Use of Structural Equation Modeling to improve the Plastic Waste Management of a Brazilian capital

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Abstract. This paper aims to use Partial Least Square Structural Equation Modeling (PLS-SEM) to suggest improvements for increasing the performance of plastic waste management in Salvador, the third most populated Brazilian city, in a country that keeps open dumps as the destination of most of the Municipal Solid Waste (MSW). To achieve the objective, it was necessary a literature review of successful cases from countries and an analysis of the local market. The data collection concerns plastics recycling and profiles of waste management companies. There was also: elaboration and delivery of a survey to the academic and professional public; analysis via software of the data collected; and suggestions regarding plastics recycling rate, market maturity of this kind of waste, and socioeconomic and infrastructural aspects for optimized reverse logistics performance (effectiveness with efficiency). Thus, it must achieve more profitability in reducing waste in inadequate spots and feeding socio-environmental entrepreneurship for the benefit of the Circular Economy. The coefficients of determination, outer loadings, outer weights, collinearity statistics, and bootstrapping values were measured. They suggested that the model is regular for recommending improvements.

Keywords: Plastic Waste Management, Circular Economy, Structural Equation Modelling.

1 Introduction

1.1 Plastics manufacturing and waste management

Due to reasons such as the growth in the use of plastics in the last decades, as well as an increase in the consumption of oil to fulfill the expanding demand for this type of material, the discussion over plastics manufacturing and waste management has lately heated up.

Feasible MSW management practices are recycling, reuse, and Waste-to-Energy (WtE) incineration. Despite this, open dumps remain as predominant in Brazil [1].

1.2 Overview of recycling in the metropolis of Salvador

In Salvador – Brazil's third most populated city with almost 3 million inhabitants – 14 Limpurb (public urban cleaning company) partner cooperatives are in operation [2]. According to the city hall of Salvador, almost 75,000 tons of MSW (Municipal Solid Waste) monthly produced is recyclable [3]. Even though, only 2% was the recycling rate, since just 20% of the population was supported with selective collection.

According to [1], considering all MSW generated in Bahia, the percentage of what could be recycled was 31.9%, and slightly more than a third – 13.5% – corresponds to plastics. Regarding only plastics, almost half of the companies had operations in the Metropolitan Region of Salvador. Only one of the companies operated internationally, producing brooms using PET bottles after recycling them.

Concerning the waste market maturity in the state of Bahia (whose capital is Salvador), 41% of the companies have been working for 5-15 years, and 29% have been working for longer [4].

1.3 Objective

The objective of this paper is to adopt Partial Least Square Structural Equation Modeling (PLS-SEM) to suggest improvements to plastic waste management in Salvador.

2 Methodology

2.1 Choosing the PLS-SEM method

According to [5], the PLS-SEM method can be used even if the data collected do not show a Normal (Gaussian) distribution shape and when the sample size is small. Since it is more suitable for this work than CB-SEM (Covariance-Based Structural Equation Modeling), PLS-SEM was the method chosen for this research.

2.2 The procedure of the PLS-SEM method

The systematic procedure for the use of PLS-SEM is shown as follows, adapted from [6]:

- Step 1: Specify the structural model.
- Step 2: Specify the measurement model.
- Step 3: Data collection and examination.
- Step 4: PLS Path Model estimation.
- Step 5: Assessing PLS-SEM results of the Formative measurement models.
- Step 6: Assessing PLS-SEM results of the structural model.
- Step 7: Advanced PLS-SEM analyses.
- Step 8: Interpretation of results and conclusion.

2.3 Choosing the 5-point Likert scale

The adoption of a numerical scale for answer options was needed to facilitate quantitative measurement with greater accuracy of non-metric answers. The 5-point Likert Scale was adopted with the support of [6].

3 Literature Review

3.1 The Formative measurement model

A Formative measurement model allows us to find the influences of the ordinary variables – the indicators – on the maximization or minimization of an endogenous construct [6]. In Fig. 1, constructs – also called latent variables – are represented as ovals (Y1 to Y4) and indicators as rectangles (x1 to x10). Error terms concerning indicators (e7 to e10) indirectly impact endogenous constructs through indicators x7 to x10 by single-headed arrows. The structural model contains the error terms z3 and z4 concerning endogenous constructs associated with Y3 and Y4 [6].

Each construct score is calculated as a linear combination of each adjacent element's score multiplied either by that element's outer weight w_i (in case of an indicator x_i) or by that element's path coefficient c_i (in case of a construct Y_i) [6].

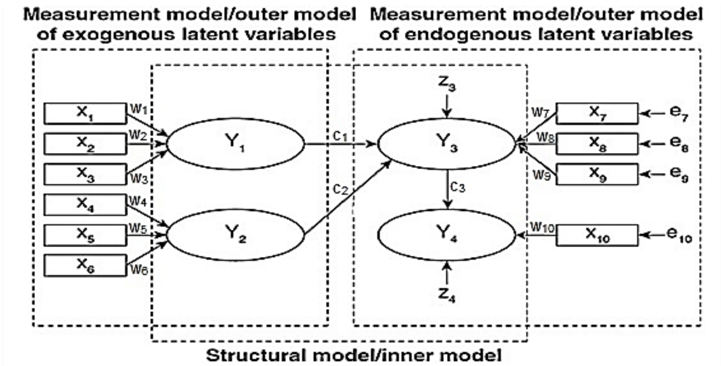

Fig. 1. A generic Formative measurement model. Source: Adapted from [6].

3.2 Criteria for the research

Bibliographical research was made about countries that have had success in reverse logistics (RL) of plastic waste, besides the search of data on both plastic recycling and waste management companies of Salvador. This made it possible to think of this metropolis with the view of foreign successful cases to suggest improvements.

3.3 The Circular Economy

The Circular Economy (CE) encourages the reinsertion of goods consumed into new production chains, with optional post-consumption transformation. According to [7], if all waste generated was used in reverse logistics, the European Union could save annually in material costs from US$340 billion to US$380 billion for a transition scenery, and US$520 billion to US$630 billion for an advanced scenery.

Actions needed to achieve these levels include: (1) planning for a recyclable plastic product with clean methods and green supply chains in manufacturing; and (2) innovative business models connecting industries to customers and RL companies, with policies that directly or indirectly support the market [8].

4 Mathematical Modeling through PLS-SEM

4.1 Relationships between constructs and indicators

For the modeling of plastic waste reverse logistics, the first 3 constructs and the first 6 indicators were adopted from the guiding professor's doctoral thesis [9]. The other constructs and indicators were thought by the student from the literature review. 14 indicators and 5 constructs (Table 1) are present in the model. Of these, the construct Performance was the one whose dependence was evaluated relative to the other items.

Table 1. Constructs and indicators in the model. Source: Adapted from [9] and [10].

Constructs	Position in the model	Indicators
Reverse Logistics Efficiency	Exogenous	EFICI-1 - complexity of waste EFICI-2 - variety of waste (types of plastic: PET, HDPE, LDPE, PP, PS, PVC, or PUR...) EFICI-3 - variability of waste
Reverse Logistics Effectiveness	Exogenous	EFICA-1 - market maturity EFICA-2 - value of waste EFICA-3 - volume processing
Reverse Logistics Performance (Effectivity)	Endogenous	DESEMP-1 - recycling rate DESEMP-2 - thermochemical conversion rate DESEMP-3 - business profitability DESEMP-4 - degree of presence of plastics sorting technologies
Municipality infrastructure	Exogenous	INFRA-1- degree of presence of selective collection in the municipality INFRA-2 - presence of Deposit-Return systems
Municipality socioeconomic aspects	Exogenous	SOCIO-1 - socioeconomic profile of the municipality SOCIO-2 - population density of the municipality

4.2 Theoretical model and hypotheses

For step 1 (from subsection 2.2), four hypotheses were elaborated based on the literature, which is presented along with the corresponding hypothesis.

By reducing waste, optimizing collection networks, and recovering value, RL efficiency is achieved. This can help companies decrease RL costs, reduce investments, and improve performance [11].

- H1: Efficiency positively influences Performance.

The fast handling of collected products, the upgrading of return policies, and the operation of take-back networks enable companies to use the resultant RL effectiveness for strengthening their competitiveness by increasing consumer confidence in both brand and image [11], which improves performance.

- H2: Effectiveness positively influences Performance.

Socioeconomic aspects comprise not only income and consumption expenses – which are positively correlated with the waste generation [5] – but also Gross Domestic Product (GDP). It is reasonable to think that the bigger the GDP, the greater the positive influence on the performance of plastics RL.

- H3: The municipality's Socioeconomic aspects positively influences the Performance.

Improper waste management infrastructure, the application of poor recycling technologies, and lack of public awareness and incentives result in inefficient and ineffective waste management and disposal [12].

- H4: The municipality Infrastructure positively influences the Performance.

The elaboration of those four hypotheses served for didactics and organization, but since categorical notions of "correct result" or "incorrect result" should not be adopted when checking hypotheses with formative models, they only checked whether influence would be exerted by each construct on the RL performance.

4.3 Measurement Model

The proposed formative structure (step 2 from 2.2) is shown in Fig. 2, with indicators in rectangles and constructs in circles.

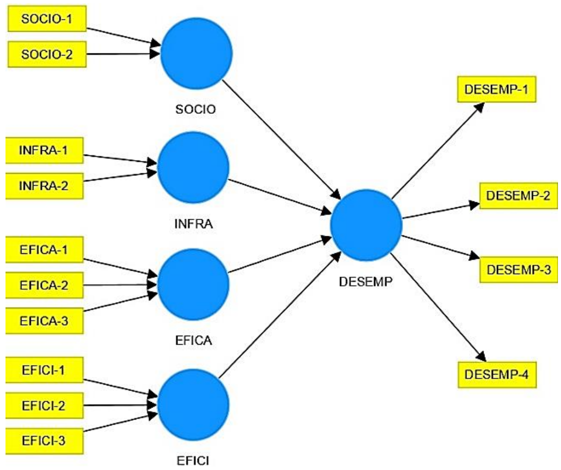

Fig. 2. Formative structure produced with each indicator linked to its construct after running the PLS-SEM algorithm with aid of the SmartPLS 4® software.

4.4 The survey and the consequential respondents' opinions

The survey collected opinions about the degree of influence of each indicator on the performance of collection, sorting, recycling, and return to the market of plastics in the metropolis of Salvador. Producing electricity through Waste-to-Energy should be adopted when recycling is impossible.

For the "10-times rule", the smallest number of respondents should be equal to ten times the largest number of structural paths directed at a construct [6], then 10 x 4 = 40. Although, 71 people among academic and professional public accepted to answer.

The data collected (step 3 from subsection 2.2) from the first three respondents are shown in Table 2. Available answer options were ranging from 1 (lower value) to 5 (upper value) about the degree of influence with which the evaluated indicator positively influenced the performance of plastics RL.

Table 2. Opinions from the first 3 respondents, acronyms meaning E-Efficiency, A-Effectiveness, D-Performance, I-municipality Infrastructure, S-municipality Socioeconomic aspects.

E1	E2	E3	A1	A2	A3	D1	D2	D3	D4	I1	I2	S1	S2
5	4	4	4	1	2	4	4	5	3	4	4	1	3
4	3	3	5	5	5	5	2	2	1	5	4	5	5
3	2	3	2	2	4	3	3	3	3	5	5	3	2

4.5 Model Simulation

The default simulation parameters of the SmartPLS 4® software were kept: all Initial Weights = 1.0; Maximum number of iterations = 300; Stop criterion = 10^-7; Do not use Lohmoeller settings; Path as weighting scheme. That is step 4 (from 2.2).

5 Results

5.1 Results with PLS-SEM algorithm

That is step 5 from subsection 2.2. A screenshot of the path coefficients found after the execution of the PLS-SEM algorithm is shown in Fig. 3. The higher the absolute value, the thicker the arrow displayed. Indicators are in yellow, and constructs are in blue.

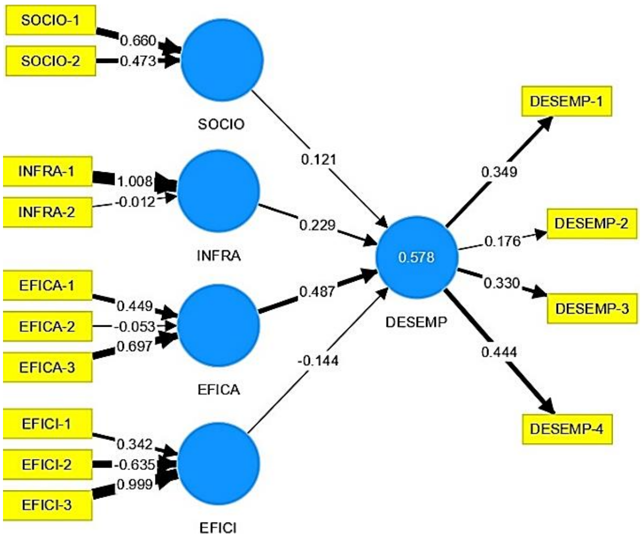

Fig. 3. Values of the path coefficients obtained after running the PLS-SEM algorithm with aid of the SmartPLS 4® software.

5.2 Checking of hypotheses

That is step 6 (from 2.2). According to Fig. 3, all exogenous – independent – constructs on the left showed a positive influence on Performance (DESEMP), except Efficiency. This is explained because its three indicators related – EFICI-1-complexity in the shape, EFICI-2-working with varieties of types of plastic in the same place, EFICI-3-variability (impurity) – had meanings in themselves not beneficial in the respondents' understanding for the RL performance. Thus, low complexity shapes, concentration on only one type of plastic, and the absence of impurity in the waste must favor performance.

The other hypotheses (H2, H3, H4) – referring to constructs that had positive path coefficients towards performance – had their positive influence confirmed but with distinct strengths (values 0.487, 0.121, 0.229), whose measurement was an intention.

5.3 The equation representing the structural model

The endogenous construct Performance (DESEMP), in this study, should be calculated by Equation 1, being ζ the noise treated in the endogenous construct.

$$\text{DESEMP} = 0.121\ \text{SOCIO} + 0.229\ \text{INFRA} + 0.487\ \text{EFICA} - 0.144\ \text{EFICI}^{*}) + \zeta \qquad (1)$$

The higher the value of the non-metric construct DESEMP, the better the outcome for the performance of plastics RL. The calculation of the exogenous constructs SOCIO, INFRA, EFICA, and EFICI can be deduced from what was explained in 3.1.

5.4 Coefficients of determination

The value of the adjusted coefficient of determination for the endogenous construct Performance was $R^2adj=0.553$; the non-adjusted coefficient was $R^2=0.578$. R^2adj considers the minimum structure necessary for the model.

5.5 Outer Weights and Outer Loadings

There were only three negative outer weights, and seven above 0.400, which confirmed a reasonable significance level of half of the indicators, according to criteria from [6], since the outer loadings were good in general. Ten were the outer loadings above 0.700, therefore high the significance level of the corresponding indicators for the model [6].

Table 3 shows the ten highest outer weights and the ten highest outer loadings values in descending order.

Table 3. Ten highest outer weights and outer loadings obtained after the execution of the PLS-SEM algorithm.

Interactions	Outer Weights	Interactions	Outer Loadings
INFRA-1 -> INFRA	1.008	INFRA-1 -> INFRA	1.000
EFICI-3 -> EFICI	0.999	EFICA-3 -> EFICA	0.936
EFICA-3 -> EFICA	0.697	SOCIO-1 -> SOCIO	0.918
SOCIO-1 -> SOCIO	0.660	EFICI-3 -> EFICI	0.845
SOCIO-2 -> SOCIO	0.473	SOCIO-2 -> SOCIO	0.833
EFICA-1 -> EFICA	0.449	DESEMP-4 <- DESEMP	0.831
DESEMP-4 <- DESEMP	0.444	EFICA-1 -> EFICA	0.828
DESEMP-1 <- DESEMP	0.349	DESEMP-3 <- DESEMP	0.815
EFICI-1 -> EFICI	0.342	DESEMP-1 <- DESEMP	0.811
DESEMP-3 <- DESEMP	0.330	INFRA-2 -> INFRA	0.703

[*] The negative sign in the path coefficient for EFICI is explained in subsection 5.2. It is an undesired consequence of a mistake in the meaning of the indicators EFICI-1, EFICI-2, and EFICI-3, which were inherently negative in the survey, as if it were Inefficiency and not Efficiency. The reader, if they want, is free to think that if Inefficiency obtained a coefficient of -0.144, then the correspondence for Efficiency is 0.144.

5.6 Collinearity statistics

No collinearity problem was detected. Concerning the external model, the indicator of the lowest VIF (Variance Inflation Factor) was 1.203, and the highest value was 2.013. Only values of 5.000 or above would indicate a problem [6].

Regarding the internal model, the construct with the lowest VIF obtained 1.252, against 1.659 for the highest. None was 5.000 or above. Table 4 shows all VIFs.

Table 4. External and Internal VIF values obtained after running the PLS-SEM algorithm.

Interactions	External VIF	Interactions	External VIF	Interactions	Internal VIF
DESEMP-1	1.715	EFICI-1	1.357	EFICA	1.645
DESEMP-2	1.203	EFICI-2	1.457	EFICI	1.252
DESEMP-3	1.752	EFICI-3	1.289	INFRA	1.659
DESEMP-4	1.634	INFRA-1	2.013	SOCIO	1.569
EFICA-1	1.676	INFRA-2	2.013		
EFICA-2	1.339	SOCIO-1	1.425		
EFICA-3	1.565	SOCIO-2	1.425		

5.7 Bootstrapping

In this work, bootstrapping (step 7 from 2.2) assesses the significance of the outer weights when cannot be guaranteed that the answers follow a Normal (Gaussian) distribution pattern.

The number of bootstrapping samples should be high and at least equal to the number of observations. Each sample from the total of 5000 (SmartPLS® default value) contained 45 observations. Thus, 5000 structural models via PLS-SEM were estimated. Besides the number of samples, the other conditions set were: “Bias-corrected and accelerated bootstrap” as the confidence interval method; “Two-tailed” as the test type; and 0.10 as the significance level, with the support of [6].

In Table 5, results are displayed for the outer weights – more relevant for formative measurement models than outer loadings – found via bootstrapping. There, Original sample contains the values already shown in Table 3, and the Samples mean is computed considering all the 5000 bootstrapping samples.

Special attention is given to the p-value of each outer weight, which should be smaller than the significance level (0.10) to confirm that the corresponding indicator is statistically significant. The interactions whose p-values are greater than 0.10 are not considered among the suggestions of improvement (subsection 5.8) for the plastic waste RL, which is step 8 from subsection 2.2.

Table 5. Outer weights and related statistics found via bootstrapping.

Interactions between indicator and construct	Original sample	Samples mean	Standard deviation	T statistics	P-value
DESEMP-1 <- DESEMP	0.349	0.347	0.039	8.918	0.000

Interactions between indicator and construct	Original sample	Samples mean	Standard deviation	T statistics	P-value
DESEMP-2 <- DESEMP	0.176	0.186	0.077	2.281	0.023
DESEMP-3 <- DESEMP	0.330	0.332	0.047	6.997	0.000
DESEMP-4 <- DESEMP	0.444	0.429	0.052	8.594	0.000
EFICA-1 -> EFICA	0.449	0.442	0.160	2.808	0.005
EFICA-2 -> EFICA	-0.053	-0.044	0.151	0.353	0.724
EFICA-3 -> EFICA	0.697	0.674	0.171	4.066	0.000
EFICI-1 -> EFICI	0.342	0.303	0.446	0.766	0.444
EFICI-2 -> EFICI	-0.635	-0.374	0.521	1.219	0.223
EFICI-3 -> EFICI	0.999	0.712	0.541	1.846	0.065
INFRA-1 -> INFRA	1.008	0.998	0.176	5.740	0.000
INFRA-2 -> INFRA	-0.012	-0.018	0.247	0.048	0.962
SOCIO-1 -> SOCIO	0.660	0.634	0.259	2.548	0.011
SOCIO-2 -> SOCIO	0.473	0.463	0.270	1.753	0.080

5.8 Suggestions for improvement of the plastic waste RL

Suggestions concerning the plastics recycling rate

The plastics recycling rate (DESEMP-1 indicator of coefficient 0.349 in Fig. 3 and seventh indicator in Table 1) influences the reverse logistics performance. Materials to increase the rate should be considered in industrial production, namely (1) black polypropylene; (2) crystallized PETE (Polyethylene Terephthalate); (3) odor-free recyclable plastic; (4) fluorescent markers for improving sorting [12].

Suggestions concerning market maturity

The maturity of the plastics waste market (indicator EFICA-1 of coefficient 0.449) makes more likely investments in sorting technologies (DESEMP-4 of coefficient 0.444) that allow dealing with the variability of the plastic waste (EFICI-3 of coefficient 0.999). Allied with this, it makes it possible to work with a greater volume of plastics (EFICA-3 of coefficient 0.697) due to the increase in capacity arising from the investment, which allows greater profitability (DESEMP-3 of coefficient 0.330).

The market maturity also positively influences the complexity of waste (EFICI-1 of coefficient 0.342) in the medium- and long-term. It encourages changes in the shapes and sizes produced in the plastics industry to better serve the recycling market. The maturity should also influence the increase of power production from the thermochemical conversion (DESEMP-2 of coefficient 0.176) of unrecyclable and more energetic plastics to supply the municipality's electrical distribution network.

Suggestions concerning socioeconomic and infrastructural aspects

People in a condition of socioeconomic vulnerability should be encouraged by public policies to organize themselves into cooperatives and/or socio-environmental impact companies to strengthen the outcome of waste pickers' work and generate more income for all involved. This not only raises RL performance, but also improves the socioeconomic profile of the municipality (SOCIO-1 of coefficient 0.660), uses population density (SOCIO-2 of coefficient 0.473) in favor, and provides increased waste sorting for selective collection (INFRA-1 of coefficient 1.008).

Deposit-return machines (DRS) can be installed in parks, streets, and avenues, for increasing plastics recycling. The DRS scheme consists of charging the consumer of a bottled beverage a cash deposit when it is purchased, later then the deposit is recovered when the bottle is returned. This scheme has been successful in Norway, Sweden, Finland, Denmark, and Germany, the latter with 93% of PET bottles recycled in 2015 [13].

6 Conclusion

According to suggestions from this paper, plastic waste companies that improve their performance (effectiveness with efficiency) in reverse logistics must achieve optimized recycling productivity and competitive market prices, thus enabling the generation of more jobs and boosting economics.

Even though the model was elaborated regarding the infrastructural and socioeconomic issues of the Brazilian metropolis of Salvador, the model can be a basis – which may require adaptations – for other cities worldwide with analogous characteristics.

The opportunities promoted by Reverse Logistics must feed the social, environmental, and sustainable entrepreneurship – which should receive economic support – to increasingly reduce the waste of materials in inadequate destinations, reinforcing the Circular Economy. In addition, the budget planning for medium- and long-term public policies must be more assertive if the model here proposed is improved with a survey involving a larger sample size, including adjustments after the results.

7 Future Developments

As a suggestion for future research, more attention to MSW (Municipal Solid Waste) should involve:

- Study with other components of MSW, such as metals and electronic waste, through a partnership with other researchers.
- Use of the same methodology in cities around the globe of analogous size to Salvador.
- Put into practice – in the management of MSW in Salvador – the results of a broader and more definitive version of this study.
- The use of PLS-SEM in conjunction with ISM-MICMAC in a hybrid model, as shown in the doctoral thesis from [14], that would give more sophisticated and instructive results for society and both public- and private- management.

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