International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

Solid Waste Management Performance Assessment Model for Owerri Municipality

Eunice D. Macpepple[1,2], Celestine C. Egwuonwu[2] and Cyprian N. Tom[1].

[1]*Department of Agricultural and Environmental Engineering, Rivers State University of Science and Technology, Port Harcourt, Nigeria*
[2]*Department of Agricultural and Bio-systems Engineering, Federal University of Technology, Owerri, Imo State, Nigeria*

Date of Submission: 01-10-2024 Date of Acceptance: 10-10-2024

ABSTRACT: In this research, a solid waste management performance model was developed for Owerri municipality. This was necessitated by the existing poor waste management and service provision in the area. The present system performance and ideal real time model expectations were investigated. The model was developed in line with the established balance score card (BSC) concept using MATLAB 2021a software. 30 performance indicators were identified from 4 component objectives enshrined in globally accepted solid waste management systems and processes, namely, customer perspective (CP), internal process perspective (IPP), learning and growth perspective (LGP) and financial perspective (FP). These indicators were used as building blocks for developing the model. Indicators for physical parameters included leachate temperature, total dissolved solids (TDS) and total suspended solids (TSS). Leachate analysis confirmed the presence of high concentrations of TDS (6723kg/m), TSS (5731kg/m), total ammonia (186kg/m), and high BOD (137kg/m) and COD (614kg/m) levels, respectively at the active official dumpsite in the study area. The corresponding model results showed an overall SWM performance of 37.5%. The FP scored 0%. Outcome showed that specific areas that needed improvement were in the areas of waste collection coverage, final disposal, environmental endurance, inclusivity, financial sustainability and recycling and treatment facilities. The study also disclosed a systematic method for assessment of performance of the integrated solid waste management system (ISWMS) in the municipalities.

KEYWORDS: Solid waste, Management, Owerri, Performance assessment, model development.

I. INTRODUCTION

In spite of the improved development of science and technology, solid waste management is still a serious environmental problem for most communities all over the world [1].Just like other public utilities like electricity, roads, health, water, etc., municipal solid waste management as a system also need to carry out performance assessment to improve on their key components. This makes for the sustainability of the system by assessing their existing performances with the help of a well-structured and comprehensive performance assessment model. Performance assessment identifies the performance gaps in a system and compares it with better or more ideal systems for improvement and maintenance purposes. Performance assessment helps to ascertain the efficiency of any organisation or system; and benchmarking stirs the desire for improvement and/or upgrade. This makes for continual comparison of products, services, methods, or processes to identify performance gaps, with goals to learn from the best and to note out possible improvement areas.

Solid waste management system performance should not be left out too. Local communities need to know their waste management performance levels in order to determine best practices for improving them. Thus, the effectiveness and efficiency of waste services which depend on a variety of parameters requires assessment and benchmarking to determine their necessary combination for optimum results and also in order to identify the achieved progress of waste services. Local authorities can then optimize their services and set targets for best practices. In 1994, Aalborg Charter conducted research on the role of performance monitoring, exchanging experience and using indicators for sustainable growth among local authorities; and benchmarking was rendered a very important tool for improving waste services [2]Important benefits for both the waste service authority and the community might include effective monitoring of operations, better co-operation between authorities of different communities or greater areas, as well as in-depth analysis of related problems and enhanced elaboration of alternative solutions [2].

One of the ways of assessing the performance of solid waste management systems is by employing benchmark indicators. These indicators assess the delivery of solid waste management services, provides relevant data for decision-making and monitors changes over time. It also compares performances across cities irrespective of their level of income [3]. An indicator works as a descriptive function of a phenomena, idea or activity. It describes how the state of a phenomena actually is by providing relevant data or information. It makes a complex environment easier to understand and exposes hidden areas of an activity. It can be a single data or a collection of data. [4] highlighted that Parsons saw the need to develop indicators for solid waste management in 1906, for municipal solid waste management (MSWM) data standardization across cities, direct comparisons and correct conclusions so many can benefit from the process. They defined indicators as important for the evaluation and improvement of MSWM and also for the diagnosis of system status and problem detection. According to [5], performance indicators (PIs) are the primary inputs to a conventional performance benchmarking process where the participating municipalities detect their underperforming key components through cross-comparison with other municipalities operating in the region that possess similar demographic, geographic, environmental, and financial settings.

To achieve sustainability of the solid waste management systems in the gulf region, [6] developed a performance assessment model for two municipalities in the Qassim region, using a hierarchical-based top-down model. They identified most of their performance indicators via literature, and seven key components selected and imputed into the model. The authors employed the top-down method of deductive reasoning, assessing relevant information from solid waste management (SWM) experts in academia, SWM managers and literature, defining the framework and sustainability criteria of the system. This framework was comprised of performance objectives, attributes and indicators. To establish weighted scores for system analysis, a universe of discourse was developed from literature in the absence of relevant data from the municipalities. Data variables were identified from each set of objectives and their associated indicators selected based on the needs of the region. 18 sub models were developed to assess system performance.

To assess the performance of the solid waste management system in the Loule municipality in Portugal. [7] developed a model which employed performance indicators developed by the municipality’s waste management agency, called The Division of Hygiene and Urban Solid Waste (DHURS). The DHURS on the other hand, had employed the balance score card (BSC) management tools from the private sector, customizing it to suit the needs of their public sector in the area of solid waste management. This tool was developed by [8], and was aimed at giving managers, operators and business executives of an organization, a clear and quick view of complex environments/systems simultaneously. They looked at a business from four critical perspectives, namely, client/customer perspective, internal processes perspective, learning and growth perspective and financial perspective. The tool generally tracks the key elements of an organization’s strategy. Since the overall objectives of the public sector deferred from that of the private sector in the areas of “centralized organizational structures, complex decision-making processes, increased competitiveness, budget constraints, cultural and social changes, increased expectation of society, rapid technological changes and the need for communication and survival”, there was a need for a redefinition of the original perspectives of the BSC model.

[9] developed a methodology for evaluating municipal solid waste systems for the ASEAN region using scoreboards as a tool for the management and improvement of municipal solid waste practices. The principles of sustainable development, integrated solid waste management and the waste management hierarchy were relied upon to identify performance indicators. The indicators were arrived from reviews of study teams set up by the organization, comprising of selected individuals, experts and researchers who were drawn from the government, institutions, community, private sector and even internationally. Data and information covering institutional framework, waste reduction/avoidance, storage and collection, resource recovery, disposal and public awareness were made available to several pools of study groups to analyse using the integrated waste management (IWM) scoreboard. Indicators

identified were service performance, resource input and efficiency.

[10]analysed the recycling capacity of the Corumbatai basin waste management system in Sao Paolo, Brazil, by employing performance indicators. They identified six distinct indicators from literature, questionnaires and field research to analyse the different stages of the waste management system in their municipality.

II. MATERIALS AND METHODS

Study Area

Owerri city is located in the South Eastern zone of Nigeria, and lies between latitude 50°N to 60°30′N and Longitude 60°E to 70°34′E, sitting at the intersection of roads from Port Harcourt, Onitsha, Aba, Orlu, Okigwe and Umuahia. It has a total landmass of 24.88 square kilometers and a projected population of 632,781 (2019 estimates) based on 2012 estimates. And it is forecasted by [11] to be one of the biggest cities come the year 2025 due to its annual population growth rate of 3.2 percent. The weather and climatic conditions in Owerri encourages economic activities such as agriculture (palm products, corn, yams, cassava, etc.), tourism, and small-scale industries [12]. Owerri has an average temperature of about 27˚C (80˚F). Its vegetation is typically rain forest (although some parts consist of Guinea Savanna due to poor environmental management and pollution). Its inhabitants are mainly civil servants, traders and farmers who are predominantly native [13]. Owerri West is a Local Government Area of Imo State, Nigeria. Its headquarters are in the town of Umuguma. A very large portion of the local government constitute the capital city of Imo State, Nigeria. It has an area of 295 km² and a population of 99,265 at the 2006 census. Owerri West comprises of the following communities: Umuguma, Avu, Okuku, Oforola, Obinze, Nekede, Ihiagwa, Eziobodo, Okolochi, Emeabiam, Irete, Orogwe, Amakohia, Ndegwu and Ohii.

Materials

MATLAB R2021a software (developed by MathWorks, United Sates) was employed for developing the model. The performance indicators for the model were obtained via primary and secondary sources. Primary data were obtained through one-on-one interviews with the waste management operators and management at the Owerri Eastern Waste Management Company (EWAMAC). Data for the individual performance indicators were also retrieved from solid waste characterization study, environmental impact assessment study, questionnaire survey, personal site-specific observations, structured interviews, semi-structured interviews and meetings with stakeholders and service providers. Secondary data was gotten from literature.

Model Development

Assessment of the current waste management infrastructure and service provisions was achieved by applying a model to evaluate their performances. Global benchmarking indicators used for the assessment covered the four business perspectives adapted from the original balance core card (BSC) approach developed by Kaplan & Norton (1992), which was re-designed to suit the integrated solid waste management concept [9, 14] Component objectives under the customer perspective (CP) included waste management quality of service, public participation and environmental impact; objectives for the internal process perspective (IPP) included operational and infrastructural processes; the learning and growth perspective (LGP) had personnel adequacy, well-being and workplace performance as its component objectives; while the financial perspective (FP) was concerned with the economic viability of the system [6, 9, 15, 16].

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

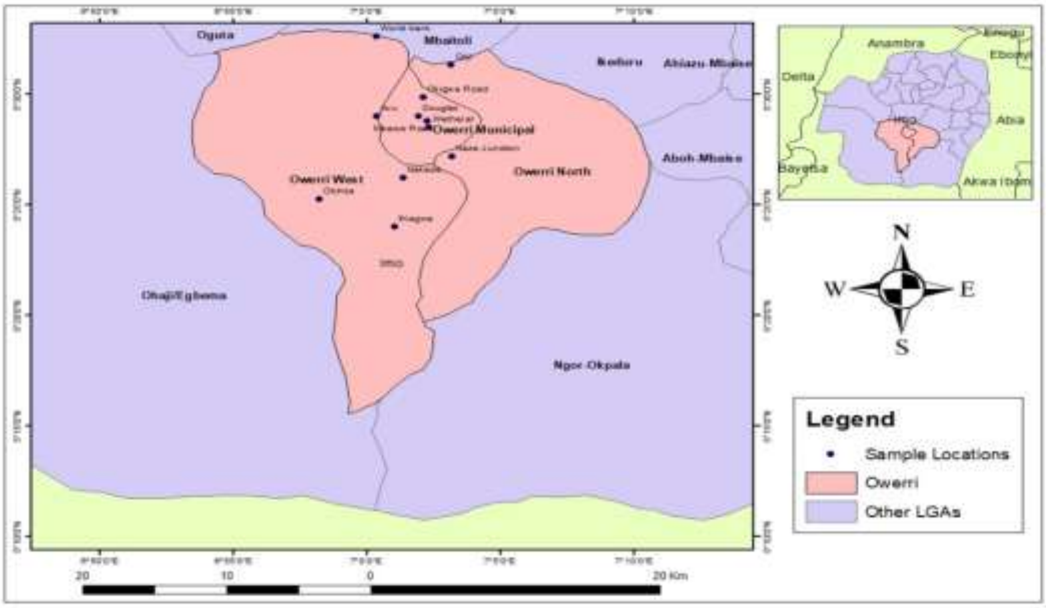

Figure 1. Map of Owerri Municipality

To build the model, indicators tied to component objectives were identified and variables as a means for measurability developed. A Universe of Discourse (UOD) or Domain of Discourse (DOD) was established which had performance ratios for global benchmarking (Table1). Under the CPcomponent, indicators included solid waste production per capita, coverage of collection service and persons not satisfied with the waste management service. The IPPincluded indicators of waste segregation at dumpsites, total percentage tonnage of municipal solid waste dumped, among other indicators. Table 2 shows all the benchmarking indicators used. Each indicator set was imputed into Simulink using the Mamdani fuzzy logic inference system, where rules were created to rank the real-life scenario of current SWM practices and infrastructure in the study areas. Sub-models where developed for each set which were all integrated to give a weighted score to enable a comparison with other municipalities. Input variables were first fuzzified, then rules were applied to them and the system evaluated, after which the rules output were aggregated and finally de-fuzzified (Figure 2). The input variables were assigned three membership functions each on a scale of low, medium and high; while the single output variable was also assigned three membership functions on a low, medium and high scale.

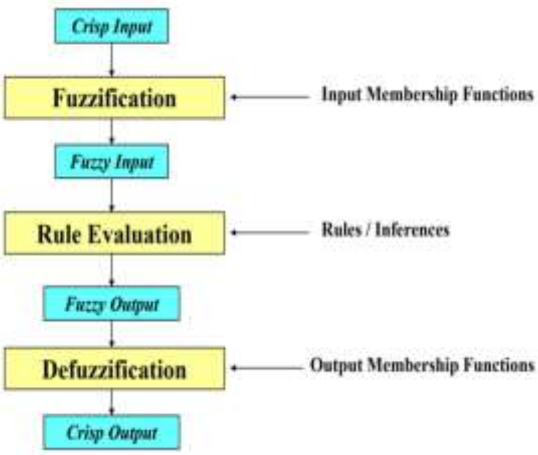

Figure 2. The Fuzzy System

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

Fuzzy logic is a function that maps a set of inputs to outputs using human interpretable rules rather than more abstract mathematics. When system assessments involve a lot of quantitative data, the fuzzy inference system comes in handy, where crisp inputs with precise values are converted to variables in a fuzzification process [17].Complex system behaviours are modeled into simple logic rules, which are then implemented in a fuzzy inference system (FIS).

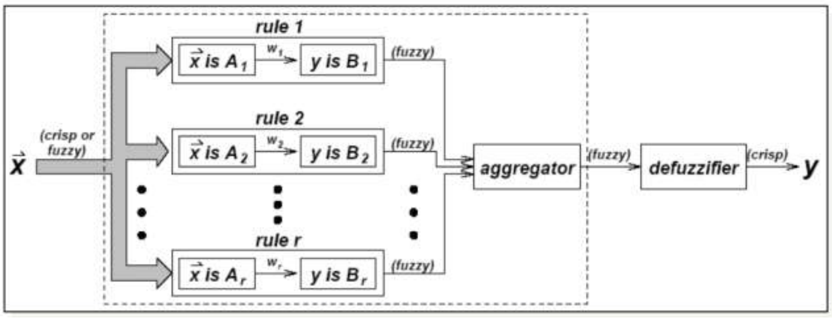

Figure 3. The "If-Then" Fuzzy Rules

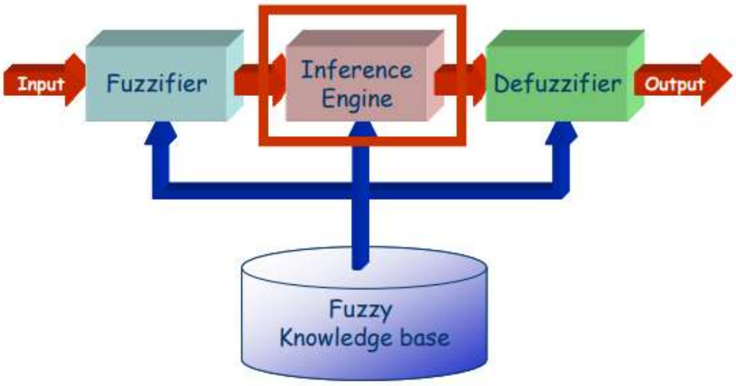

Figure 4. Inference Engine

Each input variable has membership functions comprising of their range, type and parameters. The Mamdani FIS creates a control system by synthesizing a set of linguistic control rules obtained from experienced human operators, and the output of each rule is called a fuzzy set. There is a rule editor where rules that control the behaviour of the system are drawn up and edited if need be. The rules in the rule editor are combined together using different real time scenarios and occurrences to toggle what will be the outcome under different circumstances. Expert knowledge plays an important role in this exercise. The FIS interprets the values in the input vector and assigns values to the output vector with the aid of the rules. The "if-then" statements (Figure 3) are used to formulate the conditional statements that comprise fuzzy logic. The "if" part of the rule is called the antecedent or premise, while the "then" part of the rule is called the consequent or conclusion. So generally, the input to the "if-then" rule is the current value for the input variable, and the output is an entire fuzzy set, which is defuzzified by assigning one value to the output. The rules are obtained from experienced human operators and real-life observations. Figure 4 shows the inference system with known knowledge base.

Each fuzzy set was comprised of performance indicators with their associated parameters. The customer perspective variable set contained 15 variables, the internal process perspective set had 9 variables, while the learning and growth perspective set had 6 variables. The financial perspective set, which contained 3 variables was not analysed due to absence of reliable physical data from responsible authorities. The variable inputs mapped in the fuzzy inference system each had performance levels attached to them to evaluate the system. The "low" (0-3.5/0-35%) value corresponded to a risk or unproductive level, the "medium" (3.5-6.5/35%-65%) value corresponded to an average performance requiring

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

appreciable improvement, while the "high" (6.5-10/65%-100%) value means excellent. Each of the four performance perspectives were attributed a weight of 100% each in the study. A general view of how the model works is seen in Figure 5.

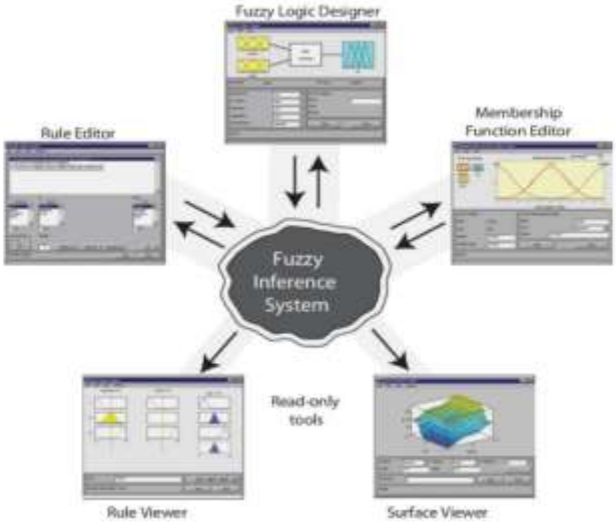

Figure 5. General View of the Fuzzy Inference System

Data for the 30 identified performance indicators which were imputed in the models were retrieved from the questionnaire survey, one-on-one interviews with the employees and heads of operations in the waste management agency in Owerri. The questionnaire was divided into 6 sections having a total of 64 questions. The sections involved demographics, household waste generation and disposal, community involvement in SWM, public acceptance of the SWM, community awareness about SWM and waste management employees. Other data were harnessed from the personal interviews with the WM professionals and field employees.Questionnaire validation was conducted through expert's assessment, pilot test and Cronbach's Alpha analysis (CA). The pilot test was conducted with 250 questionnaires. The CA analysis using SPSS for 85% of the questions raised in the pilot study was 0.89, which indicated a good internal consistency in the responses. Subsequently, a total of 1000 copies of questionnaire were distributed, and 874 retrieved. This indicated a 92.85% returned questionnaires.

The MATLAB models were validated using the system validation document, imbedded in the program. Here reference input values, FIS output values and reference output values are seen, and errors identified, corrected and the model re-ran in Simulink. The model outlook is shown in Figure 6.

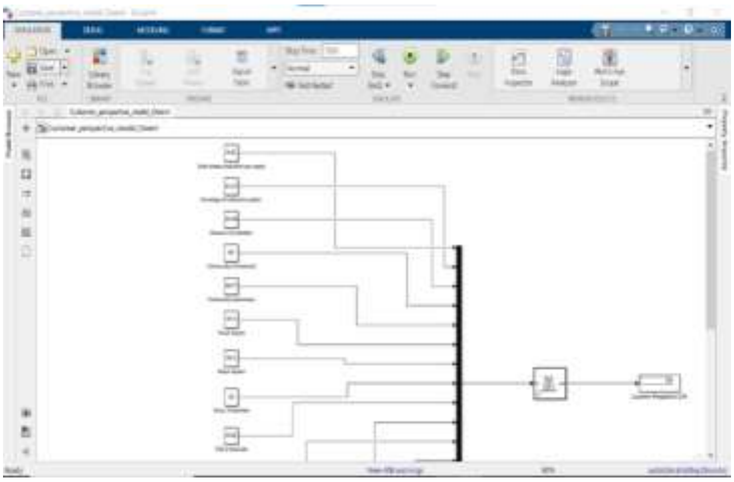
Figure 6. Model in MATLAB Window

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

III. RESULTS AND DISCUSSION

Indicator values for coverage of collection systems for the municipality is shown in Table 3. These were obtained from personal one-on-one interviews with relevant personnel bordering on haulage truck capacity, evacuation area, frequency and efficiency of the waste management agency in Owerri.Indicators for customer satisfaction was arrived at via questionnaire results. The residents' views on their acceptance of government methods on managing solid waste, their extent of management, their level of expected improvement and how they viewed the efficiency of house-to-house waste collection, were all combined to give a rating on their satisfaction. Results for community involvement indicator was gotten from the customers from questions raised in the areas of interest in waste segregation, participation in environmental sanitation, attendance in community waste management meetings, reuse of waste, willingness to pay for waste disposal and inclusivity in waste management.

The level of customer awareness of solid waste management was identified via questions raised in the areas of how well they knew about the negative effects of poor solid waste management, whether the media was involved in raising their awareness, knowledge of safe disposal practices, waste minimization, knowledge of waste-to-energy potentials, final disposal of their waste and whether they are informed about their government plans concerning waste management.

Qualitative questionnaire feedback on the level of visual and odour impact, material recovery and recycling awareness, insufficient waste collection trucks serving their locations, and how willing the residents were to segregate their waste and to pay for waste disposal were received. Leachate results for physicochemical and heavy metal composition of sampled leachate from a major dumpsite in Owerri (Nekede) were analysed. Performance indicators for staffing level, personnel wellbeing and training were obtained through one-on-one interviews with responsible officers at the waste management agency in Owerri and their field employees.

Three sub models for customer perspective (CP), internal process perspective (IPP) and learning and growth perspective (LGP)were developed in Simulink using fuzzy logic. There were 15 input variables for the CP model (Figure 7), 9 input variables for the IPP (Figure 8), and 6 input variables for the LGP (Figure 9).

61.3% of the municipality was reported to be successfully covered in waste evacuation. These value along with the other 14 variables were imputed into fuzzy logic, exported to MATLAB and simulated to give defuzzified performance results. Each model component was populated with the indicators identified for it and the "if" "then" rules developed for each model. All three sub models were assigned rules based on different real time behaviours of their indicators. In the customer perspective model for example, an ideal rule set developed was: "if the solid waste production per capita is low, and the coverage of collection system is high, and the number of persons not satisfied is low, and the community involvement is high, and the community awareness is high, and the visual impact is low, and the odour impact is low, and the temperature of leachate is low, and the TDS in leachate is low, and the TSS in leachate is low, and the BOD of leachate is low, and the COD of leachate is low, and the nitrates in leachate is low, and the phosphorous concentration in leachate is low, and the ammonia concentration in leachate is low, then the customer perspective performance is high" These rules were finally defuzzified to give an output performance value, which was either low, medium or high.

All the four component objectives were placed on a 100% scale, 0-35% for low performance, 35-65% medium performance and 65-100% for high or excellent performance. The three simulated models for each component scored 50% on the rating scale This gave the overall performance score of the solid waste management systems in the region of 37.5%, implying that their performances are way below average, hence a lot of improvement required in the indicator variables identified.

The CP results show that Owerri has a low score for solid waste generation of 0.53kg. This is good for the system as a high score implies higher solid waste tonnage output, which will put more strain on the disposal sites. An average score of 61.27% was presented for waste management collection coverage. This is highly unsatisfactory as a less than 75% coverage is on the lowest scale in the UoD.A complaints enablement bureau and prompt response to the complaints from the customers is an effective mitigation for this indicator variable. Community involvement in SWM, though on the average scale (49.71%), needs to be given attention to by encouraging more inclusiveness via traditional and social media awareness. The visual and odour impact is very high on the UoD scale, showing immediate need for attention for sustainability. SWM operators' response in the area of swift daily evacuation of waste from the neighbourhoods and improved housekeeping at roadside receptacles, bins,

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

collection area and official dumpsites is needed to address this loophole. Leachate temperature fell on the medium range in the UoD at 33°C. Temperatures above 60°C are usually dangerous as they can cause spontaneous ignition at disposal sites. TDS in leachate is low while theTSS value is very high, being above the 2000mg/l value in the UoD. Also, the BOD was observed to be high, being 137mg/l. These high levelsare an indication of groundwater contamination by percolation around the dumpsite. On a general note, leachate treatment facilities are recommended to improve the high occurrence levels of environmental endurance (X1,3), as well as efficient recovery of recyclables and reusables at the site.

The IPP results show segregation of waste at the dumpsite to be on the low range, recording a presence of just 12.2% at the dumpsite. This little attempt at segregation was observed to be done informally by scavengers, which should not be the case. To address this area of concern, there must be a spiked interest by the government as to the importance of reuse and recycling. Optimal provision for distances between collection points/bins/receptacles and the houses is that the distances should not be too close to the houses for odour control, or too far to cause the customers to be prone to laziness so waste is not dumped halfway, causing littering.76m for Owerri is average. Distances between collection points and final disposal at official dumpsites should be such that the disposal trucks don’t breakdown at great distances. The medium range of 20m to 40m is average. The percentage range for recycling is 0% for the municipality. This is an area which must be addressed promptly if a system must be sustainable. However, the total tonnage of waste disposed at the dumpsite is a bit above average (64%) which though needs improvement, is commendable. The physical condition and efficiency of the collection trucks was seen to have a need of proper general maintenance/ refurbishment/ replacement, as a greater percentage were observed to be in bad condition. Scores for this indicator sat on the average level in the UoD, 46%. Waste collection trucks or any other equipment that is used to process waste ordinarily should be cleaned daily, so as to reduce odour and build of dirt, which may lead to diseases to the handlers especially. Therefore, cleaning should be very frequent. Results show that Owerri municipality clean their equipment at least once a day.

The LGP results show that employees assigned to collect per ton of generated waste daily is high at 5 persons. This sits on the high range in the UoD. However, the collection staff that collects waste from 1000 households in each region needs to be improved on (25 persons reportedly). Improvement also is recommended for the employees working at the dumpsite as the more persons on site, the better housekeeping. The number of accidents that occur per 100 employee per year is very high, recording 100 incidences. This can be attributed to the absence of personal protective equipment, inefficient haulage trucks and little or no personnel training.

IV. CONCLUSION

To improve on the poor solid waste management system in Owerri municipality, and for a much-needed integration of processes and sustainability, a performance assessment model was developed in this study. Relevant data was sourced to build the performance model for effective waste collection, transportation, treatment and final disposal of municipal solid waste. SWM assessment based on the original balance score card approach (BSC) was conducted. A MATLAB-Simulink model was developed using fuzzy inference system, where indicators covering the social and technical aspects of the waste management system we reemployed, giving a holistic presentation. The aim of the SWM assessment was to ensure that the system serve the public or its’ customers satisfactorily. The SWM agency in the study are expected to positively adjust and/or upgrade their services based on the outcome of the model simulation. The corresponding model results showed an overall SWM performance of 37.5%. This below average performance indicates that a large room for improvement is required in the hot spots of the four BSC perspectives. This points to the need for more robust strategies in planning, budget and finance in the system; including better communication between customers, operators and the government to enable integration and sustainability.

To improve its SWM performance in the study area, it is recommended that the waste management agency:

1. Increase its coverage of solid waste collection
2. Promptly respond to and satisfactorily resolve reported complaints from their customers
3. Involve the community in SWM decision making
4. Increase SWM awareness
5. Build adequate recycling facilities6. Construct sanitary landfills to reduce poor disposal site aesthetics, control odour and general environmental
7. Conduct campaigns and awareness of reuse strategy

8. Provide more skips and bins for temporal waste disposal, thereby, reducing litter around disposal area and the distance between users and storage containers.
9. Optimize routes for collection vehicles
10. Increase staffing level and working conditions
11. Implement strict worker health and safety regulation, particularly for the collection and disposal staff.
12. Provide relevant staff training for SWM employees.
13. Conduct adequate maintenance of equipment and use of more automated vehiclesto reduce field accidents.
14. Increase productivity ratio through more effective human resource management

REFERENCES

[1] Su, J., Xi, B. D., Liu, H. L., Jiang, Y. H., &Warith, M. A. (2008). An Inexact Multi-ObjectiveDynamic Model and its Application in China for the Management of Municipal Solid Waste. Waste Management, 28(12): 2532-2541.
[2] Karagiannidis, A., Xirogiannopoulou, A., Perkoulidis, G., &Moussiopoulos, N. (2004). Assessing the Collection of Urban Solid Wastes: A Step Towards Municipality Benchmarking. Water, Air and Soil Pollution: Focus, 4(4-5): 397-409.
[3] Wilson, D. C., Rodic, L., Cowing, M. J., Velis, C. A., Whiteman, A. D., Scheinberg, A., Vilches, R., Masterson, D., Stretz, J., &Oelz, B. (2015). 'Wasteaware'Benchmark Indicators for Integrated Sustainable Waste Management in Cities. Waste management, 35: 329-342.
[4] Cervantes, D. E. T., Martínez, A. L., Hernández, M. C., & de Cortázar, A. L. G. (2018). Using Indicators as a Tool to Evaluate Municipal Solid Waste Management: A Critical Review. Waste Management, 80: 51-63.
[5] Haider, H., Sadiq, R., & Tesfamariam, S. (2014). Performance Indicators for Small- and Medium-Sized Water Supply Systems: A Review. Environmental reviews, 22(1): 1-40.
[6] AlHumid, H. A., Haider, H., AlSaleem, S. S., Alinizzi, M., Shafiquzaman, M., & Sadiq, R. (2019). Performance Assessment Model for Municipal Solid Waste Management Systems: Development and Implementation. Environments, 6(2): 19.
[7] Mendes, P., Santos, A. C., Perna, F., & Teixeira, M. R. (2012). The balanced scorecard as an integrated model applied to the Portuguese public service: a case study in the waste sector. Journal of Cleaner Production, 24, 20-29.
[8] Kaplan, R. S., & Norton, D. P. (1992). The Balanced Scorecard: Measures that Drive Performance, 71-79.
[9] Puthillath, B., & Sasikumar, R. (2015). Integrated solid waste management score board-a tool to measure performance in municipal solid waste management. International Journal of Emerging Trends & Technology in Computer Science (IJETTCS), 4(5), 2.
[10] Luz, F. G. F., Rozenský, L., Vrba, Z., Hansen, J. M., Jan, L. Í., Dolista, J., & de Castro, M. C. A. A. (2021). Assessment of Municipal Waste Management Systems Using Performance Indicators to Analyze Recycling Capacity: The Case Study of Corumbataí Basin, São Paulo State, Brazil. In Waste Forum: 61-77.
[11] Ezeah, C., & Roberts, C. L. (2012). Analysis of Barriers and Success Factors Affecting the Adoption of Sustainable Management of Municipal Solid Waste in Nigeria. Journal of Environmental Management, 103: 9-14.
[12] Ugorji, H. I., Onwujiariri, C. M., &Nkwocha, E. E. (2020). Solid Waste Generation and Disposal in Owerri Municipality, Imo State, Nigeria. International Journal of Scientific Engineering and Science, 4(7): 67-73.
[13] Adogu, P. O. U., Uwakwe, K. A., Egenti, N. B., Okwuoha, A. P., &Nkwocha, I. B. (2015). Assessment of Waste Management Practices Among Residents of Owerri Municipal Imo State Nigeria. Journal of environmental protection, 6(5): 446-456.
[14] Un-Habitat. (2010). Solid waste management in the world's cities: Water and sanitation in the world's cities 2010. Routledge.
[15] Mendes, P., Santos, A. C., Nunes, L. M., & Teixeira, M. R. (2013). Evaluating Municipal Solid Waste Management Performance in Regions with Strong Seasonal Variability. Ecological Indicators, 30: 170-177.
[16] Zaman, A. U. (2014). Identification of key assessment indicators of the zero waste management systems.Ecological indicators, 36, 682-693.
[17] Sadiq, M., & Jain, S. K. (2014). Applying Fuzzy Preference Relation for Requirements Prioritization in Goal Oriented Requirements

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

Elicitation Process. International Journal of System Assurance Engineering and Management, 5: 711-723.

Table 1. Universe of Discourse (UOD) of Performance Indicators

NO	Performance Indicator (PI)	Units	Universe of Discourse (UOD)		
			Low	Medium	High
CP	**Customer Perspective**				
CP1	Solid waste production per capita	kg/cap/day	1–1.3	1.2–1.6	1.5–2
CP2	Coverage of the collection service	%	<75–85	80–95	90–100>
CP3	Persons not satisfied with the waste management services	%	<10–25	20–40	30–50>
CP4	Community's involvement in improving existing practices	Qualitative	0-4	2.5-7.5	6–10
CP5	Community awareness about importance of SWM	Qualitative	0-4	2.5-7.5	6–10
CP6	SWM Visual impact	Qualitative	0-4	2.5-7.5	6–10
CP7	SWM Odour impact	Qualitative	0-4	2.5-7.5	6–10
CP8	Leachate temperature	(ºC)	0–25	<20-50>	45>
CP9	(TDS) in leachate	mg/L	0–20000	<15000-40000>	35000–50000>
CP10	Total suspended solid (TSS)	mg/L	200–500	400–1000	800–2000
CP11	BOD in leachate	mg/L	<2000–6000	<5000-12000>	11000–30000>
CP12	COD in leachate	mg/L	<3000–10000	<9000-20000>	19000–60000>
CP13	Nitrates (NO3)	mg/L	<5–20	15–40	30-60
CP14	Phosphorous concentration in leachate	mg/L	1–25	20-50	40-100
CP15	Ammonia concentration in leachate	mg/L	<10-150	100-500	400-800>
IPP	**Internal Process Perspective**				
IPP1	Waste segregation at official dumpsite/landfill	Qualitative	0-4	2.5-7.5	6–10
IPP2	Average distance between collection points and the houses	m	<30–50	40–100	80–200>
IPP3	Average distance travelled by collection trucks	km/vehicle/day	<10–30	20–40	30–50
IPP4	% of municipal solid waste recycled	%	<10–40	30–70	60–80>
IPP5	Total % tonnage of municipal waste landfilled	%	<20–40	30–70	60–100
IPP6	Physical condition of collection trucks	%	<0–20	25-65	70-100
IPP7	Presence of waste recycling facilities	Qualitative	0-4	2.5-7.5	6–10
IPP8	Equipment cleaning frequency	No./week	<2-3	3-5>	5>
IPP9	Inefficient waste collection trucks	%	<0–20	25-65	70-100
LGP	**Learning and growth perspective**				
LGP1	Employees per ton of daily waste generated	No./ton	0-3	2-5>	4-6>
LGP2	No. of collection staff (including drivers) per 1000 households	No/1000 houses	<10–25	<20-40>	35–60>
LGP3	No. of employees working at dumpsite (responsible for disposal only) per ton of daily waste generated	No./ton	0-20	25-45	45-100>
LGP4	Working accidents	No./100 employee/year	0-3	<2-6>	5-10>
LGP5	No. of sick days taken per field employee	No./field employee	0-5	3–10	8-20>
LGP6	Personnel training	Days/employee/year	0-10	8–25	20–50>
FP	**Financial Perspectivr**				
FP1	Collection cost per kg of waste generated	NGN/ton	<100-400	300-600	1000>
FP2	Cost of municipal waste disposal per ton	NGN/ton	<10,000-20,000	30,000-50,000	50,000>
FP3	Recycling cost per ton of waste generated	NGN/ton	5,000-10,000	15,000-35,000	50,000>

Adapted from [6]

Table 2. Component Objectives, Performance Indicators (PIs), and Data Variables.

Generation 1—Component Objectives	Generation 2—Sub-Components (Level 1) (PM)	Generation 3—Sub-Components (Level 2) (PM)	Generation 4—Performance Indicators (PIs)	Data Variables/Decision Variables 1	Possible Improvement Actions
X1-Customer Perspective (CP)	X1,1-Quality of Service X1,2-Level of Public Participation X1,3-Environmental Endurance	X1,3,1-Impacts of physical parameters X1,3,2-Impacts of biochemical parameters X1,3,3-Impacts of chemical parameters	X1,1,0,1-CP1: Solid waste production per capita (G3, G5) X1,1,0,2-CP2: Coverage of the collection service (G7, G8) X1,1,0,3-CP3: Persons not satisfied with the waste management services (G9) X1,2,0,1-CP4: Community's involvement in improving existing practices (Qualitative) X1,2,0,3-CP5: Community awareness about importance of SWM (Qualitative) X1,3,0,1-CP6: Visual impact X1,3,0,2-CP7: Odor impact X1,3,1,1-CP8: Temperature of leachate (E62)	G3: Total population in service area G5: Average weight of solid waste per day (D) G7: Total area under the jurisdiction of the municipality (km 2) G8: Area served by the municipality (km 2) (D) G9: Total number of reported complaints (written or telephonic) (D) E62: Temperature of leachate (◦C) E68: Nitrates (NO3) in leachate (mg/L)	• Average weight of solid waste should be reduced by promoting recycling and reuse practices by implementing two-bin and three-bin systems, i.e., reducing G5 • Increasing coverage of service area, i.e., G8 • Prompt response and satisfactory resolution of reported complaints, i.e., G9 • Involving community in the decision-making process, i.e., increasing CP4 and CP5
			X1,3,1,2-CP9: (TDS) in leachate (E62) X1,3,1,3-CP10: Total suspended solid (TSS) (E70) X1,3,2,1-CP11: BOD in leachate (E71) X1,3,2,2-CP12: COD in leachate (E72) X1,3,3,1-CP13: Nitrates (NO3) (E68) X1,3,3,2-CP14: Phosphorus concentration in leachate (E76) X1,3,3,3-CP15: ammonia concentration in leachate (E78)	E70: TDS in leachate (mg/L) E71: BOD in leachate (mg/L) E72: COD in leachate (mg/L) E76: (PO4) phosphate concentration in leachate (mg/L) E78: Concentration of ammonia gas in landfill (mg/L) E80: (TSS) Total suspended solid (mg/L)	• Increasing awareness among public through traditional and social media, i.e., improving CP • Increase plantation around the landfill site to reduce visual impact, i.e., CP6 • Use best housekeeping practices to control odor, i.e., CP7 • Install an efficient leachate treatment facility, i.e., improve X1,3. • Efficient recovery of recyclables and reusable to improve leachate quality, i.e., reduced E70, E71, E72, E76, E78, and the cost of leachate treatment.

Adapted from [6]

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

Table 2. Continued

X2-Internal Process Perspective (IPP)	X2,1-Efficacy of waste generation, separation, recycling and collection systems X2,3-Efficiency of physical systems	X2,1,1-Waste Handling and Separation Rate X2,1,2-Collection/Transfer and Transport Rate X2,1,3-Recycling Efficiency X2,1,4-Landfill and Disposal Efficiency	X2,1,1,1-IPP1: Waste segregation at dumpsite for recycling X2,1,2,1-IPP2: Average distance between collection points and the houses (O33) X2,1,2,2-IPP3: Average distance travelled by collection trucks to dumpsite/landfill (O36, P58) X2,1,3,1-IPP4: % of municipal solid waste recycled (G6, O31) X2,1,4,1-IPP6: Total % tonnage of municipal waste disposed/landfilled (G6, O41) X2,3,0,1-IPP5: Presence of waste recycling facilities X2,3,0,2-IPP7: Equipment cleaning frequency (P56) X2,3,0,3-IPP8: Inefficient waste collection vehicles (P53) (P58) X2,3,0,4-IPP9: Physical condition of collection trucks	G3: Total population in service area G6: Total weight of waste O31: Amount of recycled waste per day (D) O33: Average distance between the houses and the collection bin O36: Average daily distance travelled in Km by the collector trucks (D) O41: Total % tonnage of municipal waste landfilled	• Increase the amount of recyclable waste (O31) • Increase awareness about recycling through workshops to reduce O41 • Reduce average distance between the users and storage containers by adding more containers to the system (O33) • Optimize routes of collection vehicles, i.e., reduce O36 • Increase sustainable recycling and reuse practices to reduce O51
X3-Learning and Growth Perspective (LGP)	X3,1-Personnel Adequacy X3,2-Wellbeing and workplace performance	X3,1,1-Staffing level X3,1,2-Productivity ratio	X3,1,1,1-LGP1: Employees per ton of daily waste generated (G6, S12) X3,1,1,2-LGP2: No. of collection staff (including drivers) per 1000 households (G3, S15) X3,1,1,3-LGP3: No. of employees working at dumpsite/landfill per ton of daily waste generated (S13, S17) X3,2,0,1-LGP4: Working accidents (S12, S21) X3,2,0,2-LGP5: No. of sick days taken per field employee (S12, S18) X3,2,0,3-LGP6: Personnel Training (S12, S20)	G3: Total population in service area G6: Total weight of waste (D) S12: Total number of full-time employees (D) S13: Weight in ton of average daily waste generated (D) S15: No. of collection staff (D) S17: No. of employees working at dumpsite/landfill (D) S18: No. of sick leaves taken by the employees (D) S20: Number of days for personnel training (D)	• Maintain number of employees, i.e., increase S12, S15, S17 in case of understaffing • Reduce total waste generation by improving sustainable recycle and reuse practices, i.e., reducing G6 • Implement strict worker health and safety regulation, particularly for the collection and disposal staff to reduce S18 and S21 • Increase number of training hours, i.e., S20 • Adequate maintenance of equipment and use of automation can reduce field accidents, i.e., S21

Adapted from [6]

Table 2. Continued

				S21: Number of working hours lost due to field accidents in a year (D)	• Increase productivity ratio through more effective human resource management, i.e., X3,1,2
X4-Financial Perspective (FP)			X4,0,0,1-FP1: Collection cost/ton of waste generated (G6) (E92) X4,0,0,2-FP2: Cost of municipal wastes disposal per metric ton (O51) (E90) X4,0,0,3-EF3: Recycling cost/ton of waste generated (G6) (E95)	G6: Total weight of waste O51: The tonnage of waste disposed of to landfill in addition to Municipal E90: Operational cost of landfill and MRF during an assessment period E92: Total collection cost incurred E95: Weight of recycled solid waste	• Increase recycling and reuse of waste to reduce total weight of weight and consequently reduce EF1 and EF2 • EF3 will increase with installation of MRF, some cost should be recovered from the community, i.e., improved level of public participation (X1,2) can help to achieve this objective • Frequent willingness to pay surveys can be conducted to evaluate the feasibility of generating

Adapted from [6]

Table 3. Percentage Coverage of Solid Waste Collection Service

Coverage of Collection Service	**OB**	**NE**	**IH**	**AV**	**DO**	**WE**	**MR**	**OR**	**OJ**	**WB**	**NJ**	**Average**
Haulage truck capacity	5	20	10	10	>20	10	10	10	5	20	20	
Area of Evacuation	Dumps	SD	Dumps	Dumps	Skips	Skips	Skips	Skips	Skips	SD	Skips	
Final point of disposal	OD	OD	OD	OD	OD	OD	OD	OD	OD	OD	OD	
Evacuation frequency	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	
Evacuation efficiency (%)	54	49	47	50	65	78	59	69	48	74	81	**61.27**

OB=Obinze, NE=Nekede, IH=Ihiagwa, AV=Avo, DO=Douglas, WE=Wetheral, MR=Mbaise road, OR=Okigwe road, OJ-Orji, WB=World bank, NJ=Nazi junction, SD=Skips and Dumps, OD=Official dumpsite

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

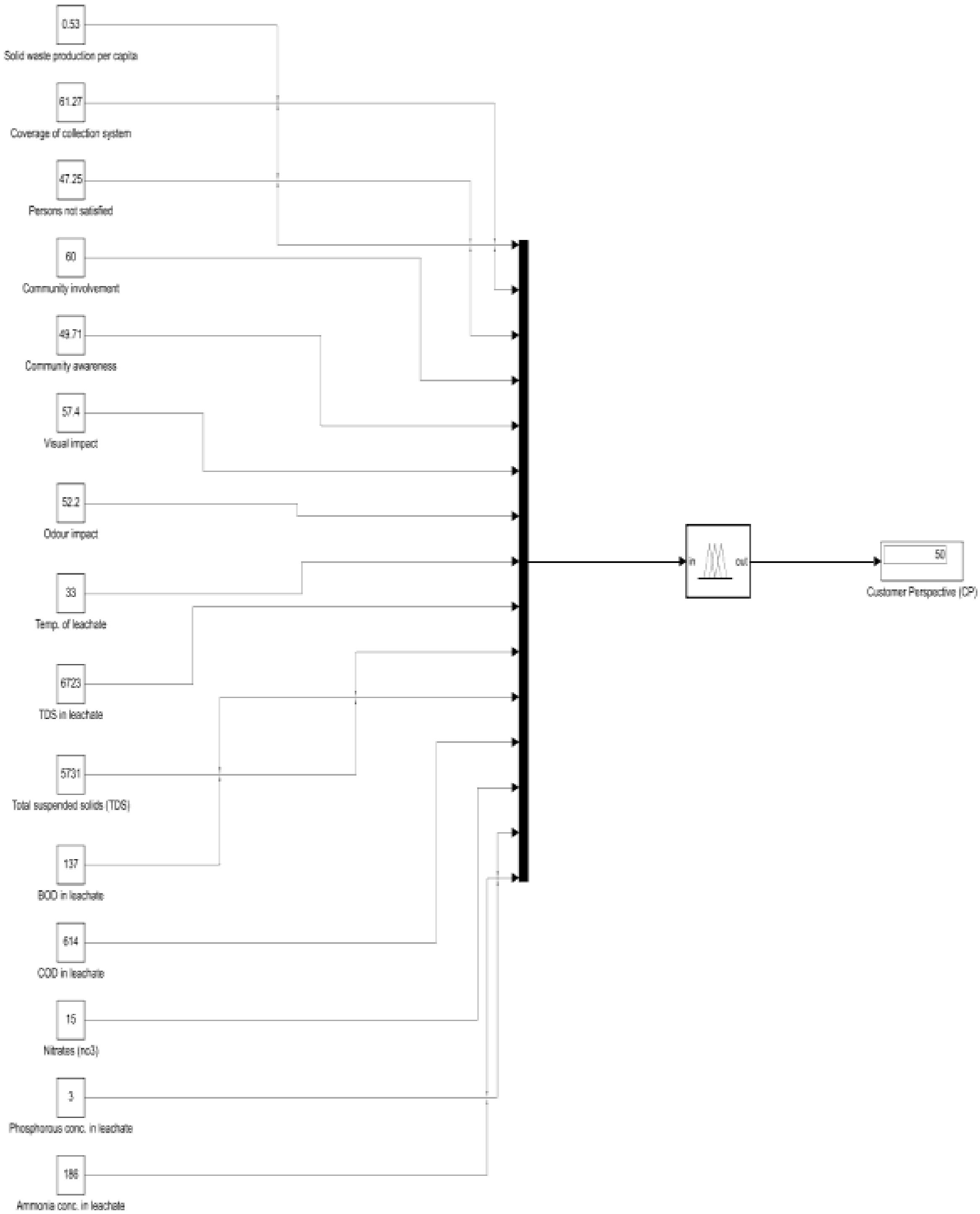

Figure 7. CP Simulink Model

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

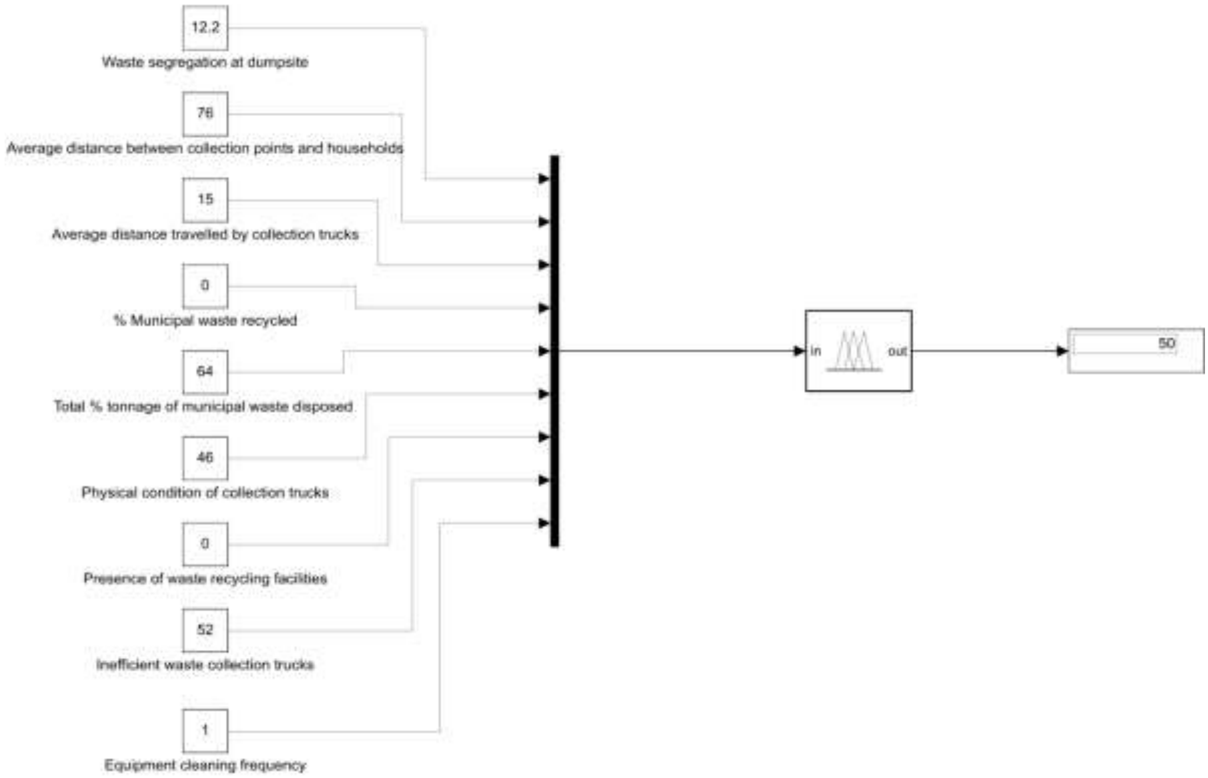

Figure 8. IPP Simulink Model

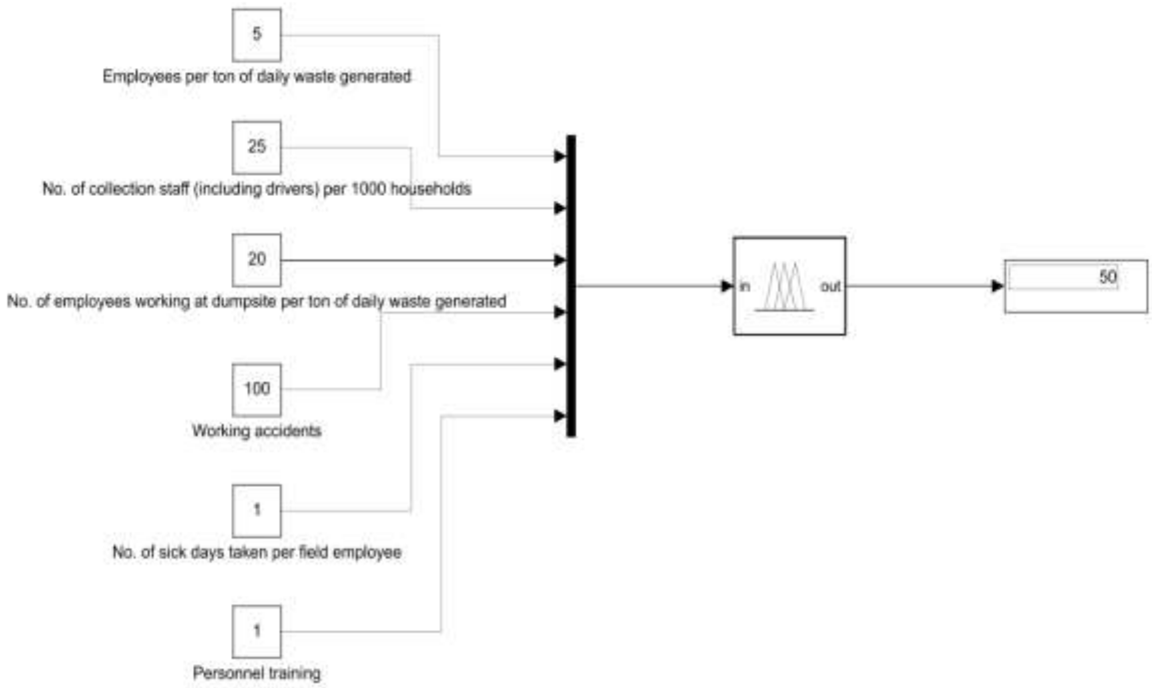

Figure 9. LGP Simulink Model

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 10 Oct. 2024, pp: 13-28 www.ijaem.net ISSN: 2395-5252

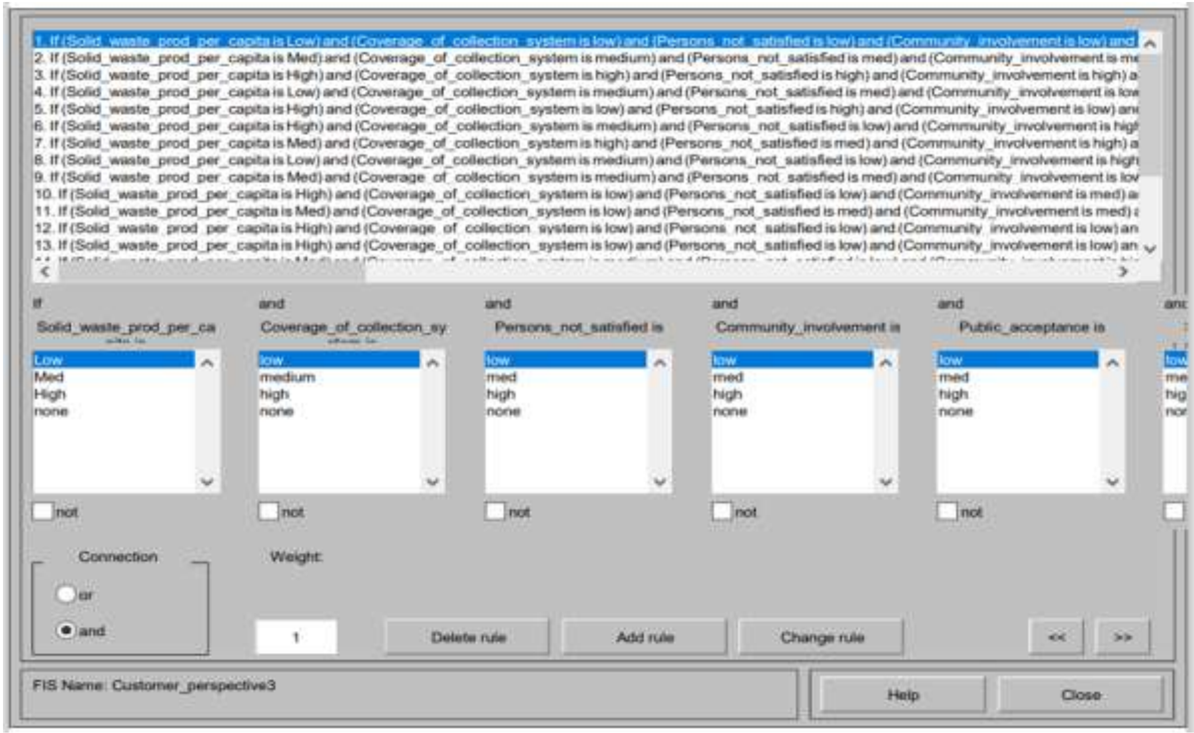

Figure 10. Rule Editor for CP

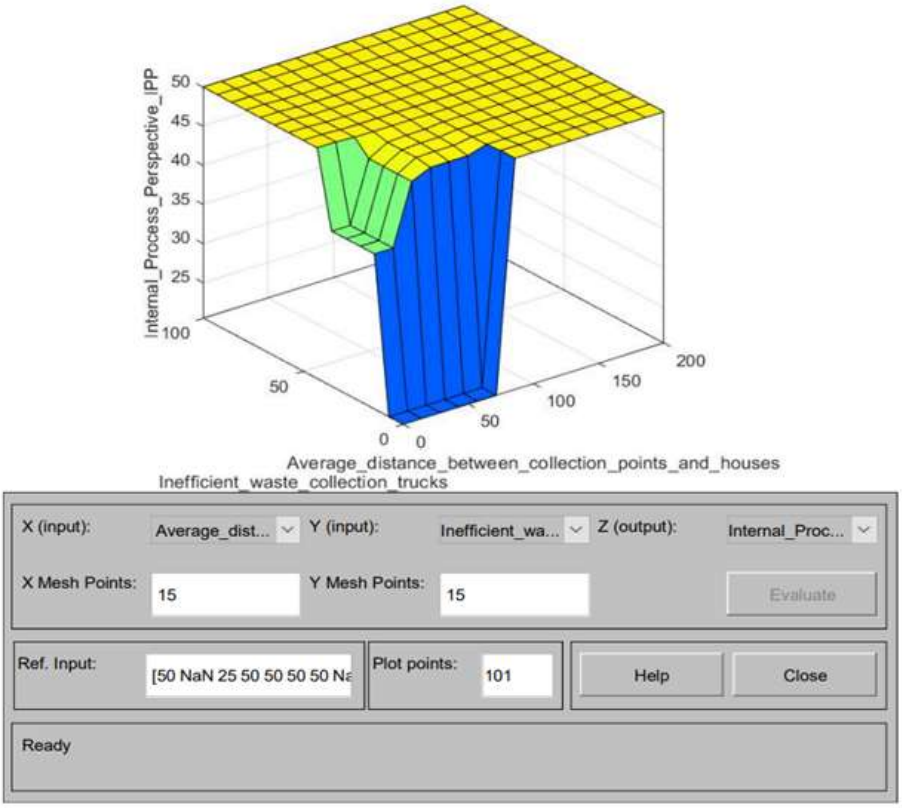

Figure 11. Results for IPP vs. Inefficient Waste Collection Trucks and Average Distance Between Collection Points and Houses