Critical Success Factors of Sustainable Collection and Transportation in Municipal Solid Waste Management System for Indian Cities: An Analysis using ISM and Fuzzy-MICMAC

Smeetasree Pati
Research Scholar, Department of Management Studies
Indian Institute of Technology, Roorkee, India
spati@bm.iitr.ac.in

Rajat Agrawal
Professor, Department of Management Studies
Indian Institute of Technology, Roorkee, India
rajatfdm@iitr.ac.in

Abstract

In recent years, the continuously growing municipal solid waste (MSW) has been a global concern due to growing urbanization, dynamic changes in the market, and the harmful impact of MSW on the environment. Hence, collecting the generated waste from different sources and transporting it to different disposal options is the beginning of achieving sustainability. To remain an environment-friendly, long-term economically growing and social supportive system, ensuring the integration of sustainability in the collection and transportation (C&T) phase is of particular importance for the municipal solid waste management (MSWM) system. Thus, this paper identifies the critical success factor for sustainable C&T of the MSWM system for Indian cities. These factors are analyzed further to understand the relationship of one another and importance of the successful sustainable C&T through Interpretive Structural Modelling and Fuzzy-MICMAC. The findings will be helpful for decision-makers in making decision on adoption of these factors.

Keywords
Municipal Solid Waste Management System, Sustainable Collection and transportation., Sustainability, Interpretive

1. Introduction
In past decade, the exponentially growing generation of municipal solid waste (MSW) has been a global concern. Moreover, a complete system for handling MSW called Municipal solid waste management (MSWM) system comprises an implementation of several activities starting from collection and transportation, segregation, processing and disposal. It is estimated that in 2031 urban India will generate 450,132 tonnes per day (TPD) of MSW and 120 crores TPD in 2050, as against 147,613 TPD in 2020 due to urbanization (CPHEEO, 2016;CPHEEO, 2017;MoHUA, 2020). India collected 50-80% of its generated MSW (Kaza et al.,2018). In India, 43% of collected MSW is sent to landfills and 23% to treatment(CPCB, 2017) . The collection and transportation (C&T) account for 70% of the total cost based on the fuel price and geographical area. Furthermore, this amount exceeds 80% and 50% in low-income and middle-income countries, respectively. Thus, a minor change in investment will affect the economic and environmental dimensions (Morais et al.,2021). Since C&T of MSW is the first step towards the transformation of waste to valuables, there is a need to make decision carefully. This phase includes picking up waste from generators and transporting it to the transfer station or processing unit. Improper C&T practices tend to open dumping and littering of MSW, causes health risk to human beings and street animals, and impure the land and water, which deviate from the sustainable development goals (SDG) established by United Nations (Messerli et al.,2019). Thus, the integration of sustainability concept with C&T will provide a solution to these issues. A sustainable MSWM system encourages the waste back into the chain to be recycled, reused and reproduced. By visiting the MSWM unit and discussing with the stakeholders, the authors found that the concept of sustainability is far away from the present system. Thus, the current study encourages to find the critical success factors (CSF) for C&T phase of the MSWM system to be sustainable. In addition to CSF selection, efficient techniques are needed to analyze its impact on the system and make effective decision on the adoption of CSF. Past research has implemented several multi-criteria decision-making (MCDM) tools to

analyze factors in different sectors (Bhatnagar et al.,2022, Khofiyah et al.,2021). In this context, the integration of Interpretive Structural Modelling (ISM) and Fuzzy MICMAC analysis has been used to rank identified CSFs, determine the importance of individual CSFs using the fuzzy number and identify the relationship among CSFs (Ahmad et al., 2019; Kumar et al., 2019, Shen at al.,2016; Yih and Lin et al.,2007).
The remainder of this paper is divided into three sections. Section 2g presents the research methodology. The result of analysis is discussed in Section 3. In Section 4, the managerial implication is presented. Finally, Section 5 reports the conclusion and future scope of the study.

2. Research Methodology and Data Collection

To address the above-outlined issues, we conducted a literature review to understand better the current state of sustainability in C&T phase of MSWM system. The literature review started with the keywords (municipal solid waste, municipal solid waste management, collection, transportation, sustainability, waste management) through the databases (web of science, scopus). With the search and restrictions only to include journal articles and conference papers written in English and relevant to the current topic from 2002 to 2022, we obtained 26 relevant papers from the databases. Of these papers, we have chosen 19 factors related to C&T of MSW to be sustainable. The identified factors are again validated by interviewing experts in the area of environmental engineering and experience in the waste management sector. A total of 25 experts are contacted to validate the enablers. However, ten experts responded till the completion of the process. The experts are in the designation of commissioner, professor, team lead, consultant, manager and environmental engineer, having more than 15 years of experience. The experts were requested to add or delete any enabler. This process is repeated till an agreement is reached. The final set of twelve CSFs is presented in Table 1. The interrelationship among CSFs was done using ISM , as shown in section 2.1, and the importance of these on the system was analyzed using Fuzzy MICMAC analysis , as presented in section 2.2.

Table 1.Identified Critical Success Factors for adoption of Sustainability in C&T phase of MSWM system

Code	CSF	Brief Description	Reference
C1	Renewable Energy	Replacing fossil fuel with renewable energy to move towards low carbon economy, climate change mitigation and sustainable system.	Cobo et al., 2018 ; Niziolek et al., 2018 ; Rodrigues et al., 2018 ; Leal et al., 2016
C2	Sustainability Awareness	It acts as a preventive action and a first pillar of minimizing health risk and protecting the environment.	Da Silva Alcantara Fratta et al., 2019; Fuss et al., 2018 ; Wilson et al., 2015
C3	Public-Private Partnership	The increasing amount of MSW generation, budgetary constraints and lack of human resources became limitations for responsible authority. Thus, the Public-private partnership is foremost vital for C&T phase.	Srivastav and Kumar, 2021 ; Batista et al., 2021 ; da Silva et al., 2019
C4	Formalizing Worker	The open dumping and littering of MSW attract scavengers unaware of personal protective equipment and result in skin diseases, respiratory problem , and many more. To avoid the unsustainable system, they should be part of either private or public organizations. In turn, Formalizing workers is foremost essential.	Mohan and Joseph et al., 2021 ; Abu Hajar et al., 2020 ;Ferronato et al., 2019 ; Ibáñez-forés et al., 2019 ; Botello-Álvarez et al., 2018 ;Wilson et al., 2015
C5	Public Pressure	It enhances the implementation of sustainability practices and handling MSW.	Expert opinion
C6	Real-time Information Sharing	It allows interactions among the actors of C&T phase, which helps in decision-making, better services, and smooth functioning.	Jatinkumar shah et al., 2018 ; Hacer and Braida, 2015
C7	Maintenance Practices	Maintenance practices is not only for repairing damaged ones but also improves efficiency of vehicles which reduces transportation costs and carbon emissions.	Ravindra et al., 2015

C8	Flexible Schedule	It allows maximum collection of MSW.	Expert opinion
C9	Infrastructure Development	Road improvements and the essential infrastructure required, such as a collection unit, to eliminate the stated issues.	Ghiani et al., 2021 ; Vanapalli 2021; Mostafayi, 2020 ; Asefi and Lim, 2017
C10	Optimal Resource	The decision on number of vehicles, route to be followed, number of workforces and other related resources required for C&T would be optimum for economic benefit and environmental protection.	Batista et al, 2021 ; Mostafayi, 2020 ; Louati et al., 2019 ; Asefi and Lim, 2017
C11	Training and Education	Educating students regarding MSW impact, reduce littering and training to the workers enhances the service.	da Silva Alcântara Fratta et al., 2019 ; Fuss et al., 2018 ; li et al., 2018 ; Ezeah and Roberts, 2012
C12	Strategies for the uncertainties	Certain uncertainties, such as flood, COVID-19 affect the regular C&T which encourages strategies for the same.	Expert opinion

2.1. Developing ISM hierarchy

The relationship among enablers was established considering the opinion of experts to form a structural self-interaction matrix (SSIM). The relation among pairs is symbolized in the form of V (enabler i influence enabler j), A (enabler j influence enabler i), X (enabler i and j affect both of them), and O (enabler i and j have effect on none of them).

The initial reachability matrix (IRM) shown in Table 2, is developed by replacing symbols in SSIM with binary digits according to the rule given below:

- Convert element(i,j) to 1 if element(i,j) has 'V' or 'X'
- Convert element(j,i) to 1 if element(i,j) has 'A' or 'X'
- Convert element(i,j) and element(j,i) to 0 if elements have any other symbol.

The IRM was tested for transitivity to form Final Reachability Matrix (FRM) as presented in Table 3, where 1* presents the change in relationship among CSF. FRM is used to develop Reachability set (CSF itself along with others which helps to achieve it), antecedent set (CSF itself along with others by which it is achieved) and interaction set (the common CSF among reachability and antecedent set). The CSF having same reachability set and interaction set presents the top level of the ISM hierarchy. The top-level CSF represents the most achieved by others. The CSF found in the previous iteration is removed from other enablers for further iteration. The iteration is repeated till there is no CSF left. The final leveling is represented as ISM and shown in Figure 1.

2.2. Fuzzy MICMAC analysis

The diagonal elements of FRM are replaced to 0 for establishing Binary direct reachability matrix (BDRM). The expert opinion helped to convert BDRM to Fuzzy direct reachability matrix (FDRM) , as shown in Table 4. The experts are given feedback on the fuzzy scale: 1 for very strong, 0.75 for strong, 0.5 for medium, 0.25 for weak, and 0 for no influence for each pair of enablers in BDRM. The final FDRM is developed by considering the average of each pair. The fuzzy MICMAC stabilized matrix is established using max-min fuzzy composition theory, where matrixes are multiplied repeatedly till a stable Driving Power (sum of row values) and Dependence power (sum of column values) are achieved. The max-min fuzzy composition represents that the multiplication of two fuzzy set results in another fuzzy set as shown in Equation

$$S = s(i,j) = max_{u=1}^{v}[min\{m(i,k), n(k,j)\}] \quad i,j = 1,2,3,\dots,n \qquad 1$$

The result of Fuzzy MICMAC analysis portrayed in Figure 2, categorized the CSFs into four clusters as discussed below:

Autonomous CSF- These CSF have low driving and dependence power. These CSF have a low or no impact on the system and can be consider at any point of time.

Dependent CSF - These have high dependence and low driving powers. These are achieved by other CSF and take the position at the top level of hierarchy. Thus, they are applied at the end after implementing others.

Linkage CSF- These have high driving and high dependence power. It affects the whole system if there is a small change as it is sensitive in nature. These are placed at inter-medium level of hierarchy.
Driving CSF- These have high driving and low dependence power. It helps to achieve another CSF. So, these are placed at bottom level of hierarchy and input for the system.

Table 2: Structural Self-Interaction Matrix (SSIM)

	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1
E1	O	O	O	A	A	V	O	O	O	O	O	
E2	O	O	O	O	O	O	O	X	O	V		
E3	X	V	O	O	O	O	O	O	V			
E4	O	V	V	O	V	O	O	O				
E5	V	O	O	O	O	O	O					
E6	V	V	V	O	O	V						
E7	O	A	O	O	V							
E8	O	O	O	V								
E9	O	O	A									
E10	A	V										
E11	O											
E12												

Table 3.Final Reachability Matrix (FRM)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1	0	0	0	0	0	1	1	1	0	0	0
E2	1*	1	1	1*	1	1*	1*	1*	1*	1*	1*	1*
E3	1*	0	1	1	0	1*	1*	1*	1*	1*	1	1
E4	1*	0	0	1	0	1*	1*	1	1*	1	1	0
E5	1*	1	1*	1*	1	1*	1*	1*	1*	1*	1*	1
E6	1*	0	0	0	0	1	1	1*	1*	1	1*	0
E7	1*	0	0	0	0	0	1	1	1*	0	0	0
E8	1	0	0	0	0	0	1*	1	1	0	0	0
E9	1	0	0	0	0	0	1*	1*	1	0	0	0
E10	1*	0	0	0	0	1*	1*	1*	1	1	1	0
E11	1*	0	0	0	0	1	1	1*	1*	1*	1	0
E12	1*	0	1	1*	0	1	1*	1*	1*	1	1*	1

3. Results and Discussions

The present study resulted in twelve CSFs through the literature review and expert opinion. These CSFs are further analyzed using integrated ISM - Fuzzy MICMAC to understand the direct and indirect relationship among CSFs and make decision for the adoption of CSFs in the current system. The result of integrated methodology can be understood by the level, driving and dependence power. From results of Figure 1, it can be observed that Level 5 is developed at the end of leveling and consists of C2 (Sustainability Awareness) and C5 (Public Pressure). Moreover, the implementation of sustainability, the awareness in the society is essential to change public attitude toward MSW. With the promotion of awareness, the authority has to implement policies and regulation to continue operation. The CSFs in Level 5 lead to Level 4, includes C3 (Public-Private Partnership) and C12 (Strategies for the uncertainties).C3 compensate the shortages of fiscal funds in government organization and human resources. Also, developing C12 directs to avoid failure of the current system during uncertainty. In Level 3, C4 (Formalizing workers) improves the societal value of waste pickers, provides better education and economic stability. The CSFs in Level 3, 4 and 5 are the driving enablers except C3 , as shown in Figure 2.

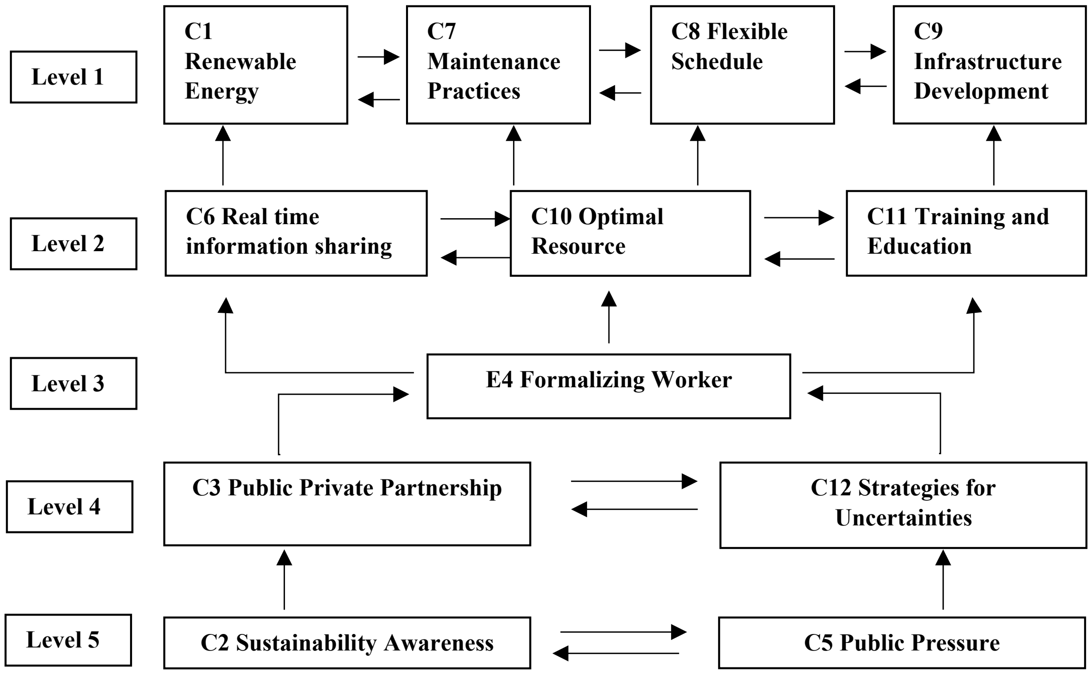

Figure 1: ISM Hierarchy

Table 4. Fuzzy Direct Reachability Matrix (FDRM)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	0	0	0	0	0	0	0.5	0.75	0.75	0	0	0
E2	0.25	0	0.25	0.5	0.75	0.25	0.25	0.25	0.25	0.25	0.5	0.25
E3	0.25	0	0	0.25	0	0.5	0.25	0.25	0.25	0.5	0.25	0.25
E4	0.25	0	0	0	0	0.5	0.75	0.75	0.5	0.75	0.75	0
E5	0.25	0.75	0.75	0.75	0	0.5	0.25	0.25	0.25	0.25	0.25	0.5
E6	0.25	0	0	0	0	0	0.75	0.75	0.75	0.75	0.75	0
E7	0.25	0	0	0	0	0	0	0.25	0.25	0	0	0
E8	0.25	0	0	0	0	0	0.75	0	0.75	0	0	0
E9	0.25	0	0	0	0	0	0.25	0.5	0	0	0	0
E10	0.25	0	0	0	0	0.75	0.75	0.25	0.75	0	0.75	0
E11	0.25	0	0	0	0	0.75	0.5	0.25	0.5	0.75	0	0
E12	0.25	0	0.75	0.75	0	0.75	0.25	0.25	0.25	0.5	0.25	0

However, the dependence power of C2, C4, C5 and C12 are 7.5, 4.5, 6.75 and 5.25, respectively. C4 leads to Level 2 which consists of C6 (Real-time Information Sharing), C10 (Optimal Resource) and C11 (Training and Education). C6 is a connector between the actors involved in C&T as well as helps in deciding the resources required. C10 encourages to use required resources for the system. C11 will always move the system to a sustainable one. These enablers represent the linkage category. C6, C10 and C11 have dependence power 4.75 and driving power 5.75. Then, the top level of the hierarchy is Level 1, which includes C1 (Renewable energy) to compensate the natural fossil fuel, C7 (Maintenance practices) to avoid abruption of the process, C8 (Flexible schedule) to maximize the MSW collection, and C9 (Infrastructure development) to smoothen the process. The top level CSFs are driving enablers except C1, as the outcome of from Fuzzy MICMAC analysis. C7, C8 and C9 have driving power of 7.25. However, C1 and C3 present in the autonomous CSF. India is a developing country and depends on others for energy products, so entirely depending on sustainable energy sources may not be economically sustainable. While public- private partnership is well-accepted in different sectors, very few private organizations are developing currently due to being unaware of MSW.

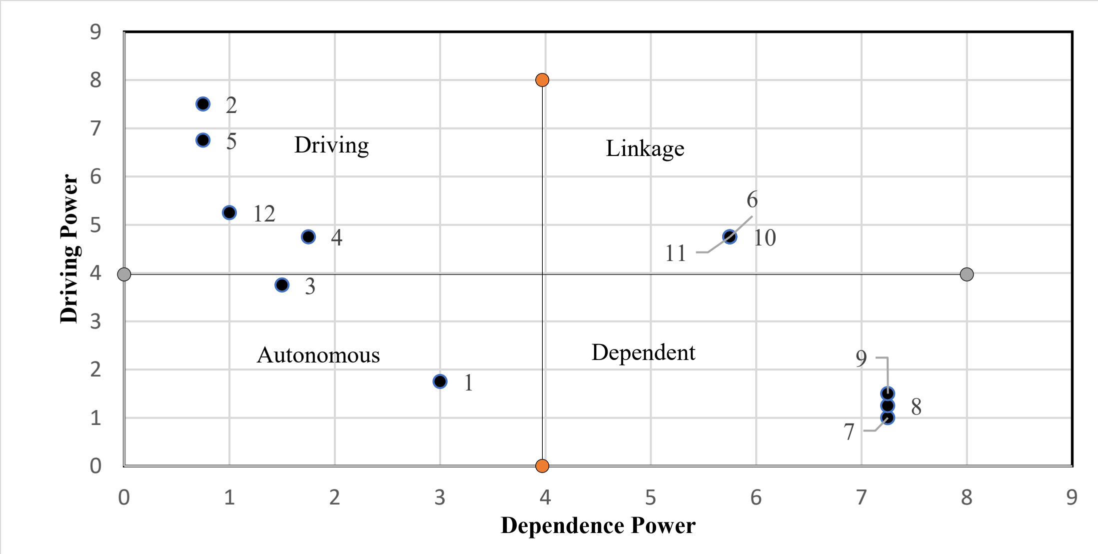

Figure 2:Fuzzy MICMAC Classification

4. Managerial Implication

The current study contributes toward improving the existing knowledge in C&T phase of MSWM system through the ISM model. From the result of ISM hierarchy, the public pressure and sustainability awareness is the most influencing factor for achieving sustainability in the system. However, public pressure, sustainability awareness, strategies for the uncertainties and formalizing worker have high impact on the system's improvement as resulted from Fuzzy MICMAC analysis. It allows the increase in awareness about the CSFs concerning the sustainability adoption in the Indian MSWM system. The identified direct and indirect interconnectedness among CSFs shapes the C&T phase related decisions. Moreover, knowledge on driving and dependence power will help the managers to understand the impact of CSF on system and implementation stage of CSF in Indian MSWM system.

5. Conclusion and Future scope

The initial step of MSWM is the C&T phase, which collect MSW for further processing. To protect environment, reduces the impact to society and economic growth, this study found CSF for sustainable C&T of MSWM system. These CSF were analyzed using ISM to interpret the inter-relationship among enablers and Fuzzy MICMAC to categorize CSF for analyzing its impact on system. Fuzzy-MICMAC analysis depicts the importance of driving and dependence power while making decisions. Moreover, result indicated that the implementation of these CSF would achieve some targets of sustainable development goals in C&T of MSWM system for Indian cities. The result of the study would be helpful for decision-makers to focus on the specific enablers and improvements for the same. Since, the primary input for the used technique is expert opinion, a biased opinion on the topic will affect the output of the system. The number of experts selected for the study is limited and therefore, could not be generalized to other sectors. Thus, identified CSFs can be tested for other sectors and other developing countries. Different mathematical modeling can be done for each CSF improvement. The developed model can be validated using in-depth case study and structural equation modelling.

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Biography

Smeetasree Pati is research scholar**,** Department of Management Studies, Indian Institute of Technology, Roorkee, India. Her research interests include Supply Chain Management, Optimization. She has completed her Master of Technology in Industrial Engineering and Management and Bachelor of Technology in Mechanical Engineering.

Dr. Rajat Agrawal is presently working as Professor, Department of Management Studies, Indian Institute of Technology, Roorkee, India. He has more than 25 years' experience in teaching and research published more than 100 papers in International and National journals and Conferences. His research interests include Operations Management: Supply Chain Management, Quality Management, Inventory Management, Manufacturing Strategy, IPR, Innovation, Business Models, Entrepreneurship: IP Management, General Management: Indian Models of Management, Ethics in Management, Spirituality.