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Developing a Dynamic Model for Sustainable Management of Municipal Solid Wastes to Reduce Landfill

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ABSTRACT

Due to the issues present in the urban waste management system in the metropolis of Tehran and the inherent dynamics of the waste management system, it is necessary to use a system dynamic model to examine it. In this study, a system dynamic model was first designed and validated for optimal solid waste management in the Tehran metropolis using the landfill reduction approach based on expert judgment. The statistical population included 45 municipal waste management experts, and the opinions were gathered using a questionnaire, the validity of which was confirmed by experts and the reliability confirmed by Cronbach's alpha. Data analysis was then conducted using heuristic factor analysis and structural equation modeling through the least squares method. Based on the findings, the system dynamic model consists of six distinctive components: technological and managerial (intra-municipality), population, education level, cultivation, citizenship, and economy (external factors). The variance values for each of the above-mentioned components were 0.819, 0.574, 0.990, 1.000, 0.983, and 0.978, respectively. According to the results, these variables could explain a total of 0.683% of the variability associated with waste landfills in Tehran, indicating an appropriate model fit. Concerning the derived effect size, the technological component (F2=90.567) had the highest effect on waste landfill reduction in Tehran. All model paths had t values greater than 1.96, confirming all research hypotheses. The obtained results indicated that the developed dynamic model has a good fit and may be utilized in planning for landfill reduction in Tehran.

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INTRODUCTION

Nowadays, urban waste management has become one of the most significant environmental problems in Iran. According to reports from the Ministry of Interior of Iran, the high rate of urbanization, an increase in population, the growing trend of various types of waste, and the landfilling of more than 75% of collected waste in rural and urban areas have created various environmental problems. On the other hand, leachate generation, greenhouse gas emissions from landfills, and ineffective short- and long-term waste management planning due to the failure to cover all related factors such as waste generation, collection and transfer, processing and disposal, and waste separation at source, have exacerbated environmental issues in Iran (pazoki & Ghasemzadeh, 2020). In addition, schemes and initiatives for source separation of waste at the source have not met their intended goals, and landfilling remains the primary method of waste disposal in Iran. This issue is of great significance to Tehran as the capital of Iran, one of the largest cities in West Asia, and the 21st largest city in the world (Gholampour Arbastan & Gitipour, 2022).

With a population of nine million and an area of approximately 730 square kilometers,

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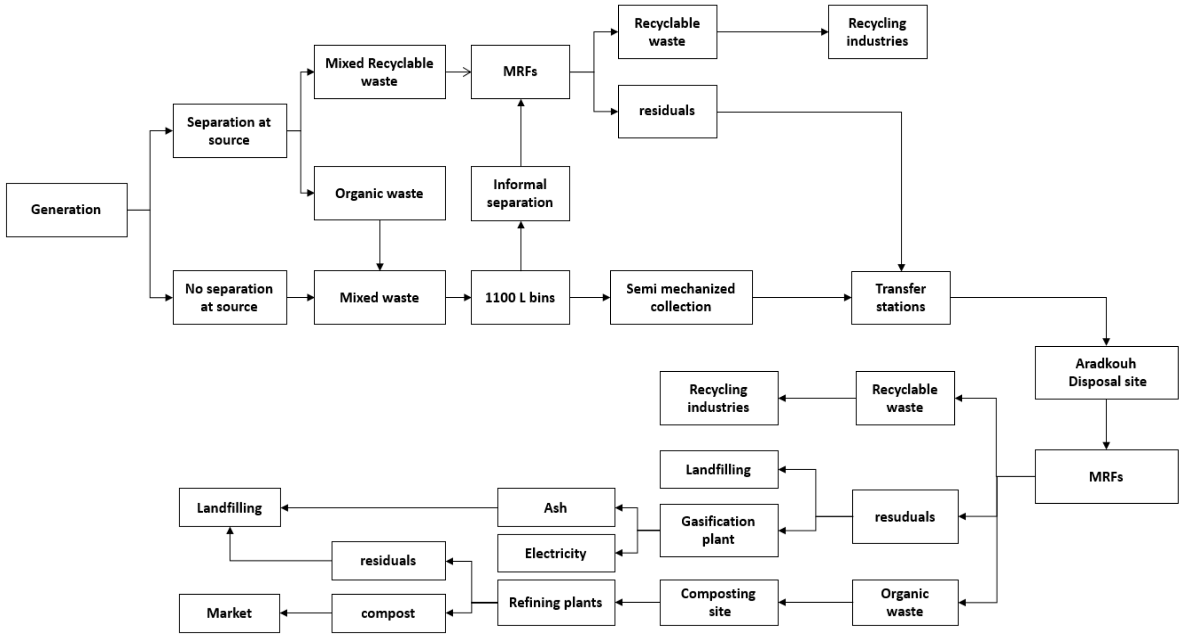

Fig. 1. Waste management process in Tehran (Rupani *et al*., 2019, Islamic City Council of Tehran, 2021)

Tehran contains 22 districts and 123 urban service districts (Gholampour Arbastan & Gitipour, 2022). Fig. 1 illustrates the flow of municipal waste from residential and commercial sources in Tehran. All collected waste from Tehran is transported and processed at the Aradkouh final disposal site, which has served as the city's sole waste disposal location for the past five decades. This site spans an area of 1024 hectares and is situated approximately 23 kilometers southeast of Tehran.

The waste management system in Tehran faces several institutional, technical, economic, environmental, and sociocultural challenges. Institutionally, there is a lack of central planning and specialization, weaknesses in management and outsourcing models, and insufficient integration of monitoring within the waste management cycle. The organization focuses more on execution rather than policy and planning, and there is no mechanism to organize informal agents involved in dry waste management. Technically, there is a need for infrastructure improvements, better personnel training, and capacity building for new technologies. The absence of a central waste data recording system and an integrated system for tracking waste collection routes and times further complicates the situation. Economically, financial transparency and sustainability are major issues, with most funds being spent on waste collection rather than more holistic management strategies (Khosravani *et al*., 2022; Ghasemzadeh *et al*., 2022).

Environmentally, Tehran’s waste management system has a high reliance on landfill usage, which is above the global average, and faces challenges in measuring and monitoring health and safety impacts. The production of dry waste is on the rise, and there are significant adverse health and environmental effects due to inadequate use of protective equipment by garbage collectors. Socioculturally, there is a low level of public participation and awareness in waste management, with a significant informal sector involved in garbage collection, including working children. This lack of social solidarity and efficient citizen participation in waste separation further exacerbates the system’s inefficiencies (Maleki Delarestaghi *et al*., 2018; Khosravani *et al*., 2022).

Previous studies have shown that various factors influence the waste management process (Adeleke *et al*., 2020; Araiza-Aguilar *et al*., 2020). While certain factors fall under the jurisdiction of waste management executives (municipalities) and are subject to modification, others, such as macroeconomic variables, lie outside municipal authority and management capabilities. For instance, Moradikia *et al*. (2021) revealed that macro variables such as the price index of consumer goods and services, the exchange rate of the US dollar (declared by the Iran Central bank), as well as the exchange rate of the Euro (declared by their Iran Central bank) highly affect the generation of waste in Tehran. Thus, the complexity of the interrelationships and internal relationships between macroeconomic factors, populations, and environmental, managerial, and technological variables, are rarely considered in the process of short- and long-term waste management planning in Iran and other countries. This shortcoming has resulted in the development different local decision-making models for optimal and effective planning.

Among the developed models, the system dynamic model (SDM), which considers causal and internal relationships between variables and the delay or unequal effects of parameters over time, is deemed a suitable model for long-term evaluations (Ostadi Jafari & Rasafi, 2012). The SDM was developed in the 1960s as a method of modeling and simulating long-term decision analysis regarding industrial management concerns. In this regard, several studies have examined the use of SDM to improve waste management in Tehran. Ghorbani and Gazeri Neyshaboori (2015) presented a dynamic model for determining the factors affecting hospital waste management in Tehran. In addition, Afshar Kazemi and Eftekhar (2010) described the municipal solid waste (MSW) management system and dynamic modeling methodology and analyzed the results after developing the model in Vensim software under validation tests in Tehran during 2007-2020.

Mirbabayi and Afshar (2011) used Vensim software to simulate waste flow using a systemic approach. Khorasani *et al*. (2010) employed the SDM to project the waste generation rates in the city of Mashhad during 2011-2051 based on the relationship between economic costs, population growth, generation records, and per capita rate change in the number of households. In addition, Ebrahimi *et al*. (2016) used the SDM (Vensim software) and time series method (ARMA technique) to project the amount of waste generated in the city of Isfahan based on data related to waste generation during 1996-2011, demographic data, and other factors. Furthermore, Afshar Kazemi *et al*. (2016) conducted a further study on the dynamic modeling of waste management in Tehran. In another study, Farahani *et al*. (2013) measured the amount of waste produced in Qom city based on several factors such as population growth and migration, income, inflation, consumption pattern, product quality, product packaging, and environmental training for the 2011-2031 period.

Kharazmi and Valipour Erami (2013) used planning based on a system dynamic model and causal loops to provide an effective model in the waste management field in northern Iran, especially Sari city. Pourhosseini and Jalayeri (2014) evaluated the role of solid waste recycling in reducing environmental pollution using the system dynamic approach. Moreover, Tanhaziyari and Sheybani (2017) presented a model for integrated municipal waste management in Bushehr city using SDM, SPSS statistical software, and the SWOT method.

Different studies on the system dynamics of waste management in Tehran and Iran aim to increase waste source segregation. Consequently, the present study seeks to develop a dynamic model for optimal waste management in Tehran based on maximizing Aradkouh landfill reduction. Furthermore, in this study, Partial Least Squares (PLS) and Structural Equation Model (SEM) were used for the first time to evaluate and validate the proposed dynamic waste management model in Tehran. Along with the development of the aforementioned model, this issue can be considered the innovation of this study. The main questions of this study are: how is modeling using PLS and SEM methods conducted to evaluate and validate the dynamic waste management system model in Tehran, and what results will it yield? At the end of this study, the results of these two models are compared. These models, considering the dynamic and comprehensive nature of the waste management system, can help make more optimal and

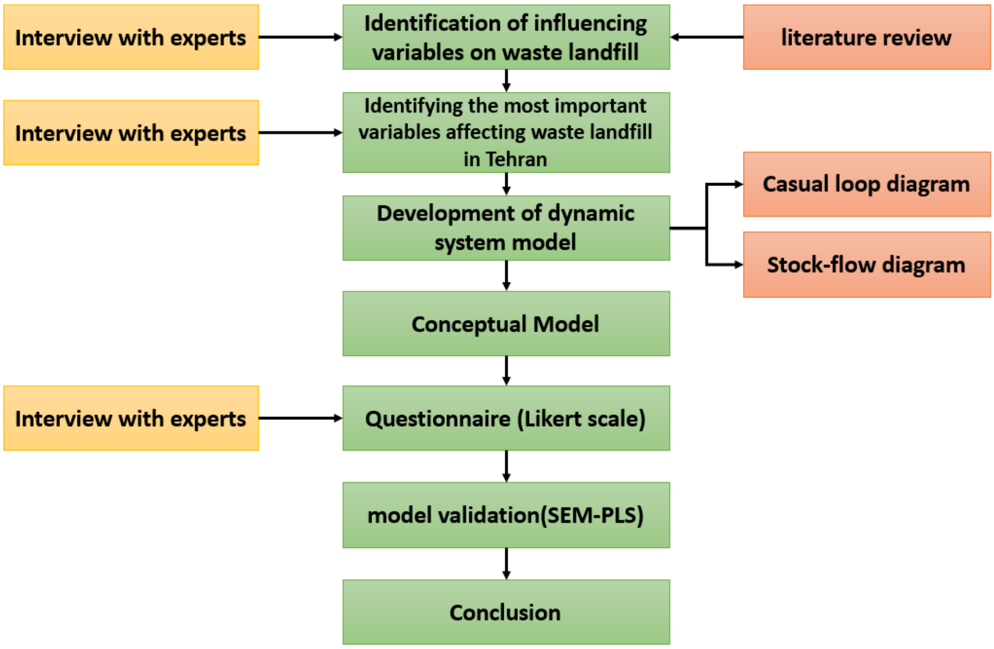

Fig. 2. The algorithm used in this study

engineered choices.

MATERIALS AND METHODS

Fig. 2 illustrates the algorithm used in this research. A set of variables and dimensions related to the problem were first extracted by reviewing the results of previous studies and conducting interviews with a number of experts in municipal waste management. Then, a questionnaire was developed to identify the final variables and their associated dimensions influencing the amount of waste disposed of in Tehran's landfills. In addition, 22 waste management specialists were consulted. The selection criteria for the expert included a minimum of five years of experience in the field of municipal waste management, a master's degree in environment and waste management, work experience at a university as a faculty member in the fields of environmental engineering and environmental health, and those involved in important relevant organizations such as the Department of Environment and Ministry of Interior (DEMI). According to the Cronbach's alpha coefficient, the questionnaire's reliability was satisfactory (r=0.786).

The design and validation of an SDM in order to be used in optimal waste management of Tehran were considered in the study based on landfill reduction approach. A general view is required in any model to understand a system's structure better. This general view in SDM is called the causal loop diagram (CLD) (Ahmadvand *et al*., 2014). To this end, Fig. 3 displays the CLD of the SDM and the relationships between the variables involved in the waste management process in Tehran. The CLD in SDM helps to understand how variables interact nonlinearly in a complex system (Ma *et al*., 2022). The CLD contains variables and arrows interconnected with + and - signs, indicating that the variable at the end of the arrow decreases or increases as the variable at the beginning of the flash increases or decreases (Chaerul *et al*., 2008). For instance, the total amount of municipal waste in Tehran increases (+) with an increase in population, whereas the amount of waste generated per capita in Tehran decreases (-) with an increase in the quality and quantity of public training. Creating a suitable CLD is essential for developing the Stock-Flow Diagram (SFD) in SDM and implementing the model (Sokhulthaman *et al*., 2016).

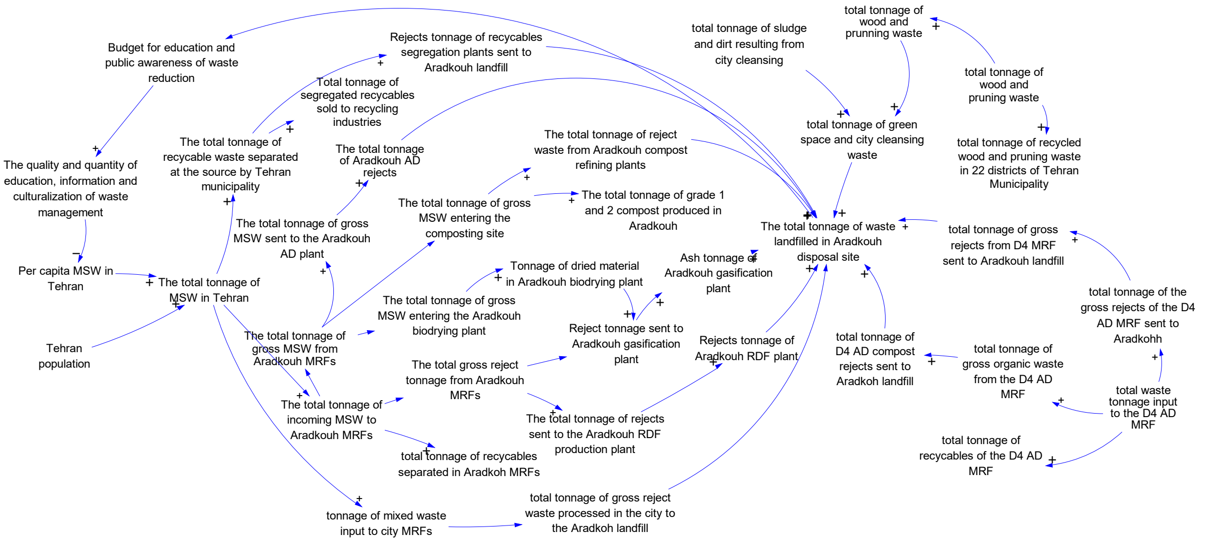

Fig. 3. Causal loop diagram of the dynamic system model in waste management

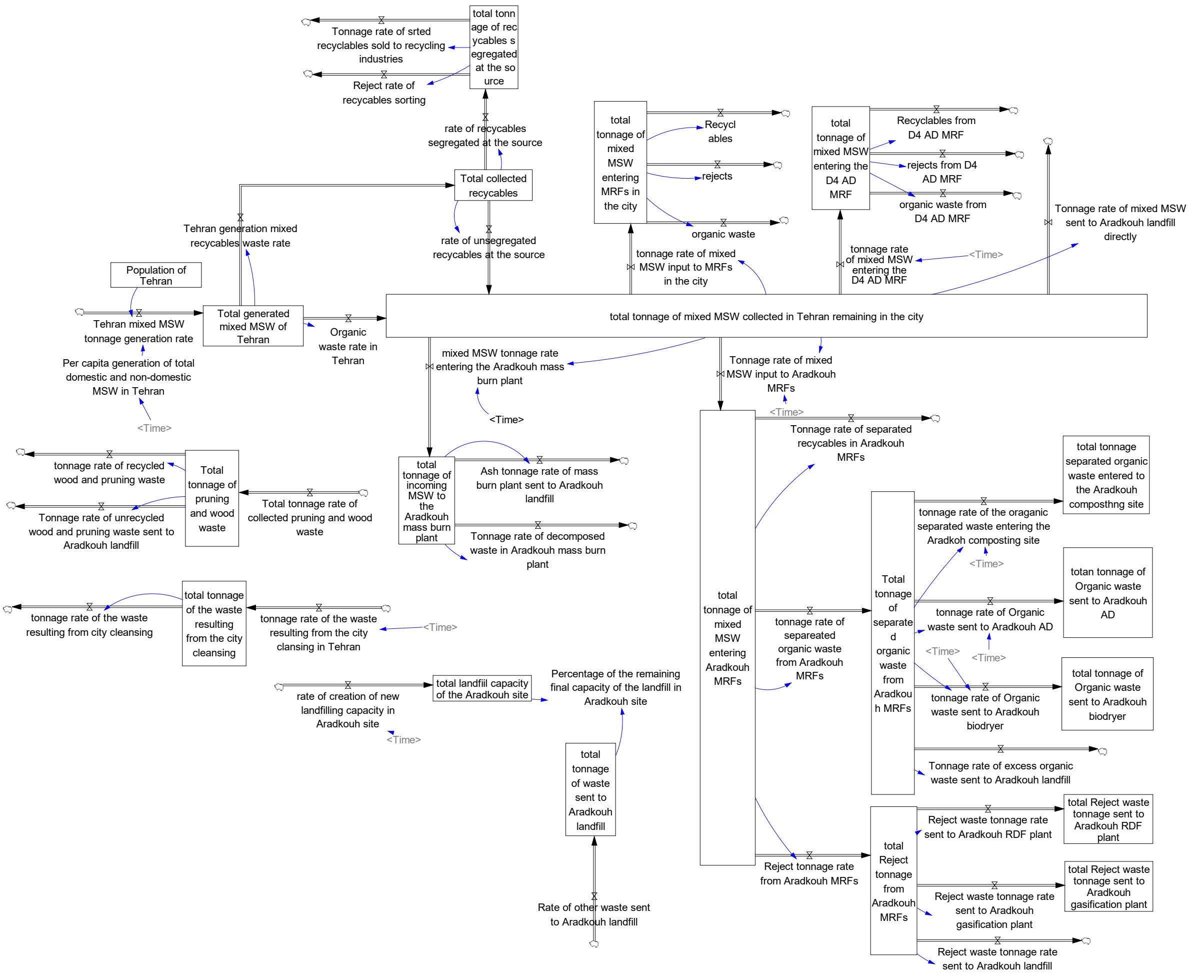

Fig. 4. The stock-flow diagram of system dynamic model

The CLD is a theoretical framework for production analysis and waste management systems (Rafew & Rafizul, 2021).

After improving and confirming the CLD of the dynamic model by experts, the available

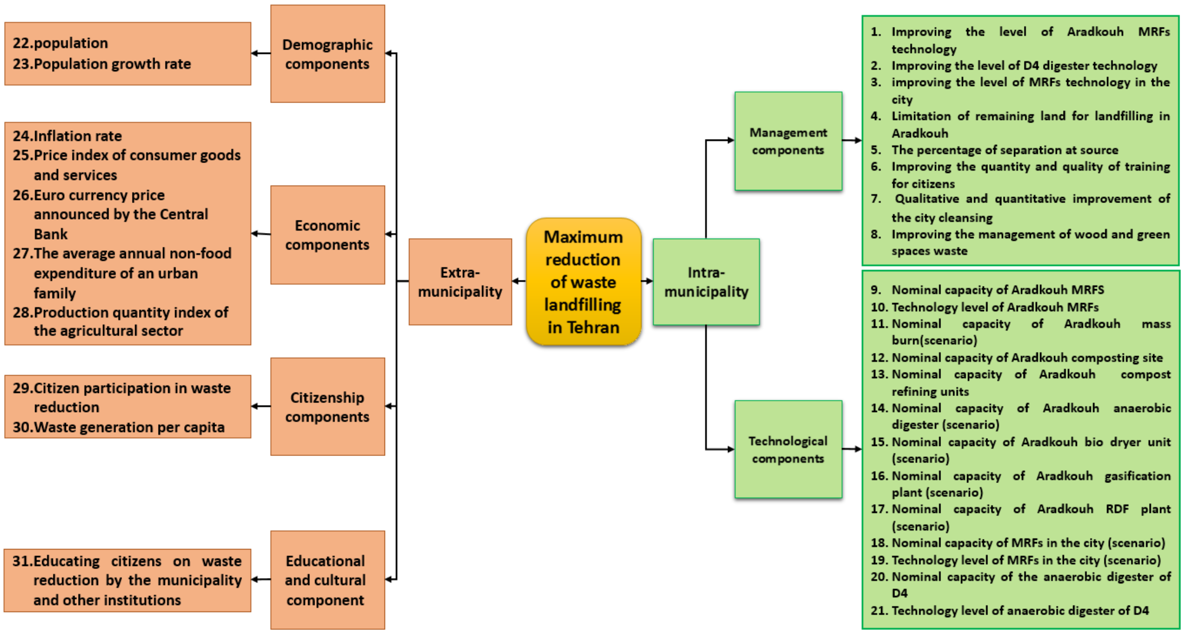

Fig. 5. The conceptual model of the study

historical data of the model variables were collected and a SFD was created for the model. Fig. 4 displays the SFD of the dynamic model of Tehran waste management system considering possible technologies that may be used in the coming years. The SFD obtained using the CLD consists of four main components: stock, flow, converters, and connectors. Indeed, SFD is a quantitative computational model developed by a computer (Ma *et al*., 2022). The CLD and the SFD are simply two different versions of an SDM. The difference is that the former is written with arrows and words and seeks to explain the issue better. The second consists of computer equations and enables numerical simulation of the model and quantitative analysis (Yuan *et al*., 2012).

After preparing SFD, the dynamic model was validated utilizing various tests, including apparent validity, boundary adequacy, and extreme condition tests. The relevant conceptual model was drawn according to the outputs of CLD and SFD which reflects the final opinions of experts and factors influencing the reduction of the waste landfill. Fig. 5 shows the conceptual model of the study. Although the validity of the developed SDM was confirmed using the above-mentioned tests, two methods of SEM and PLS were used for the validation of the conceptual model. To this end, three primary steps were considered for the model's advanced evaluation.

In the second step, a five-option Likert-scale questionnaire was developed and distributed to 45 municipal waste management experts. In the third step, the results were analyzed using the SEM and PLS methods after collecting the experts' completed questionnaires. The greatest advantage of this method over the others is its applicability to small samples and situations where the number of measurement items is small, and the distribution of variables is uncertain (Rashidi *et al*., 2020).

RESULTS AND DISCUSSION

In this study, an SDM of waste management in Tehran was developed and validated using the SEM and PLS techniques. Initially, the Kaiser-Meyer-Olkin (KMO) and Bartlett's tests were used to assess the validity of the data obtained from 45 waste management experts regarding the model's effectiveness for factor analysis. The KMO test and Bartlett's test can be used to

Table 1. Value of Kaiser-Meyer-Olkin, Bartlett test and significance level

Kaiser-Meyer-Olkin	Bartlett test	df	sig
0.836	264.938	15	0.000

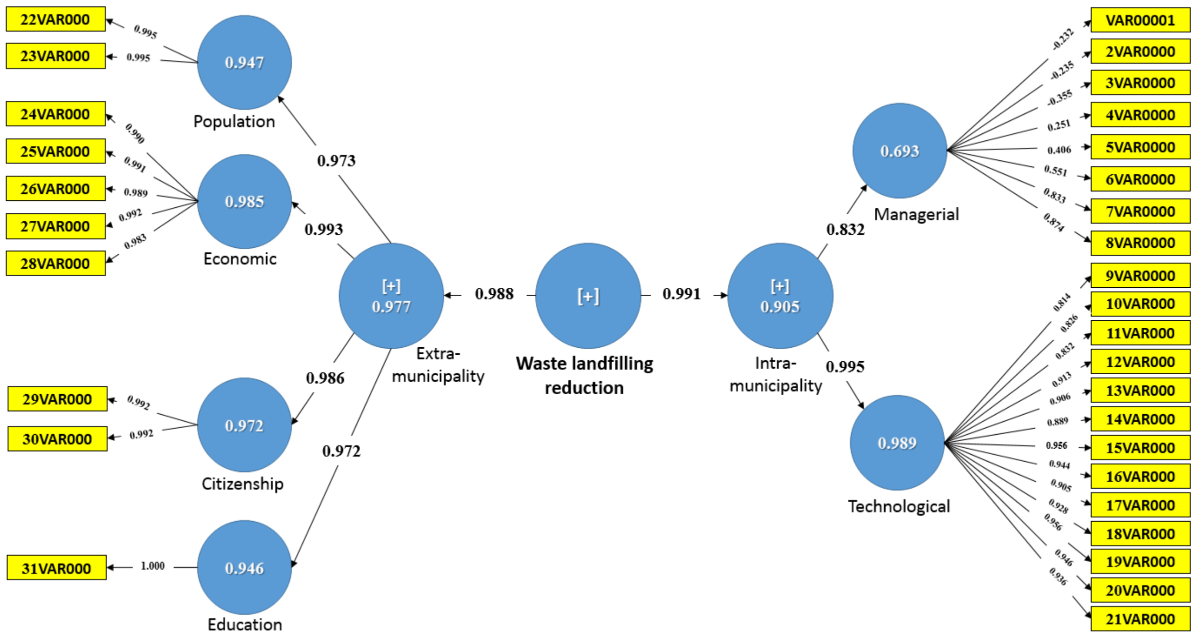

Fig. 6. The values of factor loading and path coefficients in the structural equation model

evaluate the suitability of data for analysis (Kamaruddin *et al.*, 2019). The KMO index shows that the sample size is sufficient for exploratory factor analysis. In some references, a KMO measurement value of more than 0.5 (Khan *et al.*, 2019), and in others, a value of more than 0.6 (Tam *et al.*, 2018) is considered acceptable. Table 1 presents the results of the KMO coefficient, Bartlett's test, and significance level for the intended data.

Based on Table 1, the KMO coefficient equals 0.836, and because its value is greater than 0.5, the sampling adequacy criterion and the applicability of the defined factors are estimated to be met (Abaszadeh *et al.*, 2016). The significance of Bartlett's test result (264.938) at an error level of less than 0.01 suggests that the correlation matrix between items is not the identity matrix. Although there was a strong correlation between the items within each factor, there was no correlation between the items of one factor and those of the other factors (Anabestani *et al.*, 2020).

Measurement model fitting

This study utilized reliability and validity to examine the measurement model fitting. In addition, the factor loading coefficients, Cronbach's alpha, and combined reliability were calculated to evaluate the measurement models' reliability. Fig. 6 depicts the SEM's values of factor loading and path coefficients.

The reliability of each item is the amount of factor loading in each variable, and its value ranges from 0 to 1. If the factor loading value is less than 0.3, the relationship will be deemed weak and discarded. However, it is acceptable if the value falls between 0.3 and 0.6, and it is highly desirable if the value is greater than 0.6. (Rezazadeh & Davari, 2014). All factor loadings of this model's components are rated as highly desirable, as shown in Fig. 6. Notably, the 31 variables presented in Fig. 6 are identical to the 31 variables shown in Fig. 4.

Table 2. Results of Cronbach's alpha

Components	Education	Economic	Population	Citizenship	Extra-municipality	Intra-municipality	Technological	Managerial	Waste reduction
Cronbach's alpha Alpha > 0.7	1.000	0.994	0.989	0.983	0.995	0.933	0.981	0.933	0.972

Table 3. Composite reliability of the model

Components	Education	Economic	Population	Citizenship	Extra-municipality	Intra-municipality	Technological	Managerial	Waste reduction
Composite reliability (CR > 0.7)	1.000	0.996	0.995	0.992	0.995	0.952	0.983	0.800	0.981

Table 4. Results of variance extracted

Components	Education	Economic	Population	Citizenship	Extra-municipality	Intra-municipality	Technological	Managerial	Waste reduction
AVE (AVE>0.5)	1.000	0.978	0.990	0.983	0.955	0.574	0.819	0.574	0.684

Table 2 displays the results of calculating the existing model's Cronbach's alpha value. Considering the high Cronbach's alpha values of 0.7 (Zebunnesa Rahman *et al*., 2017), all of the model's components have good reliability, indicating that measurement models have adequate internal reliability.

In addition to the conventional Cronbach's alpha, the composite reliability criterion was used to determine the reliability of each construct in this study. This criterion is superior to Cronbach's alpha coefficient in that the reliability of constructs is not calculated as an absolute but rather as a correlation between the constructs. Both of the aforementioned criteria are used to measure reliability more accurately. A composite reliability value of greater than 0.7 for each construct indicates good internal stability for the measurement models, whereas a value of less than 0.7 indicates unreliability (Halder & Singh, 2018; Pongpunpurt *et al*., 2022). Table 3 displays the model's overall reliability values. This table calculates the composite reliability value for all model variables above 0.7, indicating the model's high internal reliability.

After evaluating the reliability, convergent validity is the second criterion for examining measurement models. The average variance extracted (AVE) measures convergent validity, which evaluates the degree of correlation between each construct and the question (indicators). The AVE represents the average variance between each construct's individual indicators. Numerous studies have indicated that the acceptable value of AVE is greater than 0.5 (Dalila *et al*., 2020; Halder & Singh, 2018; Pongpunpurt *et al*., 2022). Based on the findings of Table 4,

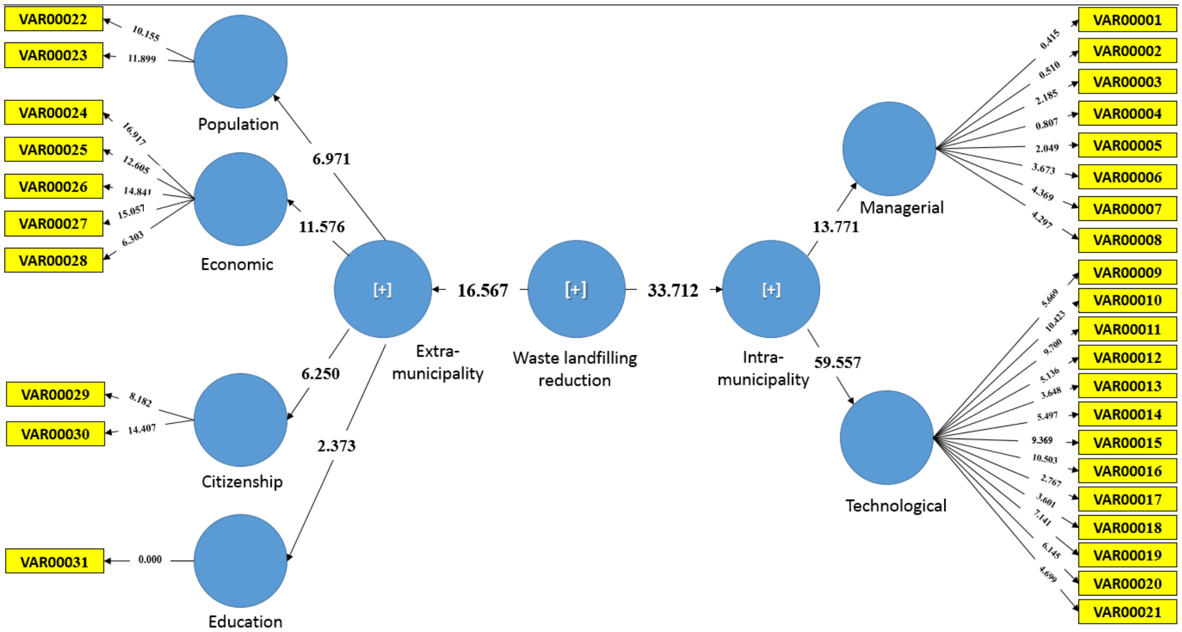

Fig. 7. The amount of t reported for evaluating the structural model fit

Table 5. Coefficients of determination

Components	**Education**	**Economic**	**Population**	**Citizenship**	**Extra-municipality**	**Intra-municipality**	**Technological**	**Managerial**
R^2	0.946	0.985	0.519	0.972	0.977	0.982	0.989	0.693

the amount is greater than 0.5 for all model components. The model's convergence validity is therefore confirmed.

Evaluation of structural model fit

In this study, the significant Z or t-value coefficients at a 95% confidence level were used to evaluate the study's structural model fit (Owojori *et al.*, 2022). If the t values are greater than 1.96, the relationship between the constructs and the research hypotheses is correct with a 95% level of confidence (Alavi *et al.*, 2015; Chukwuemeka *et al.*, 2012; Obsa *et al.*, 2022). In this study, the main hypothesis was that education, economy, population, technology, and management significantly impact the amount of waste landfill reduction in Tehran, both within and between municipalities. Fig. 7 depicts the t values used to evaluate the model's structural component. The fact that the path numbers exceed 1.96 demonstrates the paths' significance, the structural model's validity, and the research hypothesis's confirmation.

The determination coefficient (R^2) was computed and presented in this study to determine the structural model's fit. As criteria for weak, average, and strong R^2, the values 0.19, 0.33, and 0.67 were introduced, while a high R^2 value indicates a better fit of the model (Khorasani & Hoseini Zarabi, 2014). According to the values in Table 5, R^2 is only average for the population (0.519) but high for the other components.

The effect size of F^2 indicates the strength of the association between model components and the relative contribution of each exogenous variable to R^2 in the target structure. According to

Table 6. Effect values of F^2

Components	Education	Economic	Population	Citizenship	Extra-municipality	Intra-municipality	Technological	Managerial
F^2	17.359	66.450	17.760	34.910	42.651	53.695	90.567	2.254

Table 7. Stone- Geisser values

Components	Education	Economic	Population	Citizenship	Extra-municipality	Intra-municipality	Technological	Managerial
Q^2	0.076	0.270	0.476	0.365	0.136	0.208	0.311	0.064

Cohen's kappa coefficient, the values of 0.02, 0.15, and 0.35 represent small, average, and large effects, respectively (Ghafourian *et al*., 2021). Table 6 demonstrates that the amount of F^2 for all the components is high (greater than 0.35), with technology being the most effective (90.567).

The Stone-Geisser criterion (Q^2) is another method for measuring the performance of a model's prediction. As a relative measure of prediction correlation, the Q^2 criterion values of 0.02, 0.15, and 0.35 indicate that an exogenous construct has a small, average, or large prediction correlation, respectively (Asiaei *et al*., 2022; Kock & Hadaya, 2018). Table 7 displays the model's Stone-Geisser values. In terms of education and management, the model's predictability is the average based on the obtained values. In other instances, the value is also deemed to be high.

Hypothesis testing

Based on the PLS method's data analysis algorithm, the factor loading associated with the hypotheses and paths, the significant Z coefficients (t values), and the standardized coefficients for each path were evaluated. Considering the absolute size of the coefficients, coefficients greater than 0.1 in various references indicate an effect on the path. If the significant coefficient is greater than 1.96, the path coefficients and the assumption of a relationship between model components are confirmed with a 95% confidence level. Based on Table 8 and the fact that the value of the t coefficients for each path is greater than 1.96, the predicted paths were statistically significant at a confidence level of 95%, and all hypotheses regarding the relationship between research constructs were confirmed.

The results of this study are consistent with those of Hazeri and Saraei (2019) on population, economic, managerial, and technological variables, Salehi *et al*. (2018) on educational and economic variables, Afshar Kazemi *et al*. (2016) on technological and managerial variables, Rakhshaninasab and Safari (2016) on managerial, educational and economic variables, Abad Nourozi Hahan and Sabz Alipour (2016) on population, citizenship, and educational variables, Ghafar Panah *et al*. (2020) on technological, managerial, economic, population, educational and citizenship variables and Moradikia *et al*. (2021) on economic variables. Based on the extracted effect size and the opinion of experts, the technological component (improving the level of waste treatment) had the greatest effect on waste landfill reduction in Tehran.

Table 8. T-values and test results of research hypotheses at 95% confidence level

path	mean	standard deviation	t-statistics	P-values
extra-municipality → education	0.697	0.410	2.373	0.018
extra-municipality → economic	0.944	0.086	11.576	0.000
extra-municipality → population	0.888	0.140	6.971	0.000
extra-municipality → citizenship	0.881	0.158	6.250	0.000
intra-municipality → technological	0.983	0.017	59.557	0.000
intra-municipality → managerial	0.852	0.060	13.771	0.000
waste landfill reduction → extra-municipality	0.952	0.060	16.567	0.000
waste landfill reduction → intra-municipality	0.974	0.029	33.712	0.000

In the developed SDM, Tehran's processing technology included the use of cylinder-shaped screens, a separation hall, and magnets. The processing quality can be improved by using technologies such as Eddy Current, a variety of screens, and even classification based on Near-Infrared (NIR) spectroscopy. It is suggested that future studies regarding macroeconomic indicators in the extra-municipality in various areas of MSW management from the production stage to the final landfill consider the SDM and numerically examine the role and effect of inputs, organizations, and ministries included in Iran Waste Management Law (2004) in this model.

CONCLUSION

In this study, an SDM was designed and validated for the optimal management of MSW in Tehran using a landfill reduction approach. The process of identifying the extracted factors and variables to design this SDM is based on reviewing sources and receiving the opinion of experts. Based on the calculated indicators, the reliability and validity of the model were confirmed. The structural model was evaluated using relevant indicators, and the structural model fit was confirmed. Accordingly, it is possible to optimize the solid waste management system and reduce the waste landfill percentage in Tehran by developing a model based on economic, educational, population, citizenship, technological, and managerial variables in two dimensions intra-municipality and extra-municipality.

AUTHOR'S CONTRIBUTIONS

Saeed Moradikia (Ph.D. Candidate) and Babak Omidvar were involved in the conceptualization, methodology, formal analysis, development & validation of system dynamic model and writing original manuscript preparation; MAA and ES contributed to review and revise.

GRANT SUPPORT DETAILS

No financial assistance was provided for this research.

CONFLICT OF INTEREST

The authors confirm that there are no conflicts of interest regarding the publication of this manuscript. Additionally, the authors have strictly adhered to ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, duplicate publication and/or submission, and redundancy.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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