous material can be therefore controlled in a long period. However, due to the highest value of people's safety, the combination of all necessary measures with high degree was always recommended.

The SEERC was discussed and studied in this work, however, to further investigate the SEERC and provide more concrete help to local society, the parameters, data and conditions in the specific places should be involved. More effect factors and alternative methods should be involved during the data collection and analysis. This required the further efforts in future studies as well as the cooperation between global researchers.

Overall, the result in this work delivered significant information to researchers and decision makers for the further development of sustainable control for SARS-CoV-2 spreading and COVID-19 epidemic.

CRediT authorship contribution statement

Han Yu: Han Yu contributed significantly to conceptualization, methodology, study plan, experiment (questionnaire survey) design, data analysis and visualization. Besides, Han Yu is the main contributor of manuscript writing. Han Yu was also partly responsible for experiment operation and data collection. Xuying Ye: Xuying Ye significantly contributed to conceptualization, study plan and questionnaire survey arrangement, he also contributed importantly to result analysis and discussion. Minying Zhang: Minying Zhang mainly contributed to conceptualization, study plan and questionnaire survey arrangement. Minying Zhang was also partly responsible for result analysis and discussion. Fenghao Zhang: Fenghao Zhang contributed significantly to data collection and analysis. He also participated in the discussion of study plan and experiment design. Yao Li: Yao Li mainly contributed to the methodology and the design of experiment. She also participate in the data collection and analysis. Suxun Pan: Suxun Pan contributed significantly to methodology, study plan and questionnaire survey arrangement. She also played a key role in research supervision as well as manuscript revising and editing. Yuanning Li: Yuanning Li is the main contributor of data collection and processing. She also contributed significantly to methodology, study plan, data analysis and supervision. Hongbing Yu: Hongbing Yu is the main contributor of conceptualization, he also led and supervise the whole research process from methodology to manuscript writing. Besides, he provide and arrange financial support and necessary resources for study in this work. Chengzhi Lu: Chengzhi Lu contributed significantly to conceptualization, study plan and questionnaire survey arrangement, he also contributed importantly to result analysis and discussion.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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