# Adaptations of Municipal Solid Waste Management Systems in Response to the Coronavirus Pandemic

**Ana Daniela Pinto, Juyeong Choi, Tarek Abichou, Fehintola Sanusi, and Emilia Aninat**

## 1 Introduction

Pandemics are massive outbreaks of contagious diseases that not only affect public health but also cause significant social, political, economic, and environmental disruptions while disrupting essential services, such as waste management. According to the Solid Waste Association of North America (SWANA), the changes in waste volume and solid waste source result from the issued work-from-home advisories and stay-at-home ordinances [13]. This pandemic has changed our daily routine activities and has led to the shift of waste production trends. Consequently, regional municipal solid waste management systems (MSWMSs) have been facing various challenges in their operations. For instance, the amount and frequency of online shopping have increased drastically due to local business closures, and thus increasing packaging waste volumes such as used cardboard and plastic. Another reason for these changes in waste volume is the excessive stockpiling behavior due to panic buying of long-life food, toilet papers, disinfectant products, and other essential goods [8]. Likewise, the package of online delivery food and takeout has increased since people are spending more time in their residences and cannot dine-in restaurants. This increase in packaging waste affects the municipal waste facilities' capacities and increases the environment's pollution due to plastics and other non-biodegradable materials [16]. Concerns about the transmission of the disease via surface contact have risen, leading to several states like New York and New Hampshire to suspend their single-use plastic bans temporarily [10]. These changes in policies and fear of transmission via surfaces have caused increased plastic waste and changes in consumers' mindset on recycling. Additionally, people's new habits,

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S. Walbridge et al. (eds.), *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, Lecture Notes in Civil Engineering 251,
https://doi.org/10.1007/978-981-19-1029-6_13

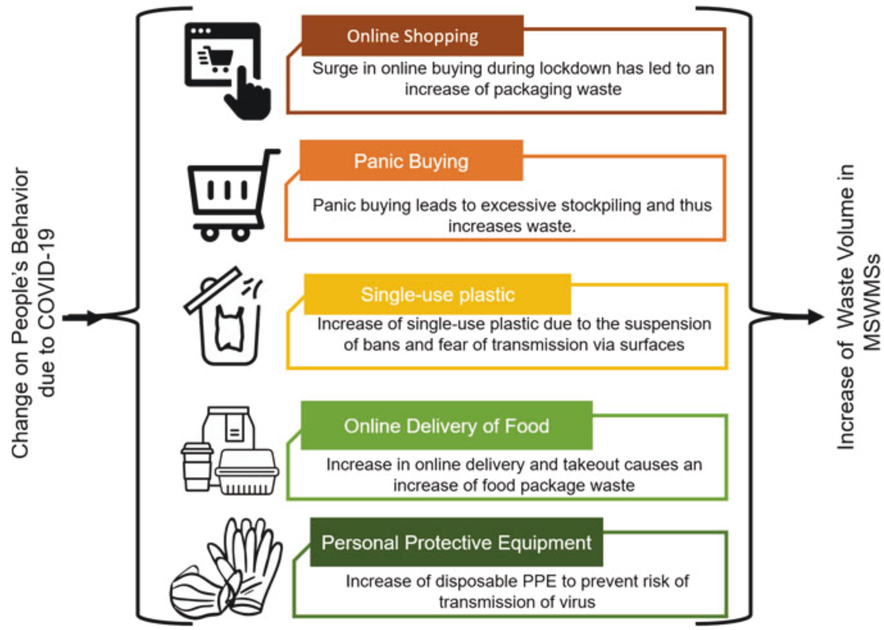


**Fig. 1** Impact of the COVID-19 pandemic in people's behavior leads to changes in waste volume

such as the use of disposable personal protective equipment (masks, face shields, and gloves), have increased the volume of plastic waste [16]. Figure 1 shows, in brief, the repercussions of people's behavioral changes due to the COVID-19 pandemic on municipal solid waste management.

As of March 12, 2021, various responses have been implemented to minimize the spread of the COVID-19 coronavirus and minimize its toll in our society, from the closure of business to lockdowns in order to ensure people's safety. Also, in an effort to mitigate its negative impact, many countries have endeavored to maintain indispensable services essential to the population's welfare during this type of disastrous event. One of these essential services is waste management services; this includes waste collection, treatment, and disposal. MSWMSs play a significant role in protecting communities by minimizing waste contamination and limiting the spread of infectious diseases [5, 15]. MSWMSs not only provide waste services that protect the environment but also safeguard the well-being of the people by reducing the hazardous waste exposure. If such critical infrastructure fails, it would incur serious environmental challenges, health problems, and even economic concerns. Despite the importance of waste management as an essential service, most pandemic-related studies have primarily focused on the pandemic's impact on public health systems. This means that there is limited or lacking details on how pandemics have affected individual MSWMS entities (i.e., landfills, waste incineration facilities, materials recovery facilities, waste transfer station, and waste collection) and how these entities have been implementing adaptive measures in response to pandemic-related challenges. Furthermore, the MSWMS operations changes due to the infection concerns and travel bans have restricted MSWMS's ability to receive external support. This has make MSWMSs rely only on their limited resources to provide waste services.

To address this gap, this research uses a three-phase framework to understand and characterize the adaptation processes of MSWMSs with respect to their challenges during the pandemic. Through this framework, we identified a wide range of waste management and operational challenges along with adaptive measures taken by different MSWMSs in the U.S. Please note that this study reports these challenges and adaptive measures in terms of system structure, urban settings, and other regional factors. The next section presents prior studies on resilience assessment of MSWMS in extreme events such as a flood [3], which lead to the gap in the current best management practices to effectively tackle the challenges emerging during the pandemic. This is followed by the proposed three-phase framework. Lastly, we identified challenges and measures taken by MSWMSs made during the pandemic along with a discussion on their different adaption processes.

## 2 Municipal Solid Waste Management Systems' S Resilience During a Natural Disaster

The operations and design of MSWMSs can be largely affected by natural disasters, such as hurricanes and floods. In preparation for such disruptive events, researchers and government agencies have developed qualitative and quantitative guidelines for regional MSWMSs in advance to guide public agencies on the effective management of the systems [14]. For instance, Beraud et al. [3] used functional analysis to understand the complexity of a theoretical household waste management system and demonstrated its application to guide the preparedness of an existing waste management system for flood events. To ensure that the system remains in operation at an acceptable level of operation even during the disruptive events, this study considered both external (e.g., regulatory authorities) and internal system components [3]. Phonphoton and Pharino [9] employed a system dynamic approach to demonstrate the system connections and changes emerging within waste management operations during flooding situations. To be more specific, this study evaluated a network vulnerability of different MSWMSs (at a district level) to access waste management processes following the disasters. Mamashli and Javadian [7] also demonstrated how the operations of an MSWMS can be adapted in the event of uncertainties characterized by unpredictable extreme events (e.g., in the form of urbanization and changes in waste generation patterns). The authors proposed a municipal solid waste network design to optimize the network efficiency by considering facility locations and the impacts of waste generation on the community. Bavaghar Zaeimi and Abbas Rassafi [2] also proposed a fuzzy chance-constrained optimization model to design the operations of an MSWMS. The authors also claimed that it is important to determine the optimal locations for waste facilities while minimizing the overall system's operational costs in order to remain resilient to urcertain extreme events.

Although some studies have explored issues faced by MSWMSs during natural disasters or other disruptive events, most of these studies are not applicable to the development of strategies for pandemic events since pandemic events differ from natural disasters due to their nature and characteristics. For instance, the primary sources of generated waste during a pandemic are usually affected (e.g., household waste) while in the case of natural disaster, primary sources of waste are due to the impacts on the built environment such as buildings and other civil structures. Also, unlike in natural disasters, MSWMSs experience different sets of physical and social challenges (e.g., change in public policies and people's lifestyle) and operational strains. For instance, during pandemics, it is observed that there can be increased residential waste generation, as opposed to during storms or flooding where there are more other waste categories such as construction and demolition waste generated are from impacts to the built environment. Also, pandemics influence human interaction in the system more than affects the built environment, such as structures, buildings, and roads. Lastly, due to the ephemeral nature of the data generated during the pandemic, there is a lack of adequate information to properly plan for MSWMSs operation during a pandemic, making it difficult to develop best management practices for future pandemics. There is a need to understand and document the pandemic's impact in diverse MSWMSs along with their adaptive processes. To address this gap, this study seeks to promptly identify a broad range of waste management operational challenges during pandemic events and identify various adaptive measures undertaken by different MSWMSs. These results will guide researchers, private businesses, public solid waste agencies and regulators toward creating and implementing resilient waste management initiatives for pandemics.

## 3 A Three-Phase Framework to Characterize Adaptation Processes of Municipal Solid Waste Management Systems During the Pandemic

This research used a three-phase framework to characterize the adaptation process of different MSWMSs in response to their challenges during the COVID-19 pandemic (Fig. 2). The first phase focuses on the development of a baseline structure to capture the important characteristics of each MSWMSs. The second phase emphasises on the data collection process. It explains the process from deciding the target participants to the actual focus group interview. In the third phase, the team uses the developed baseline structure as the reference to understand the adaptation process of MSWMSs in terms of composition, control, and interdependencies.

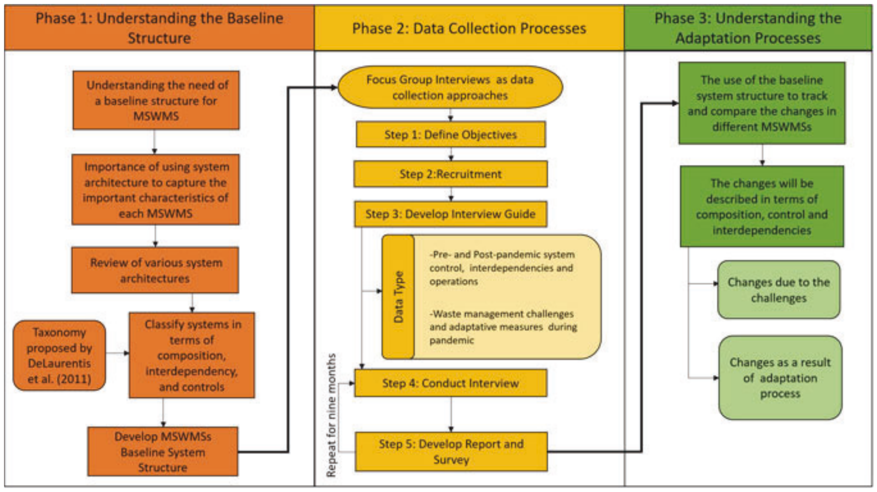


**Fig. 2** Research framework

### *3.1 Phase 1: Understanding the Baseline Structure*

The variations in the structure of MSWMS across different municipalities have made it difficult to observe the unique challenges and adaptive processes; therefore, it is important to use a baseline structure for comparison purposes. With the help of this baseline structure, we will capture important pre-pandemic and in-pandemic characteristics of each MSWMSs in question. In order to understand the system characteristics, this study explores various system classifications. For instance, Maier proposed a taxonomy based on the operational and managerial independence of the system's components [6]. According to Maier [6], characteristics of systems of systems such as geographic distribution and complexity of the components should not be used as classifiers of a system. Shenhar [12] also introduces a taxonomy in which the systems are classified according to four technology levels and three system scope levels. Given that MSWMSs vary from urban to rural settings in terms of entities, relationships, and control, we would use the taxonomy proposed by DeLaurentis et al. [4]. According to the authors, entities represent any physical or nonphysical independent systems. For example, waste collection companies, landfills, local government agencies, and material recovery facilities are independent system entities involved in MSWMSs. Relationships mean how the entities are interrelated and communicate with one another, and control refers to whether entities are granted autonomy or centrally controlled.

We will create our baseline system structure based on the understating of the proposed design variables (entities, interdependencies, and control). As seen in Fig. 3, each box represents all entities that are part of the MSWMS, while arrows represent the relationship between entities, and each color inside the box represents the control of each entity. Such visualization is used as the means to facilitate identifying

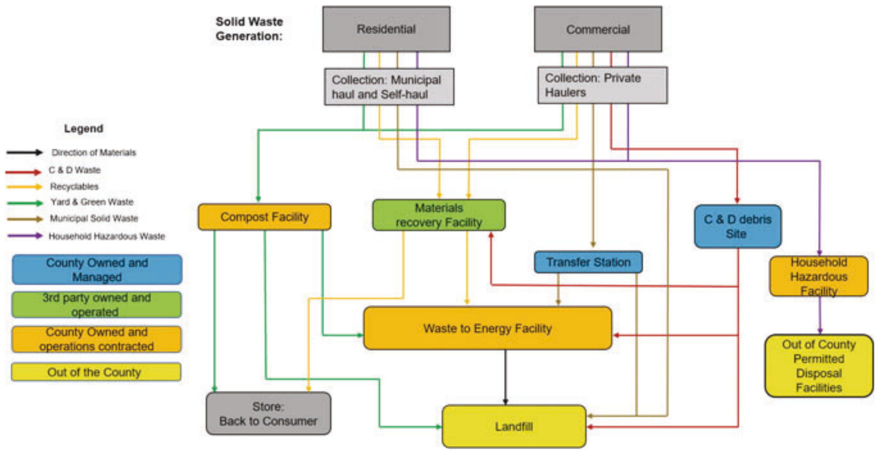


**Fig. 3** Development of the baseline structure

the unique structure of different MSWMSs and detecting any emerging adaptation processes during the course of the pandemic. Furthermore, the development of the baseline structure helped us identify challenges and distinguish entities' emerging behaviors within their systems through comparison with future system structure during the pandemic.

## 3.2 *Phase 2: Data Collection Processes*

After understating the importance of a baseline structure and developing it for each participating MSWMS (Fig. 3), the team started the data collection process. This research used focus group interviews as the data collection approach. The team decided to target U.S. states that were the most impacted such as Florida, New York, and California, to obtain as much insight as possible. As part of the selection process of participating systems, we have selected several MSWMS with varying urbanization levels since the effects of this pandemic and the responses would also vary from urban to rural settings. Since we wanted to understand the adaptation process of the MSWMS, we decided to perform this data collection throught May 2020 until February 2021 via video and audio conference. This timeline would help us understand the evolution of both challenges and adaptive measures. After defining the objectives and target participants, we were able to start the recruitment process. The recruitment of MSWMSs representatives from the areas of interest was conducted through email. Next, the interview guide was developed and provided during the kick-off meeting. During this session, the team explained each meeting's aim and devised the research questions in a sequence manner. By following this guide, the study obtained all necessary information for the research from each meeting and kept us in an hour limit interview. The study met with the participants once every month over nine months to collect as much data as possible. The questions formulated covered all the data types (management challenges, adaptive measures, and pre-and in-pandemic system structure) needed to fulfill the research objectives. Consequently, the study conducted online interviews following the developed interview guide to address the research's main goals. For accuracy purposes, each conducted research interview was digitally recorded and later transcribed into a report. This report would help recall all the interview questions and answers. The team also created a survey spreadsheet that was sent afterward to each participant to confirm our findings. The data collection process was repeated over nine months to capture various impacts on MSWMSs in different municipalities and observe how their responses evolve.

### *3.3 Phase 3: Understanding Adaptation Processes*

MSWMS entities' challenges will change during the pandemic; therefore, their adaptative actions will also evolve over time. As such, it is important to track and understand the adaptive processes of MSWMSs during a pandemic as a time-bound process. Using the system architecture developed in Phase 1, this study captured any changes in the structures of the MSWMSs as a result of entities' measures. Using the proposed system architecture, we have observed and documented system changes in terms of interdependency, composition, and control. For example, local solid waste authorities can loosen up contractual requirements for waste collection service providers by temporarily changing waste pickup policies so that the waste collectors can focus more on collecting residential waste [1]. This is an example of changes in the system control. Another example of a possible change that can be seen using the system architecture is the change waste stream (e.g., an increase in recycling stream and a decrease of household hazardous waste stream) as changes in interdependency because MSWMS would prioritize the waste stream that has increased and thus changed the flow of the materials between facilities to withstand this change in volume. As for changes in composition, this can be seen, for example, if there are any suspension services or facilities' closure as it would mean that the entity would not perform its function.

# 4 Adaptation of Municipal Solid Waste Management Systems During the Pandemic

## 4.1 Challenges and Adaptations of MSWMSs

Although MSWMSs' structure can vary across municipalities, they can also share common functions and operations to provide waste services. After establishing baseline structures of all of the participating MSWMSs, the team was able to find the major challenges that affect the waste management systems and their associated adaptive measures. The study divides these challenges into several categories such as health challenges, business continuity challenges, waste collection, waste landfilling, and recycling challenges. Tables 1 and 2 summarize the causes of the challenges, the challenges themselves, and their related adaptive measure. As seen in these tables, the major challenges were found in the health category.

## 4.2 Unique Adaptation Processes to Different MSWMSs

The structure of different MSWMSs varies across municipalities from urban to rural settings in terms of entities, interdependencies, and control. In other words, no MSWMS is the same in terms of entities, interdependencies, and control across different municipalities. For instance, an MSWMS from Florida is known to have waste incineration facilities; however, an MSWMS in California does not have this type of entity due to its state regulations. Since they do not have the same entities, the treatment of waste would be different, and thus interdependencies would not be the same. The study also found differences in the system structure even within the same state. For example, there are two systems in Florida, System 1 and System 2. Both have solid waste, yard waste, and recyclables streams. System 1 has a transfer station, yard waste site, and landfill that the county owns and manages. It also has a material processing facility and waste incineration facility that is county-owned, but its operations are contracted. In contrast, System 2 does not have a waste incineration facility since its main focus is yard waste and recyclables. Compare to System 1, the landfill and yard waste site is county owns, and operations contracted. The material recovery facility is owned and operated by a private party. Such different natures of the systems often make them take different adaptation processes even in response to the same challenge. For example, we have two MSWMS, one from Florida and the other from California. The Florida system structure's control and composition can be seen in Table 3. It is important to mention that this system's primary means of disposal is the waste incineration facility. Unlike California's system, Florida municipal and private collection services collect both residential and commercial waste jointly. As for the recyclables, this waste stream is self-haul to the recycling drop-off centers of the county. The California system structure's control and composition can also be seen in Table 4. The main difference between these systems is that the California

**Table 1** Major health challenges in the MSWMSs

| Waste management categories | Causes | Challenges | Adaptive measure (changed system characteristics) |
|---|---|---|---|
| Waste collection | Business shutdown | A decrease in commercial waste | • Re-routed the trucks to make them more efficient (entity) |
| | | | • Cutback on overtime on the commercial side (control) |
| | Stay at home ordinances | Increase in residential waste | • Shift resources from the commercial side to residential collection (control and interdependencies) |
| | | | • Increase operating hours, drivers, trucks, and trips (entities and control) |
| Waste recycling | Recycling contamination | Improper disposal of plastics that may expose workers | • A temporary ban on plastics (control) |
| | | | • Enforce inspection of materials and acceptance of certain items only (e.g., soft plastic) (control and entities) |
| | | | • Educational outreach to create awareness on accepted materials (–) |
| Waste landfilling | Increase of waste generated | Large number of customers at landfill | • Customers wait in vehicles while staff unloads (–) |
| | | | • Increase in operational hours to meet high demand (entities and control) |

(–) No relevant characteristics for this adaptive measure

system does not have a waste incineration facility. The reason behind this is that the state of California is reducing the amount of waste incineration to help reduce air pollution [11].

Both systems were impacted with the same challenge, recycling contamination. However, their responses were different due to their composition. Since the Florida system owns a waste-to-energy (WTE) facility and it is their primary means of disposal, the system decides to change the correlation from the recycling drop-off center and material recovery facility to the waste incineration. The contaminated

**Table 2** General waste management challenges affecting MSWMSS and its adaptive measures

| Waste management categories | Causes | Challenges | Adaptive measure (changed system characteristics) |
|---|---|---|---|
| Health challenges | High public demand | Limited PPE | • Produced their own reusable masks (–) |
| | | | • Got supplies from other sources (entities and interdependencies) |
| | Closed area and limited space in facilities | Difficulty in achieving social distancing | • Enforced use of masks and hand sanitizers (control) |
| | | | • Install physical barriers, for example, by canceling face-to-face meetings and by not sharing vehicles (entities) |
| | | | • Rotate shifts for staff working from home and office (control) |
| | | | • Staggered employees start times (control) |
| | | | • A shutdown of common areas (interdependencies) |
| | | | • Suspended cash transactions and enforced online and card transactions (entity and control) |
| | Staff test positive for COVID-19 | Reduce of field operatives | • Cross-training more staff in case someone needs to be isolated (–) |
| | | | • Isolated any staff that was in contact with sick employees (–) |
| | | | • Conducted daily screening activities (–) |

(–) No relevant characteristics for this adaptive measure

recyclables were taken to the WTE facility (Fig. 4). In other words, they temporarily suspend services of the materials recovery facility. While California's system offers mainly recycling and composting services. As an adaption to the recycling contamination, they treated the recyclables at the material recovery facility; however, to avoid workers' exposure, recyclables are left for up to 3 days before sorting (Fig. 5).

**Table 3** Florida system structure's control and composition

| Entities | County owned and managed | County owned but operations contracted | Third-party owned and operated | Out of the county |
|---|---|---|---|---|
| Collection services | ✓ | | ✓ | |
| Recycling drop-off centers | ✓ | | | |
| Material recovery facility | | | ✓ | |
| Waste incineration facility | | ✓ | | |
| Yard waste processing facility | | ✓ | | |
| Household hazardous collection center | ✓ | | | |
| Collection point center | | ✓ | | |
| Landfill | | ✓ | | |

**Table 4** California system structure's control and composition

| Entities | County owned and managed | County owned but operations contracted | Third-party owned and operated | Out of the county |
|---|---|---|---|---|
| Residential collection services | ✓ | | | |
| Commercial collection services | | | ✓ | |
| Material recovery facility | | ✓ | | |
| Compost facility | | ✓ | | |
| Compost processing facility | | ✓ | | |
| Transfer station | | ✓ | | |
| Landfill | | | ✓ | |

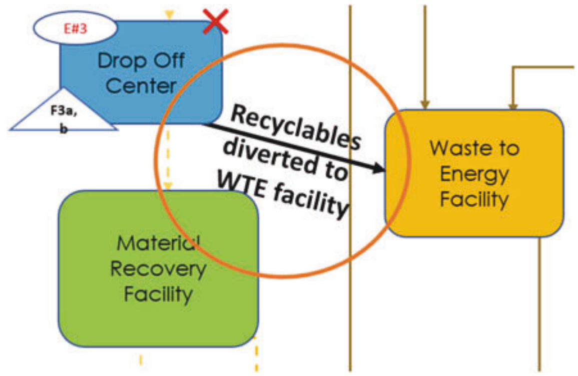


**Fig. 4** Municipal solid waste management system of Florida

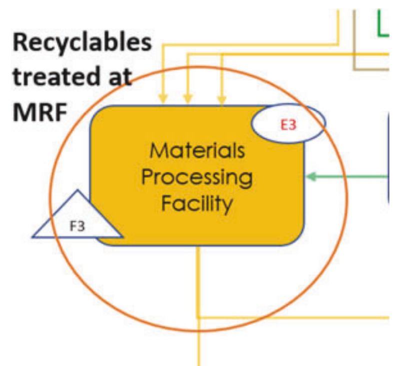


**Fig. 5** Municipal solid waste management system of California

## 5 Discussion and Conclusion

The resilience of waste management systems is an indispensable factor of public safety and sanitation in their corresponding range. After reviewing prior studies on the resilience of municipal solid waste management systems, it seems that it is not possible to apply these findings to the development of strategies for pandemic events since prior studies focus on precedent events such as natural disasters. To address this gap, this study proposed and developed a three-phase framework to understand the adaptation processes of MSWMSs with respect to their challenges during the pandemic. In Phase 1, the team develops the baseline structure and highlights the importance of using system architecture to capture the important characteristics of each MSWMS. Using DeLaurenti's proposed taxonomy of system architectures, we were able to classify systems in terms of composition, interdependency, and controls. The next step was the data collection process. As previously explained, this study used the focus group interview as the primary approach. The data collection frequency was of once every month over nine months. In the last phase, the team used the system architecture adopted in Phase 1 to track and compare changes in different MSWMSs in terms of composition, interdependency, and control. The study learned that the main waste categories that had the most challenges were waste landfilling, waste collection, recycling, and health challenges. This study also found that even though MSWMSs would have the same challenge, they may respond differently depending on their composition, interdependencies, control, or other regional factors. Just as seen previously, the coronavirus pandemic has brought about various emerging challenges that most MSWMSs have never experienced. The collection of knowledge from past disaster events is important to develop resilience strategies for MSWMSs. In addition, understanding the impact of the pandemic in terms of system characteristics will facilitate the development of guidelines more relevant to different MSWMSs for their future preparation. That is, MSWMSs can learn something from the cases of other MSWMSs by referring to their relevant system characteristics.

**Acknowledgements** This study is based upon work supported by the National Science Foundation under Grant Number CBET-2030254. The authors also would like to acknowledge the support from the participating technical assistant group members from all of the interviewed MSWMS. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the view of the National Science Foundation.

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