Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Collection and transportation system construction of potentially viral municipal solid waste during the COVID-19 pandemic in China

Ying Li,⁎, Hairui Hong, Chengshuang Sun, Zijie Geng, Cailin Zhang

⁎ Corresponding author at: School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing 102616, China.
E-mail addresses: lity@bucea.edu.cn (Y. Li), 2108570020033@stu.bucea.edu.cn (H. Hong), suncs@bucea.edu.cn (C. Sun), gengzijie@bucea.edu.cn (Z. Geng), 202004030226@stu.bucea.edu.cn (C. Zhang).

ABSTRACT

The transmission route of COVID-19 through municipal solid waste (MSW) has been confirmed and receives increasing attention. Potentially viral municipal solid waste (PVMSW) refers to the domestic waste generated by risky areas and epidemic-related populations under a major epidemic in their daily lives or in activities that provide services for their daily lives. For its potential infectivity, PVMSW should be properly collected and transported. This study aimed to standardize the collection and transportation of PVMSW and proposed specific construction schemes of PVMSW collection and transportation systems for three situations which were city-wide lockdown status, medium and high-risk area, and home quarantine separately. In the cases of city-wide lockdown status and home quarantine, PVMSW collection and transportation systems were constructed qualitatively with the examples of Wuhan and Shanghai respectively, and in the case of medium and high-risk area, the systems were constructed quantitatively through the development of a waste collection and transportation costs model. To reduce the risks of virus transmission during the collection and transportation process, the collection and transportation links should be minimized. For the disposal of PVMSW, medical waste treatment facilities and MSW incineration plants should be prioritized. Furthermore, the results showed that the total number of people and the transfer capacity of MSW transfer facility were the two main influencing factors for the selection of PVMSW collection and transportation systems in medium and high-risk area. This article could help manage MSW for preventing virus transmission during the COVID-19 pandemic or similar future epidemics.
1. Introduction

Since early 2020, public health and economies around the world have been severely impacted by the COVID-19 pandemic (Patrício Silva et al., 2021). As of June 6, 2022, more than 535,508,709 confirmed cases and approximately 6,320,620 deaths have been reported worldwide (Worldometer, 2022). The COVID-19 pandemic created a global emergency and raised environmental issues such as waste management practices (Hantoko et al., 2021). It has been proposed that the novel human coronaviruses can persist on inanimate surfaces like metal, glass or plastic for up to 9 days and spread through solid waste (Kampf et al., 2020; Mol and Caldas, 2020). Poor management of infectious municipal solid waste (MSW) poses serious risks of disease transmission for waste pickers, waste workers, and the community in general through exposure to infectious agents (Das et al., 2021). It became a challenging endeavor to ensure the waste collection, transportation, and disposal with minimal health and safety risks (Sharma et al., 2020). Potentially viral municipal solid waste (PVMSW) refers to the domestic waste generated by risky areas and epidemic-related populations under a major epidemic in their daily lives or in activities that provide services for their daily lives. Due to the potentially high risks of spreading the virus, the cautious collection and transportation of PVMSW is necessary.

Many countries adjusted the original MSW collection and transportation systems to prevent the spread of COVID-19. Manual sorting and recycling were stopped or limited due to concerns about the spread of the virus (Fan et al., 2021; Yousefi et al., 2021). Italy prohibited infected residents from sorting their waste, waste recycling programs were suspended in some cities of the United States, and legal source separation and recycling programs were paused in Tehran (Zambrano-Monserrat et al., 2020; Zand and Heir, 2020). South Korea required that household wastes generated by asymptomatic people during self-isolation were not be disposed of outside the home until they were confirmed to be negative for COVID-19 (Liang et al., 2021). In the process of waste transportation, transfer links should be minimized and special measures should be taken. In order to minimize further contact of potentially contaminated wastes with other waste surfaces or equipment, Italy recommended that once withdrawn, they must be transported directly to a disposal facility without any pretreatment (Di Maria et al., 2020). In Romania, municipal wastes generated by households with suspected cases of COVID-19 were collected by municipal waste operators and transported directly to landfill (Mihai, 2020). In Iran, national solid waste management guidelines during the COVID-19 pandemic included the use of covered trucks for transport, washing and disinfection of trucks after each working shift, use of covered bins, daily washing and disinfection of all bins and equipment, and daily disinfection of parking (Torkashvand et al., 2021). For contaminated waste treatment, in Italy, incineration (without any pretreatment or selection) as the priority option was recommended, and if no thermochemical waste treatment plant was present in the area, mechanical-biological treatment plant (with no manual selection), MSW landfill (without any pretreatment and reduced waste handling) or sterilization should be considered (Rugazzi et al., 2020). The Portuguese Environmental Agency recommended that all potentially contaminated personal protective equipment used by ordinary citizens should preferably be sent to incineration facilities, or daily landfills (Patrício Silva et al., 2021). In Brazil, waste from the care of people suspected of being infected with COVID-19 should be considered as infectious waste and should not be disposed of in landfills without previous treatment (Penteado and Castro, 2021). At present, countries are only taking emergency measures for the collection and transportation of PVMSW, the specific collection and transportation systems for the three situations of city-wide lockdown status, medium and high-risk areas, and home quarantine are still unclear, and the collection and transportation system of PVMSW has not yet been systematically established.

The research on MSW collection and transportation systems mainly focused on collection and transportation costs, carbon emissions, social impact, etc. (Zhang et al., 2021b). (Hanna et al., 2020) developed a solid waste collection route optimization model to improve collection efficiency, save collection costs and reduce emissions. (Hina et al., 2020) applied vehicle routing problem techniques using geographic information systems to select routes for collection of residential waste to minimize the travel distance, and correspondingly the time and cost of the collection process. (Xin et al., 2021) developed a mathematical planning model with the objective of minimizing the energy consumption of MSW transportation. (Taşkin and Demir, 2020) aimed to investigate the environmental and energy impacts of urban MSW collection and transportation management systems from the life cycle assessment perspective. (Wu et al., 2020) built a model for waste collection and transportation that minimized the total comprehensive costs including routes costs and greenhouse gas emissions costs. (Zhang et al., 2021a) developed a robust optimization model for multi-trip collection and transportation of MSW in an uncertain environment with the objectives of minimizing transportation costs and maximizing resident satisfaction. (Cheng et al., 2021) created an optimization model to maximize the reliability of the solid waste management system by optimizing the distribution of waste treatment demand between facilities. However, although researchers have established solid waste collection and transportation systems through various model methods, in the context of the COVID-19 pandemic, the solid waste collection and transportation system accompanied by COVID-19 has not been established. The construction of a PVMSW collection and transportation system can meet the needs of waste collection and transportation under public health emergencies. In this study, we propose specific construction plans for PVMSW collection and transportation systems under three conditions of city-wide lockdown status, medium and high-risk areas, and home quarantine, and provide targeted recommendations. This study will help to prevent the potential risk of COVID-19 transmission through the MSW collection and transportation process.

2. Materials and methods

The collection and transportation of PVMSW in China was primarily based on the original MSW collection and transportation system, which was divided into three types: direct collection and transportation system, primary transfer system, and secondary transfer system. The direct collection and transportation system is to collect and transport the MSW dispersed at each collection point directly to the MSW disposal site by waste transport vehicles. The primary transfer system is to collect and transport the MSW dispersed at each collection point to the MSW collection stations or small transfer stations, and then transport the MSW from the collection stations or small transfer stations to the MSW disposal site. The secondary transfer system is to firstly collect and transport the MSW dispersed at each collection point to the MSW collection stations or small transfer stations, and then transport the MSW to the large MSW transfer stations for compression, and finally to the MSW disposal site. PVMSW has the risks of virus transmission during the collection and transportation process, thus the collection and transportation links should be minimized. The selection order of PVMSW collection and transportation system is that direct collection and transportation system is prior to primary transfer system, and primary transfer system is prior to secondary transfer system. The secondary transfer system may be selected if and only if the city is in lockdown. For safe transport, vehicles that can be sterilized, trained drivers and waste collectors, and dedicated routes should be considered (Asian Development Bank, 2020). In addition, the novel coronavirus is sensitive to heat and can be effectively inactivated after 30 min at 56 °C (National Health Commission, 2022). PVMSW should be preferentially treated with medical waste treatment facilities or MSW incineration plants for disposal after collection and transportation. For areas without incineration capabilities, PVMSW can also be processed with alternative thermal techniques or sanitary landfill after disinfection (Ilyas et al., 2020; Peng et al., 2020; Su et al., 2021).

In this study, the collection and transportation systems for PVMSW were constructed separately for three situations: city-wide lockdown status, medium and high-risk area, and home quarantine, which may occur in the epidemic outbreak. The schemes of collection and transportation system construction were qualitatively proposed for the two situations of...
3. Results and discussion

3.1. City-wide lockdown status

The first COVID-19 case cluster was reported in Wuhan, China on December 29, 2019 (Xu et al., 2020). The COVID-19 outbreak in Wuhan was a typical public health emergency with characteristics of high contagiousness, rapid spread, and a wide reach (Liu et al., 2021b). There were about 50,333 confirmed cases of COVID-19 reported (Singh et al., 2020). To better control the outbreak, the Chinese government decided to lock down the city and build several temporary and mobile hospitals to provide more beds, better services, and treatment for more COVID-19 patients (Miao et al., 2022). The spread of COVID-19 experienced three periods of outbreak, control, and decline (Liu et al., 2021a). The PVMSW collection and transportation process also experienced transition from secondary transfer system to primary transfer system or direct collection and transportation system.

During the outbreak period, all domestic waste in Wuhan could be considered as PVMSW for various reasons such as short response time, unclear population screening, and lag of acquiring information on the waste generation source. PVMSW would follow the use of previous domestic waste collection and transportation systems. The previous systems included direct collection and transportation system, primary transfer system, and secondary transfer system. The selection order of disposal sites were medical waste treatment facilities, MSW incineration plants, other thermal treatment installations, and sanitary landfill. With the advance of epidemic control measures, the screening of epidemic-related populations was clearer, PVMSW generation sources were point distribution rather than planar distribution, and the amount of PVMSW was reduced. The domestic wastes generated by personnel in central isolation sites, medium and high-risk areas, and home isolation sites were PVMSW. To better prevent the risks of virus transmission during the collection and transportation of PVMSW, the collection and transportation links should be minimized, i.e., the direct collection and transportation system or the primary transfer system should be adopted. The collection and transportation scheme are shown in Fig. 1.

3.2. Medium and high-risk area

3.2.1. Construction concept and data

Medium and high-risk areas have higher risks due to the presence of new confirmed cases or cluster epidemic, etc. Therefore, MSW in medium and high-risk areas can be considered as PVMSW. There are three PVMSW collection and transportation systems available for the medium and high-risk area situation, which are direct collection and transportation system, primary transfer system with MSW collection station, and primary transfer system with MSW transfer station. In this section, MSW incineration plant was adopted as the disposal site of PVMSW. If A, B, C, and D are used to represent MSW collection points, MSW collection stations, MSW transfer stations, and MSW incineration plants respectively, the corresponding symbols for the three scenarios are A–D, A–B–D, and A–C–D. PVMSW collection and transportation costs was adopted as the indicator for PVMSW collection and transportation system selection. The PVMSW collection and transportation costs included energy consumption costs of transport vehicles, labor costs, MSW collection station operation costs, and MSW transfer station operation costs.

The PVMSW collection and transportation process can be divided into road sections A–B, A–C, A–D, etc. The data related to PVMSW collection and transportation costs for different road sections were acquired according to actual investigations and relevant regulations. The energy consumption costs of transport vehicles and the labor costs on different road sections are shown in Tables 1 and 2 respectively. The wages of sanitation workers in large and medium city are taken 4000 CNY/month and in small city are taken 3500 CNY/month, and the daily collection and transportation time is taken 8 h. The transfer capacity of MSW collection station and MSW transfer station was determined to be 10 t/d and 100 t/d. And the operation costs of MSW collection station and MSW transfer station was determined to be 35.64 CNY/t and 38.11 CNY/t separately. The calculation parameters of PVMSW collection and transportation costs on different road sections are summed up in Table 3.
3.2.2. Collection and transportation system construction

We took the amount of PVMSW as the independent variable to calculate the collection and transportation costs of A–D, A–B–D, and A–C–D, and then selected the appropriate PVMSW collection and transportation system. The collection and transportation costs of the three PVMSW collection and transportation systems were assigned respectively the values of 1, 0.6, and 0.5. Three cases were discussed: large and medium-sized cities, small cities, and different design transfer capacities of MSW treatment facilities. It is necessary to be mentioned that the vehicle leaves for the MSW treatment plant with a full load, but since the vehicle returns in empty, there is no labor costs for the return process.

### Table 1
Summary of energy consumption costs of transport vehicles on different road sections.

| City size Road section | Transport distance (km) | Transport distance per trip (t) | Unit distance transportation costs of unit waste (CNY·t^{-1}·km^{-1}) | One-way transportation costs (CNY/time) |
|------------------------|-------------------------|-------------------------------|---------------------------------------------------------------------|--------------------------------------|
| Large and medium       |                         |                               |                                                                     |                                      |
| A–B                    | 0.8                     | 0.2                           | 0.175                                                               | 0.03                                  |
| A–C                    | 9.8                     | 1                             | 1.925                                                               | 18.87                                 |
| A–D                    | 29.8                    | 2                             | 1.925                                                               | 114.73                                |
| B–D                    | 29                      | 2                             | 1.925                                                               | 111.65                                |
| C–D                    | 20                      | 8                             | 0.8                                                                 | 128                                   |
| Small                  |                         |                               |                                                                     |                                        |
| A–B                    | 0.4                     | 0.2                           | 0.175                                                               | 0.014                                 |
| A–C                    | 4.4                     | 1                             | 1.925                                                               | 8.47                                  |
| A–D                    | 16.4                    | 2                             | 1.925                                                               | 63.14                                 |
| B–D                    | 16                      | 2                             | 1.925                                                               | 61.6                                  |
| C–D                    | 12                      | 8                             | 0.8                                                                 | 76.8                                  |

### Table 2
Summary of labor costs on different road sections.

| City size Road section | Transport distance (km) | Speed (km/h) | Collection and transportation time (min/time) | Frequency (times/d) | Labor costs (CNY/time) |
|------------------------|-------------------------|--------------|---------------------------------------------|---------------------|------------------------|
| Large and medium       |                         |              | Transport time | Loading duration | Unloading duration | Maintenance time and rest period | Total |                         |
| A–B                    | 0.8                     | 5–10         | 10            | 10                | 5                   | 15                          | 50    | 9                       | 14.81 |
| B–C                    | 9                       | 30–40        | 20            | 5                  | 10                  | 15                          | 60    | 8                       | 16.67 |
| C–D                    | 20                      | 50–70        | 20            | 5                  | 15                  | 15                          | 75    | 6                       | 22.22 |
| A–C                    | 9.8                     | –            | 25            | 15                 | 10                  | 15                          | 90    | 5                       | 26.67 |
| A–D                    | 29.8                    | –            | 60            | 20                 | 15                  | 15                          | 170   | 2                       | 66.67 |
| B–D                    | 29                      | –            | 35            | 5                  | 15                  | 15                          | 105   | 4                       | 33.33 |
| Small                  |                         |              |               |                    |                     |                              |       |                          |
| A–B                    | 0.4                     | 5–10         | 10            | 5                  | 5                   | 15                          | 45    | 10                      | 12.5  |
| B–C                    | 4                       | 30–40        | 10            | 5                  | 5                   | 15                          | 45    | 10                      | 12.5  |
| C–D                    | 12                      | 50–70        | 15            | 5                  | 10                  | 15                          | 60    | 8                       | 12.5  |
| A–C                    | 4.4                     | –            | 15            | 15                 | 5                   | 15                          | 65    | 7                       | 14.29 |
| A–D                    | 16.4                    | –            | 35            | 20                 | 10                  | 15                          | 115   | 4                       | 25    |
| B–D                    | 16                      | –            | 25            | 5                  | 10                  | 15                          | 80    | 6                       | 16.67 |

### Table 3
Summary of calculation parameters for PVMSW collection and transportation costs on different road sections.

| City size Road section | Transport distance (km) | Loading capacity of transport vehicle (t/d) | Operation costs (CNY/t) | One-way transportation costs (CNY/time) | Labor costs (CNY/time) |
|------------------------|-------------------------|--------------------------------------------|----------------------------|----------------------------------------|------------------------|
| Large and medium       |                         |                                            | –                          | 0.03                                   | 14.81                  |
| A–B                    | 0.8                     | 0.2                                        | –                          | 0.03                                   | 14.81                  |
| A–C                    | 9.8                     | 1                                           | –                          | 18.87                                  | 26.67                  |
| A–D                    | 29.8                    | 2                                           | –                          | 114.73                                 | 66.67                  |
| B–D                    | 29                      | 2                                           | –                          | 111.65                                 | 33.33                  |
| C–D                    | 20                      | 8                                           | –                          | 128                                    | 22.22                  |
| Small                  |                         |                                            | –                          | 0.014                                  | 8.33                   |
| A–B                    | 0.4                     | 0.2                                        | –                          | 0.014                                  | 8.33                   |
| A–C                    | 4.4                     | 1                                           | –                          | 8.47                                   | 14.29                  |
| A–D                    | 16.4                    | 2                                           | –                          | 63.14                                  | 25                     |
| B–D                    | 16                      | 2                                           | –                          | 61.6                                   | 16.67                  |
| C–D                    | 12                      | 8                                           | –                          | 76.8                                   | 12.5                   |
| All                    |                         |                                            | 10                         | 35.64                                  | 356.4                  |
|                         |                         |                                            | 100                        | 38.11                                  | 3811                   |
Take the design transfer capacity of MSW collection station 10 t/d, the design transfer capacity of MSW transfer station 100 t/d, and the amount of PVMSW per person 1 kg/d as an example. It can be known that in medium and high-risk areas of large and medium-sized cities, when the number of people is less than 6000, direct collection and transportation system should be adopted; when the number of people reaches 6000, primary transfer system with MSW collection station should be launched; when the number of people reaches 20,000, primary transfer system with MSW transfer station should be launched.

2) small cities

Same as the case of large and medium-sized cities, the calculation formulas of PVMSW collection and transportation costs for small cities can be obtained as follows:

\[ y_4 = \left[ \frac{x}{2} \right] \times (63.14 \times 2 + 25) \quad (4) \]

\[ y_5 = \left[ \frac{x}{a} \right] \times (0.014 \times 2 + 8.33) + \left[ \frac{x}{10} \right] \times 356.4 + \left[ \frac{x}{2} \right] \times (61.6 \times 2 + 16.67) \times 0.6 \quad (5) \]

\[ y_6 = \left[ \frac{x}{b} \right] \times (8.47 \times 2 + 14.29) + \left[ \frac{x}{10a} \right] \times 3811 + \left[ \frac{x}{b} \right] \times (76.8 \times 2 + 12.5) \times 0.5 \quad (6) \]

In the three formulas, \( y_4, y_5, \) and \( y_6 \) represent the collection and transportation costs of A–D, A–B–D, and A–C–D respectively, and \( x \) represents the amount of PVMSW. The symbol \( \left[ x \right] \) means to be rounded.

Likewise, by integrating the above three equations and using MATLAB software for function image presentation, it could be observed that the intersection points were 8 t/d (take the rst intersection point) and 38 t/d respectively. That is, in medium and high-risk areas of small cities, when the number of people is less than 8000, direct collection and transportation system should be adopted; when the number of people reaches 8000, primary transfer system with MSW collection station should be launched; when the number of people reaches 38,000, primary transfer system with MSW transfer station should be launched.

3) different design transfer capacities of MSW transfer facilities

To measure the impact of different design transfer capacities of MSW transfer facilities (i.e., MSW collection station and MSW transfer station) on the selection of A–D, A–B–D, and A–C–D, three scenarios were created as follows. Take large and medium-sized cities as example for discussion.

Scenario 1: adjust the design transfer capacity of MSW collection station, and other conditions remain unchanged. By adjusting the design transfer capacity of MSW collection station to 8 t/d, 12 t/d, 15 t/d, and 20 t/d, it was observed that the intersection of A–D and A–B–D shifted backward as the design transfer capacity increased, and the intersection of A–B–D and A–C–D did not shift.

Scenario 2: adjust the design transfer capacity of MSW transfer station, and other conditions remain unchanged. By adjusting the design transfer capacity of MSW transfer station to 50 t/d, 150 t/d, 200 t/d, 250 t/d, and 300 t/d, it could be observed that the intersection of A–D and A–B–D basically remained unchanged, and the intersections of A–B–D and A–C–D were 10 t/d, 30 t/d, 40 t/d, 50 t/d, and 60 t/d separately. The relationship between the two is:

\[ a = 0.2b \quad (7) \]

In Eq. (7), \( a \) represents the amount of PVMSW at the intersection of A–B–D and A–C–D, and \( b \) represents the design transfer capacity of MSW transfer station.

Scenario 3: adjust the design transfer capacity of MSW collection station and MSW transfer station, and other conditions remain unchanged. The parameter settings and solution results are shown in Table 4.

It could be found that if the design transfer capacity of MSW collection station and MSW transfer station changes, the selection knots of the three PVMSW collection and transportation systems will also change, and there is roughly a positive correlation between the selection knots and the design transfer capacity of MSW collection station as well as MSW transfer station.

3.3. Home quarantine

To precisely prevent and control the outbreak of Omicron epidemic in 2022, Shanghai divided the city’s areas into three categories which were lockdown zone, control zone, and precaution zone according to the risks level. The residential areas where confirmed cases and asymptomatic cases lived and the surrounding areas with their frequent activities could be divided into lockdown zones. From two days before the cases were confirmed or found positive by nucleic acid detection until they were isolated, if they brought certain risks of transmission to people in their workplaces, activity zones, or other areas, and it was difficult to trace and determine the close contacts and sub-close contacts, the relevant areas would be divided into control zones. The areas apart from the lockdown zones and control zones were all precaution zones.

Home quarantine was present throughout the COVID-19 pandemic and included four scenarios. The domestic waste generated in four scenarios of home quarantine were all considered to be PVMSW. The first scenario was lockdown zone. The management measures of regional closure, without leaving home, and door-to-door service were implemented for high risks. PVMSW in Shanghai’s lockdown zones was collected door-to-door by collectors without contact at specified time and then transported separately and directly to MSW incineration plants, where the relevant workers took strict protective measures and enhanced disinfection during the process. The second scenario was control zone, which required residents not to leave the area and prohibited aggregation for higher risks. The third scenario was that the status of epidemic-related personnel changed from centralized isolation to home...
isolation. The populations included the recovered, close contacts and sub-
close contacts after the reduction of the precautionary level. The fourth
scenario was that there was no epidemic in a city but there were populations
from the medium and high-risk areas of other cities. The PVMSW generation
sites were dispersed and more-or-less. In view of the risks level of the four
scenarios and the characteristics of PVMSW generation, the collection and
transportation scheme are shown in Fig. 3.

4. Conclusions

The COVID-19 pandemic caused profound changes and impacts for the
management of MSW. Compared to other MSW, PVMSW has higher risks of
spreading virus. Therefore, PVMSW should be managed prudently and
properly. This paper studied the collection and transportation process of
PVMSW, and constructed PVMSW collection and transportation systems
for three situations which were city-wide lockdown status, medium and
high-risk area, and home quarantine. The links of PVMSW collection and
transportation systems should be minimized. The direct collection and
transportation system or the primary transfer system should be adopted.
The secondary transit system will only be used when the city is locked
down. It is worth mentioning that, in medium and high-risk area,
PVMSW collection and transportation system can be selected according to
the number of people in the area to minimize the collection and transporta-
tion costs. When the amount of PVMSW is between 0 and 6 t/d, the direct
collection and transportation system should be selected; when the amount
of PVMSW is between 6 and 20 t/d, the primary transfer system should be
selected; when the amount of PVMSW exceeds 20 t/d, the secondary transfer
system should be selected. And there is roughly a positive correlation
between the selection knots and the design transfer capacity of MSW
transfer facility. The results could provide reference for the management
of MSW during the COVID-19 pandemic. In the future, other aspects of
PVMSW such as the disposal of PVMSW can be studied.

CRediT authorship contribution statement

Ying Li: Conceptualization, Methodology, Project administration,
Writing - review & editing, Funding acquisition. Hairui Hong: Methodol-
ogy, Investigation, Data curation, Formal analysis, Writing - original draft.
Chengshuang Sun: Writing - review & editing, Supervision. Zijie Geng:
Writing - review & editing, Supervision. Cailin Zhang: Writing - review
& editing.

Data availability

Data will be made available on request.

Declaration of competing interest

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

Acknowledgments

This research was funded by [R&D Program of Beijing Municipal Educa-
tion Commission] grant number [SZ202110016008].

Table 4
Summary of solution results for different design transfer capacities of MSW transfer
facilities.

| Number | Design transfer capacity of MSW collection station (t/d) | Design transfer capacity of MSW transfer station (t/d) | Intersection of A-D | Intersection of A-B-D and A-C-D |
|--------|---------------------------------------------------------|-----------------------------------------------------|---------------------|-------------------------------|
| 1      | 10                                                      | 100                                                 | 6                   | 20                            |
| 2      | 12                                                      | 100                                                 | 8                   | 20                            |
| 3      | 10                                                      | 200                                                 | 6                   | 40                            |
| 4      | 12                                                      | 200                                                 | 8                   | 38                            |
| 5      | 15                                                      | 200                                                 | 10                  | 38.4                          |
| 6      | 12                                                      | 300                                                 | 8                   | 60                            |
| 7      | 15                                                      | 300                                                 | 10                  | 60                            |

Fig. 3. PVMSW collection and transportation scheme of home quarantine.
Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.157964.

References

Asian Development Bank, 2020. Managing infectious medical waste during the COVID-19 pandemic. https://www.adb.org/publications/managing-medical-waste-covid19. (Accessed 6 June 2022).

Cheng, C., Zhu, R., Thompson, R.G., Zhang, L., 2021. Reliability analysis for multiple-stage solid waste management systems. Waste Manag. 120, 650–658. https://doi.org/10.1016/j.wasman.2020.10.035.

Das, A.K., Islam, M.N., Billah, M.M., Sarker, A., 2021. COVID-19 pandemic and healthcare solid waste management strategy- a mini-review. Sci. Total Environ. 778, 146220. https://doi.org/10.1016/j.scitotenv.2021.146220.

Di Maria, F., Beccaloni, E., Bonadonna, L., Cesi, C., Confalonieri, E., La Rosa, G., et al., 2020. Minimization of spreading of SARS-CoV-2 via household waste produced by subjects affected by COVID-19 or in quarantine. Sci. Total Environ. 743. https://doi.org/10.1016/j.scitotenv.2020.146803.

Fan, Y.V., Jiang, F., Hemal, M., Klemes, J.J., 2021. An update of COVID-19 influence on waste management. Sci. Total Environ. 754, 142014. https://doi.org/10.1016/j.scitotenv.2020.142014.

Hannan, M.A., Begum, R.A., Al-Shehtawi, A.Q., Ker, P.J., Al Mamun, M.A., Hussain, A., et al., 2020. Waste collection route optimisation model for linking cost saving and emission reduction to achieve sustainable development goals. Sustain. Cities Soc. 62. https://doi.org/10.1016/j.scsoc.2020.102939.

Hantoko, D., Li, X., Pariatamby, A., Yoshikawa, K., Horttanainen, M., Yan, M., 2021. Challenges and practices on waste management and disposal during COVID-19 pandemic. J. Environ. Manag. 286, 112140. https://doi.org/10.1016/j.jenvman.2021.112140.

Hina, S.M., Szemerekovsky, J., Lee, E., Amin, M., Arooj, S., 2020. Effective municipal solid waste collection using geospatial information systems for transportation: a case study of two metropolitan cities in Pakistan. Res. Transp. Econ., 84. https://doi.org/10.1016/j.retrec.2020.100950.

Ilyas, S., Sivisattav, R.R., Kim, H., 2020. Disinfection technology and strategies for COVID-19 hospital and bio medical waste management. Sci. Total Environ. 749, 141652. https://doi.org/10.1016/j.scitotenv.2020.141652.

Kampf, G., Todt, D., Pfender, S., Steinmann, E., 2020. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. J. Hosp. Infect. 104, 246–251. https://doi.org/10.1016/j.jhin.2020.01.022.

Li, C., Wang, X., Liu, L., Wang, B., Duan, C., et al., 2020. Spatiotemporal analysis of COVID-19 outbreaks in Wuhan, China. Sci. Total Environ. 115. https://doi.org/10.1016/j.scitotenv.2020.117833-021-1407-5.

Liu, W., Wang, D., Hua, S., Xie, C., Wang, B., Qiu, W., et al., 2021a. Spatiotemporal analysis of COVID-19 outbreaks in Wuhan, China. Sci. Total Environ. 11, 33648. https://doi.org/10.1016/j.scitotenv.2020.117833-021-1407-5.

Liu, Z., Liu, T., Liu, X., Wei, A., Wang, X., Yin, Y., et al., 2021b. Research on optimization of healthcare waste management system based on green governance principle in the COVID-19 pandemic. Int. J. Environ. Res. Public Health 18. https://doi.org/10.3390/ijerph18121127.

Taşkin, A., Demir, N., 2020. Life cycle environmental and energy impact assessment of sustainable urban municipal solid waste collection and transportation strategies. Sustain. Cities Soc. 61. https://doi.org/10.1016/j.scsoc.2020.102539.

Torkabvand, J., Jonidi Jafari, A., Godini, K., Kazemi, Z., Kazemi, Z., Farzadkia, M., 2021. Municipal solid waste management during COVID-19 pandemic: a comparison between the current activities and guidelines. J. Environ. Health Sci. Eng., 1–7. https://doi.org/10.1186/s40201-020-00591-9.

Worldometer, 2022. Reported coronavirus cases. https://www.worldometers.info/coronavirus/. (Accessed 6 February 2022).

Wu, H., Tao, F., Yang, B., 2020. Optimization of vehicle routing for waste collection and transportation. Int. J. Environ. Res. Public Health 17. https://doi.org/10.3390/ijerph17144963.

Xin, C., Wang, L., Liu, B., Yuan, Y.-H., Tsai, S.-H., Huang, C., 2021. An empirical study for green transport scheme of municipal solid waste based on complex data model analysis. Math. Prob. Eng. 2021, 1–17. https://doi.org/10.1155/2021/6614132.

Xu, W., Wu, J., Cao, L., 2020. COVID-19 pandemic in China: context, experience and lessons. Health Policy Technol. 9, 639–648. https://doi.org/10.1186/s13438-020-00309-7.

Yousefi, M., Oskoei, V., Jonidi Jafari, A., Farzadkia, M., Hashem Firouz, M., Abdollahnejad, B., et al., 2021. Municipal solid waste management during COVID-19 pandemic: effects and repercussions. Environ. Sci. Pollut. Res. Int. https://doi.org/10.1007/s11356-021-14214-9.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 pandemic. Int. J. Environ. Res. Public Health 17. https://doi.org/10.3390/ijerph17144963.

Zhang, X., Liu, C., Chen, Y., Zheng, G., Chen, Y., 2021b. Source separation, transportation, and repercussions. Environ. Sci. Pollut. Res. Int. https://doi.org/10.1007/s11356-021-14214-9.

Zhang, X., Liu, C., Chen, Y., Zheng, G., Chen, Y., 2021a. Robust optimization of municipal solid waste management during the SARS-COV-2 outbreak and lockdown ease: lessons from Italy. Sci. Total Environ., 745. https://doi.org/10.1016/j.scitotenv.2020.141159.

Sharma, H.B., Vanapalli, K.R., Cheela, V.S., Ranjan, V.P., Jaglan, A.K., Dubey, B., et al., 2020. Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. Resour. Conserv. Recycl. 162, 105052. https://doi.org/10.1016/j.resconrec.2020.105052.

Singh, N., Tang, Y., Zhang, Z., Zheng, C., 2020. COVID-19 waste management: effective and successful measures in Wuhan, China. Resour. Conserv. Recycl. 163, 105071. https://doi.org/10.1016/j.resconrec.2020.105071.

Su, M., Wang, Q., Li, R., 2021. How to dispose of medical waste caused by COVID-19? A case study of China. Int. J. Environ. Res. Public Health 18. https://doi.org/10.3390/ijerph18221127.

Zhang, S., Zhang, J., Zhao, Z., Xin, C., 2021a. Robust optimization of municipal solid waste management during COVID-19 pandemic. Int. J. Environ. Res. Public Health 17. https://doi.org/10.3390/ijerph17144963.

Zhang, S., Zhang, J., Zhao, Z., Xin, C., 2021b. Robust optimization of municipal solid waste collection and transportation with uncertain waste output: a case study. J. Mater. Cycles Waste Manag., 1–8. https://doi.org/10.1007/s11683-021-00759-3.

Worldometer, 2022. Reported coronavirus cases. https://www.worldometers.info/coronavirus/. (Accessed 6 February 2022).

Y. Li et al. Science of the Total Environment 851 (2022) 157964