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Household Waste Segregation and Municipal Transport Efficiency: A Scenario-Based Structural Pathway Model for Mumbai

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***Abstract*—Municipal solid-waste collection represents a substantial operational and financial challenge for rapidly growing cities. Source segregation can potentially improve collection efficiency by allowing municipalities to manage different waste streams according to their generation characteristics and storage requirements. This study develops a scenario-based structural pathway model to examine the potential relationship between household source segregation, dry-waste collection frequency, collection-trip reduction and municipal transport-cost implications in Mumbai, India. Using a baseline municipal waste generation of approximately 6,500 tonnes per day and an assumed dry-waste share of 30%, the study estimates dry-waste generation at approximately 1,950 tonnes per day. A collection-frequency scenario is then developed by comparing daily collection with alternate-day, twice-weekly and once-weekly dry-waste collection. Under the once-weekly scenario, collection frequency is reduced by approximately 85.7% relative to daily collection. Using reported annual municipal transport expenditure of ₹883 crore and allocating 30% proportionally to the dry-waste stream, the scenario-allocated dry-waste transport expenditure is ₹264.9 crore. Applying the frequency reduction produces a potential variable transport-cost saving of approximately ₹227.1 crore per year. Sensitivity analysis using dry-waste shares of 25–30% produces potential savings of approximately ₹189.2–₹227.1 crore. These values are scenario estimates rather than observed or guaranteed municipal savings. The study argues that differentiated dry-waste collection should be considered only where source segregation, household storage capacity, separate handling and downstream recovery systems are sufficiently developed. The proposed framework provides a transparent policy benchmark and identifies operational variables that should be measured in future ward-level pilot studies.**

***Index Terms*—municipal solid waste; household waste segregation; dry waste; collection frequency; transport efficiency; scenario analysis; Mumbai; waste management policy.**

I. INTRODUCTION

Rapid urbanization, changing lifestyles, population growth and changing consumption patterns have increased the scale and complexity of household solid-waste management in Indian cities. Municipal solid waste includes a substantial household component, and its management creates environmental, operational and socioeconomic pressures, particularly in dense metropolitan areas. Earlier research has identified source segregation, collection systems, recycling capacity and disposal infrastructure as interconnected components of sustainable solid-waste management (Sharholy et al., 2008; Guerrero et al., 2013; Joshi & Ahmed, 2016).

The challenge is especially important in Mumbai because the city operates a large and resource-intensive waste collection and transportation system within a densely built urban environment. Limited land availability, high population density, pressure on disposal facilities and the continuing presence of mixed waste make waste-stream separation an important operational issue. The Solid Waste Management Rules, 2016 emphasise segregation at source, door-to-door collection, processing of biodegradable waste and scientific management of residual waste (Government of India, 2016).

Source segregation is important not only because it can improve recycling and recovery, but also because it can change the physical and logistical characteristics of municipal collection. Dry recyclable materials can generally be stored for longer periods than wet organic waste. If households consistently separate dry waste and municipal authorities maintain a separate collection stream, the frequency with which dry waste must be collected may potentially be reduced. This creates a possible link between household behaviour and municipal transport efficiency.

The economic dimension of this relationship has received less attention than the behavioural determinants of segregation. Existing studies have examined household recycling behaviour, awareness, attitudes, collection services and life-cycle costs, while city-level studies have considered alternative waste-treatment and disposal systems. However, a transparent framework connecting household segregation with collection frequency and potential transport-cost implications can help urban local bodies assess whether differentiated collection is worthy of operational testing.

The present study therefore develops a Scenario-Based Structural Pathway Model (SSPM) for Mumbai. The model is deliberately distinguished from Structural Equation Modeling (SEM). No household-level covariance matrix, latent-variable measurement model or empirical SEM estimation is claimed. Instead, the study combines secondary municipal parameters and explicit scenario assumptions to represent a logical sequence: policy and institutional intervention → improved source segregation → separate dry-waste stream → differentiated collection frequency → reduced collection trips → potential variable transport-cost saving.

The study addresses four questions. First, how much dry waste would be represented under a 30% dry-waste share of a 6,500-tonne-per-day municipal waste stream? Second, what proportion of scheduled collection trips could theoretically be avoided if dry waste moved from daily to less frequent collection? Third, what potential transport-cost implications arise when reported annual transport expenditure is proportionally allocated to the dry-waste stream? Fourth, how sensitive are these results to variation in the assumed dry-waste share?

The contribution of the study is therefore methodological and policy-oriented. Rather than presenting unsupported statistical path coefficients, the study provides an auditable calculation framework that can subsequently be tested with ward-level operational data. This distinction is particularly important because the financial consequences of collection-frequency changes depend on fixed and variable costs, vehicle utilisation, route characteristics, labour arrangements, contractor payment mechanisms and household compliance.

II. LITERATURE REVIEW

2.1 Household source segregation and waste behaviour

Household source segregation is widely recognised as a foundation of effective solid-waste management. When wet, dry and other waste streams are separated at the point of generation, recyclable materials can be recovered more efficiently and organic waste can be directed toward biological treatment. Guerrero et al. (2013) identified poor segregation, weak institutional capacity and limited recycling infrastructure as persistent challenges in cities in developing countries. Kumar and Agrawal (2020) similarly emphasised the importance of improving collection systems, public awareness and treatment infrastructure in Indian cities.

Household behaviour is influenced by awareness, convenience, social norms, infrastructure and institutional support. Pakpour et al. (2014) demonstrated the relevance of behavioural factors in household waste practices, while Wadehra and Mishra (2018) showed that interventions can influence segregation behaviour in urban India. Rousta and Bolton (2019) further highlighted source sorting as an important stage in resource recovery systems. These studies suggest that policy interventions cannot be separated from the household conditions under which waste is generated, stored and handed over to collection systems.

2.2 Municipal collection, transportation and economic efficiency

Collection and transportation constitute major operational components of municipal waste management. Transport costs include fuel, vehicle operation, maintenance and labour, and the cost structure may contain both fixed and variable components. Life-cycle and economic assessments have shown that the choice of waste-management strategy can materially affect municipal and social costs (Yedla & Parikh, 2001; Sharma & Chandel, 2016, 2021).

In a city such as Mumbai, the interaction between collection frequency and transport requirements is particularly relevant because waste must be moved through a dense urban road network. A reduction in collection frequency can reduce scheduled trips for a particular waste stream, but it does not automatically imply an equivalent reduction in total municipal expenditure. Vehicle ownership, staffing, route scheduling, contractual payments and other fixed commitments may remain unchanged. Consequently, any scenario-based cost estimate must distinguish between potential variable transport savings and total system expenditure.

2.3 Policy and institutional context

The Solid Waste Management Rules, 2016 establish source segregation as an important responsibility within the waste-management system. Municipal implementation also depends on awareness campaigns, collection infrastructure, monitoring and enforcement. The literature suggests that institutional interventions are more likely to produce durable behavioural outcomes when households have convenient facilities and predictable collection arrangements.

The experience of decentralised and participatory waste-management initiatives in other Indian cities has also demonstrated the importance of integrating households, waste workers and local institutions. The relevance of such approaches to Mumbai lies not in directly replicating another city's model, but in recognising that collection efficiency depends on coordination across the waste chain.

2.4 Research gap

Three gaps motivate the present study. First, household segregation research often focuses on behavioural determinants without translating improved segregation into municipal transport implications. Second, economic evaluations frequently compare treatment or disposal alternatives without explicitly modelling the operational pathway between source separation and collection frequency. Third, city-level policy discussions may present potential savings without sufficiently distinguishing scenario assumptions from observed financial outcomes.

The present study addresses these gaps by developing a transparent structural pathway model that links household segregation to differentiated collection frequency and potential transport-cost savings. The model is intentionally scenario-based so that its assumptions can be examined, varied and subsequently tested using operational data.

III. STUDY AREA, DATA SOURCES AND ANALYTICAL APPROACH

3.1 Study area

The analysis focuses on Mumbai and its municipal solid-waste management system under the Municipal Corporation of Greater Mumbai (MCGM/BMC). The original study materials describe the wider Mumbai Metropolitan Region as approximately 6,328 square kilometres and report a population exceeding 26 million. Because the present analysis concerns municipal collection expenditure and city-level waste-generation parameters, the operational unit is treated as Mumbai/MCGM rather than the entire metropolitan region. This distinction avoids conflating the administrative boundaries of the MMR with the municipal waste system.

The original manuscript reports municipal waste generation in the range of approximately 6,000–7,000 tonnes per day and uses 6,500 tonnes per day as the baseline for the scenario calculation. The study also refers to Deonar and Kanjurmarg as important disposal-related facilities and to the financial burden associated with waste transportation.

3.2 Data sources

The scenario model uses parameters already reported in the study materials: approximately 6,500 tonnes of municipal waste per day; an assumed dry-waste share of 30%; and annual municipal transport expenditure of ₹883 crore reported in the cited Praja Foundation/related reporting materials. The waste-composition range in the original manuscript is 25–30% dry waste, with 30% adopted as the baseline scenario.

The model does not use the previously reported SEM coefficients as empirical estimates. In particular, the earlier values $\beta1 = 0.30$, $\beta2 = 0.86$ and $\beta3 = 0.86$, together with reported standard errors, critical ratios and p-values, have been removed from the empirical results because no actual SEM dataset was available to estimate them.

3.3 Scenario-based structural pathway model

The proposed Scenario-Based Structural Pathway Model (SSPM) represents the operational logic connecting policy, household segregation and municipal transport. The model should be interpreted as a policy mechanism rather than a statistical causal model.

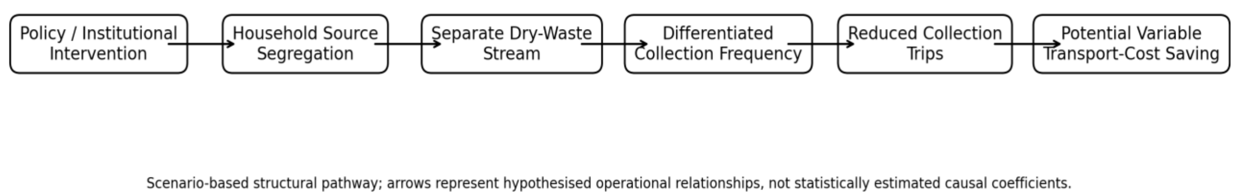

Figure 1. Scenario-Based Structural Pathway Model

The first pathway component is policy and institutional intervention, including source-segregation requirements, awareness, infrastructure and monitoring. The second is household source segregation, which determines whether dry waste remains sufficiently separate for differentiated handling. The third is the availability of a separate dry-waste stream. The fourth is differentiated collection frequency. The fifth is reduction in scheduled collection trips. The final component is potential variable transport-cost saving.

The arrows in Figure 1 are therefore directional assumptions about an operational sequence. They do not indicate estimated regression or SEM coefficients.

IV. MODEL SPECIFICATION AND SCENARIO ASSUMPTIONS

4.1 Estimated dry-waste quantity

Let total municipal solid-waste generation be MSW and the assumed dry-waste share be SDW. Estimated dry-waste generation is:

$DW = MSW \times SDW$

For the baseline scenario:

$DW = 6{,}500 \times 0.30 = 1{,}950$ *tonnes/day*

Thus, the model considers approximately 1,950 tonnes of dry waste per day under the baseline assumption.

4.2 Collection-frequency reduction

Let Fb represent baseline collection frequency and Fs represent scenario collection frequency. With daily collection as the baseline, Fb equals seven collection trips per week. The proportionate reduction in scheduled collection frequency is:

$TR = 1 - (Fs / Fb)$

For once-weekly collection:

$TR = 1 - (1 / 7) = 0.8571 \approx 85.7\%$

The 85.7% value is a mathematical reduction in scheduled frequency. It should not be described as an observed reduction in municipal trips unless operational data confirm that all routes, vehicles and collection arrangements respond proportionally.

4.3 Scenario allocation of transport expenditure

The study uses reported annual transport expenditure of ₹883 crore. For the baseline scenario, 30% is proportionally allocated to dry waste. This is an explicit modelling assumption, not a reported accounting breakdown.

$CDW = CT \times SDW$

$CDW =$ *₹883 crore* $\times 0.30 =$ *₹264.90 crore*

4.4 Potential variable transport-cost saving

If variable transport expenditure is assumed to change proportionally with collection frequency, potential saving can be expressed as:

$PCS = CDW \times TR$

For once-weekly collection:

PCS = ₹264.90 crore × 0.8571 = approximately ₹227.06 crore/year

Accordingly, the baseline model produces a potential annual variable transport-cost saving of approximately ₹227.1 crore. The result is not an observed budget saving and should not be interpreted as a forecast of total municipal expenditure.

4.5 Scenario assumptions

Table 1. Assumptions underlying the scenario model

Model element	Baseline/assumption	Interpretation
Municipal waste generation	6,500 tonnes/day	Baseline parameter used in original study
Dry-waste share	30%	Baseline scenario; original range is 25–30%
Baseline collection frequency	Daily (7/week)	Scenario baseline
Alternative frequencies	Alternate day; twice/week; once/week	Policy scenarios
Annual transport expenditure	₹883 crore	Reported secondary source
Dry-waste expenditure allocation	30% of transport expenditure	Proportional modelling assumption
Variable transport cost	Proportional to collection frequency	Simplifying assumption
Fixed/semi-fixed costs	Not separately modelled	Major source of uncertainty
Actual municipal savings	Not observed	Requires operational and accounting data

V. RESULTS

5.1 Waste-generation scenario

At 6,500 tonnes of municipal waste per day, a 30% dry-waste share produces an estimated 1,950 tonnes of dry waste per day. This quantity provides the basis for considering a separate collection schedule for recyclable and other relatively storable dry materials.

5.2 Collection-frequency scenarios

Table 2. Scenario-based transport-cost implications

Collection frequency	Approx. trips/year	Reduction vs daily	Scenario transport cost (₹ crore)	Potential saving (₹ crore)
Daily	365	0.0%	264.90	0.00
Alternate day	182.5	50.0%	132.45	132.45
Twice/week	104	71.4%	75.69	189.21
Once/week	52	85.7%	37.84	227.06

The table treats ₹264.90 crore as the annual dry-waste transport cost under the proportional allocation assumption. The cost values shown are scenario values after applying the assumed proportional relationship between collection frequency and variable transport cost.

5.3 Potential saving under weekly collection

The once-weekly scenario produces the largest potential saving in the model because one scheduled collection is assumed each week instead of seven. The resulting 85.7% reduction in scheduled frequency corresponds to a potential variable transport-cost saving of approximately ₹227.1 crore per year. This is the upper scenario within the selected collection-frequency alternatives and is not evidence that the municipality could immediately remove 85.7% of its transport budget.

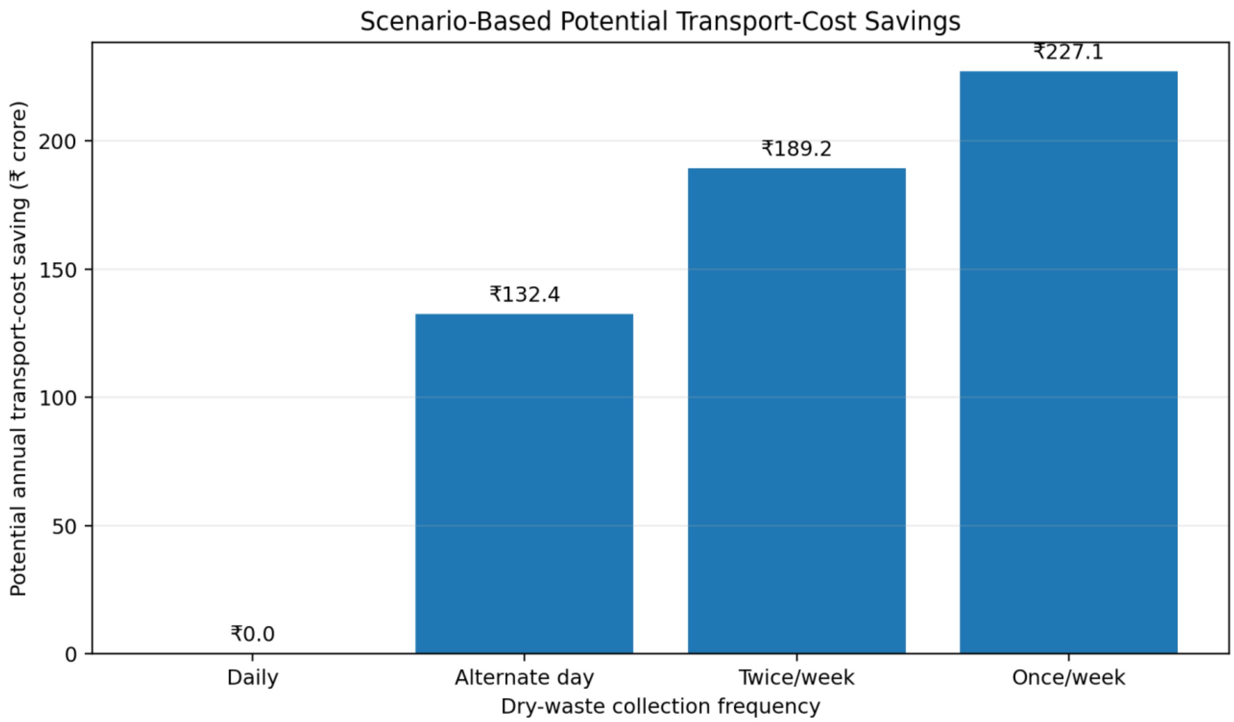

Figure 2. Scenario-based potential annual transport-cost savings under alternative dry-waste collection frequencies

5.4 Sensitivity analysis

Table 3. Sensitivity of weekly-collection saving to dry-waste share

Dry-waste share	Allocated annual transport cost	Weekly frequency reduction	Potential annual saving
25.0%	₹220.75 crore	85.7%	₹189.21 crore
27.5%	₹242.83 crore	85.7%	₹208.14 crore
30.0%	₹264.90 crore	85.7%	₹227.06 crore

The sensitivity analysis indicates that the potential saving changes materially with the assumed dry-waste proportion. At 25% dry waste, the potential saving is approximately ₹189.2 crore; at 27.5%, it is approximately ₹208.1 crore; and at 30%, it is approximately ₹227.1 crore. The direction of the relationship remains positive across the scenarios, but the magnitude is assumption-dependent.

5.5 Interpretation of the pathway

The model suggests that the economic implication of differentiated collection does not arise from policy intervention alone. The pathway requires households to separate dry waste, collection agencies to maintain that separation, and municipal operations to adapt routes and schedules. In this sense, segregation is an enabling condition for differentiated collection rather than a direct financial coefficient.

The model also illustrates why collection frequency should be treated as a policy variable rather than an automatic cost-cutting instrument. If dry waste is not effectively segregated, reducing its collection frequency could increase mixed-waste accumulation, littering, complaints or illegal disposal. Conversely, where segregation is high and dry waste can be safely stored, differentiated collection may reduce scheduled trips and the variable costs associated with those trips.

VI. DISCUSSION

The scenario results support the proposition that household source segregation can be connected to municipal transport planning through a sequence of operational decisions. This provides a useful bridge between behavioural waste-management research and municipal cost analysis. Existing literature has established the importance of segregation, awareness, collection systems and recovery infrastructure, but the present framework makes the operational link explicit.

The estimated ₹227.1 crore annual saving under the weekly scenario is deliberately presented as a potential variable transport-cost saving. Three assumptions drive the estimate: the 30% dry-waste share, the proportional allocation of 30% of transport expenditure to dry waste, and the assumption that variable transport expenditure changes in direct proportion to collection frequency. Each assumption can be challenged and replaced with better operational data.

The second assumption is especially important. Waste quantity does not necessarily determine transport expenditure in a simple one-to-one manner. A truck may be scheduled for a route regardless of the exact quantity collected, and labour or contractor payments may not decline when collection frequency changes. Consequently, the scenario estimate should be interpreted as an upper-bound-style operational benchmark under the specified proportional-cost assumption rather than as a guaranteed fiscal saving.

The third assumption concerns household behaviour. Dry waste may be more storable than wet waste, but storage capacity varies across households and housing types. Dense settlements, small dwellings and households without adequate storage facilities may not be able to hold dry waste for a full week. The feasibility of weekly collection therefore depends on local conditions.

A further issue is the integrity of the collection chain. Household segregation produces economic value only if the separated streams remain separate during collection, transport, transfer and processing. If segregated dry waste is mixed again, the intended recovery and transport benefits may be weakened. Municipal monitoring should therefore include not only collection frequency but also the quality of segregation and downstream handling.

The findings also have an environmental dimension, but this study does not quantify greenhouse-gas emissions or fuel savings directly. Fewer collection trips could potentially reduce fuel use and vehicle-kilometres, while better recovery could reduce pressure on disposal facilities. However, these environmental benefits require measurement and should not be presented as quantified outcomes of the present model.

The proposed approach is particularly suitable for pilot policy design. Instead of immediately introducing weekly dry-waste collection city-wide, MCGM could identify wards or housing clusters with high segregation rates, adequate storage and functioning dry-waste recovery systems. A controlled pilot could then compare operational indicators before and after the intervention.

The conceptual pathway also suggests a practical sequence for evaluation: measure household segregation first; verify that dry waste remains separate; introduce a differentiated collection schedule; record vehicle-kilometres and trips; monitor fuel and labour inputs; assess complaints and cleanliness; and calculate the actual change in variable transport expenditure. This would transform the current scenario model into an empirically testable policy evaluation.

VII. POLICY IMPLICATIONS

7.1 Pilot differentiated dry-waste collection

MCGM should test reduced-frequency dry-waste collection in selected wards rather than applying a city-wide change immediately. Pilot areas should have demonstrably high segregation compliance and adequate storage and recovery infrastructure.

7.2 Link frequency to segregation performance

Collection frequency can be differentiated according to the consistency of household source segregation. Areas with weak segregation should receive behavioural and infrastructure interventions before frequency is reduced.

7.3 Maintain separate collection and recovery

Reduced-frequency collection should be accompanied by separate handling arrangements so that dry waste is not mixed with wet waste after collection.

7.4 Measure actual operational savings

Pilot evaluation should record vehicle-kilometres, number of trips, fuel consumption, labour requirements, maintenance, contractor payments and route changes. These data are necessary to replace scenario estimates with observed savings.

7.5 Protect household cleanliness

Weekly collection should be considered only where household storage capacity and local waste characteristics make longer storage practical. Complaints, littering and illegal dumping should be treated as key monitoring indicators.

7.6 Redeploy released resources

Vehicles and staff whose schedules are reduced could be redeployed to underserved areas, bulk-waste collection, street cleaning or other municipal services rather than simply being removed from the system.

7.7 Strengthen awareness and incentives

Sustained awareness campaigns, clear segregation instructions, adequate bins and appropriate incentives can improve the household participation required for differentiated collection.

7.8 Improve transparency

Ward-level reporting of waste generation, segregation, collection frequency, recovery and transport expenditure would improve accountability and provide the operational data required for future modelling.

VIII. LIMITATIONS AND FUTURE RESEARCH

The first limitation is methodological: the structural pathway is not an empirically estimated SEM. It does not contain latent-variable measurement, model-fit statistics, estimated standard errors or statistically tested mediation. The pathway is a scenario framework derived from theoretical and operational logic.

Second, the model assumes that 30% of municipal transport expenditure can be allocated to dry waste because dry waste is assumed to represent 30% of the waste stream. This proportional allocation may differ from the actual accounting structure of MCGM. Third, the model assumes that variable transport costs change proportionally with collection frequency. Actual costs may contain substantial fixed and semi-fixed components.

Fourth, the model does not estimate the effects of vehicle capacity, route length, traffic congestion, collection density, storage constraints, labour contracts, fuel prices or contractor incentives. These factors may substantially change the realised financial outcome. Fifth, environmental outcomes such as fuel consumption and greenhouse-gas emissions are not directly quantified.

Finally, the analysis is focused on Mumbai and should not be generalised to other cities without recalibration. Differences in waste composition, housing structure, collection systems, road networks, institutional arrangements and municipal accounting can produce very different results.

Future research should use ward-level longitudinal or quasi-experimental data. A suitable dataset should contain collection frequency, number of trips, vehicle-kilometres, fuel consumption, labour inputs, contractor payments, waste quantity, segregation quality, recovery quantity, complaints and household storage conditions. Such data would allow the scenario pathways to be empirically tested and would permit estimation of actual variable and total cost changes.

A future study could also use a genuine SEM framework if household survey data contain multiple indicators for policy/institutional support, segregation behaviour and perceived collection effectiveness. In that case, measurement models, reliability, validity, model-fit statistics, direct and indirect effects and bootstrapped mediation could be reported. The present paper intentionally does not make those claims because an SEM dataset is unavailable.

IX. CONCLUSION

This study develops a Scenario-Based Structural Pathway Model linking household source segregation with differentiated dry-waste collection and potential municipal transport efficiency in Mumbai. The model responds to a practical policy question: whether better segregation could enable a lower collection frequency for dry waste and thereby reduce the variable transport resources required for collection.

Using 6,500 tonnes of municipal waste per day and a 30% dry-waste share, the model estimates approximately 1,950 tonnes of dry waste per day. Moving from daily to weekly collection represents an 85.7% reduction in scheduled dry-waste collection frequency. When 30% of the reported ₹883 crore annual transport expenditure is proportionally allocated to dry waste, the scenario-allocated expenditure is ₹264.9 crore. Applying the frequency reduction produces a potential variable transport-cost saving of approximately ₹227.1 crore per year.

The central finding should be interpreted as a scenario benchmark, not as an observed municipal saving. Sensitivity analysis shows potential weekly-collection savings of approximately ₹189.2–₹227.1 crore when the dry-waste share varies from 25% to 30%. The magnitude depends strongly on assumptions concerning waste composition and the relationship between collection frequency and variable transport expenditure.

The policy implication is that differentiated dry-waste collection should be implemented cautiously and progressively. High source segregation, adequate household storage, separate collection, downstream recovery and operational monitoring are necessary conditions for a successful intervention. A ward-level pilot with transparent performance indicators would provide a more reliable basis for city-wide adoption than a simple administrative reduction in collection frequency.

The study's broader contribution is to demonstrate a transparent pathway from household behaviour to municipal operations and potential economic efficiency without overstating the evidence. Future empirical work using ward-level operational and financial data can test the proposed pathway and determine the actual transport, financial and environmental effects of differentiated dry-waste collection.

X. STATEMENTS AND DECLARATIONS

Ethical Approval

The underlying household research was conducted in accordance with applicable institutional ethical standards.

Consent to Participate

Informed consent was obtained from participants involved in the underlying household research.

Consent for Publication

The authors consent to publication of the manuscript.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship or publication of this article.

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Data Availability

The secondary parameters used in the scenario model are identified in the manuscript. Any underlying household dataset, where applicable, can be made available by the corresponding author on reasonable request, subject to applicable confidentiality and ethical restrictions.

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