Tackling the Mess: System Conceptualization through Cross-Impact Analysis

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Abstract

A common first step for building a system dynamics model is the selection of variables. This is one of the most important activities in the construction process because they constitute the building blocks upon which the explanations for complex patterns of behavior are proposed based on the interrelations of those variables. This work aims to present an option to systematically help to guide the selection of key variables integrating quantitative and qualitative analysis. A current project in Colombia that develops a dynamic conceptualization for Solid Waste Management policy-making is used as an example.

Keywords: *conceptualization, cross-impact method, MICMAC, variables selection, solid waste management*

1. Introduction

We develop models of systems. However, conceptualizing is still one of the least understood steps in the modeling process. Nathaniel Mass chaired a famous plenary session on methods of conceptualization at the 1981 International System Dynamics Conference. The question posed by Mass were published in 1986 in an article (Mass 1986) that John Sterman wonderfully introduced as follows: “Conceptualization is really jargon for the mysterious process of creating a new idea, a word designed to make the creative act sound scientific, scholarly, and repeatable” (p. 76). However, there are tools that may help to guide the conceptualization process. In this paper we show how we used the Cross-Impact Method for building a first causal-loop diagram in a solid-waste management project integrating both qualitative and quantitative elements. We believe that this method provides a useful way to systematically think and conceptualize complex issues and can support model building processes.

The article is organized as follows. The next section briefly presents the method; the construction of a cross-impact matrix and the importance of graphical representation are highlighted. The third part illustrates this method as it was used in a current project in solid-waste management; the identification of the problem, the pre-selection of variables, the identification of stakeholders and the selection of key variables are underlined. The final result, a first causal-loop diagram allowing for a dynamic conceptualizing of the problematic situation is presented. The last section summarizes the main points.

2. Methods

Prior to model construction a minimal and reliable understanding of the complexity of the matter to study is mandatory. That understanding is possible through a selection of elements that the modeler establishes as relevant (Sterman 2000). The ability for capturing the important variables over the less important ones is a demanding task improved with experience and time. The selection process is ruled by qualitative data collection of information trough an informal and intuitive way. And yet, both quantitative and qualitative data should be collected schol (Scholz and Tietje 2002). Cross-impact analysis involves the identification of constituent variables of an event or a system and allows for the evaluation of the interaction between variables (Godet 2006). The Cross-impact analysis was developed in the 60's by Theodore Gordon and Olaf Helmer and since then it has been studied in many fields.

The method consists of three stages. The first one is the problem identification in which the current state of the situation is described. The second one is the identification of variables and stakeholders where interactions between variables are established and, finally, in the third stage the identification of key variables is done through structural analysis.

2.1 Problem Identification

In this stage, an event is identified and should be defined in a precise way. To ensure that goal, much information is required to support the facts that are describing the current state of the situation (Godet 2000, 2008). This step draws a parallels with what Sterman (2000) calls "problem articulation".

2.2 Variables and Stakeholders Identification

Once the problem has been identified and articulated, a set of variables and stakeholders are listed. The modeller should keep in mind the fact that they are affecting the problem and therefore the system. It is suggested that the set should not exceed 80 variables (Godet 2000)

2.3 Structural Analysis, Key Variables Identification with MICMAC

It is important to select which variables are sufficient for a valid description of the current state of the case and its dynamics (Scholz and Tietje 2002). The selection of variables which are both influential and dependant is the first evidence of dynamics in a system (Godet 2008), that is, the fact that an endogenous and dynamic view lie beneath a good *systemic* conceptualization.

2.3.1 Cross-impact Matrix (Direct and indirect)

To determine potential interactions in a set of variables, the construction a cross-impact matrix for scaling the most relevant direct impact variables should be done (Table 1).

	Var 1	**Var 2**	**Var 3**	**Var j**	**Influence** **(*y* coordenate)**
Var 1	0	Var 2,1	Var 3,1	Var j,1	Var 2,1+ Var 3,1 + Var j,1
Var 2	Var 1,2	0	Var 3,2	Var j,2	Var 1,2 + Var 3,2 + Var j,2
Var 3	Var 1,3	Var 2,3	0	Var j,3	Var 1,3 + Var 2,3 + Var j,3
Var i	Var 1,i	Var 2,i	Var 3,i	0	Var 1,i + Var 2,i + Var 3,i
Dependence **(*x* coordenate)**	Var 1,2 + Var 1,3 + Var 1,I	Var 2,1 + Var 2,3 + Var 2,i	Var 3,1 + Var 3,2 + Var 3,i	Var j,1 + Var j,2 + Var j,3	

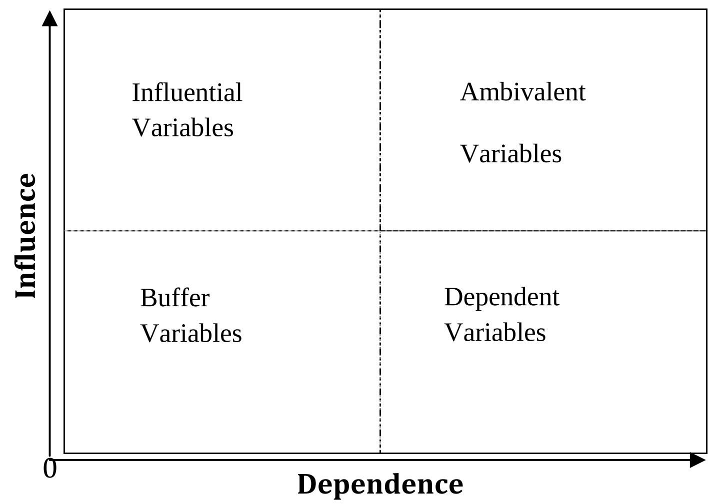
Table 1. Impact matrix model

If there is a direct relation between two variables, the influence could be rated in different levels; low (1), medium (2) high (3) or potential (4) from a variable i to a variable j. The grading in the matrix is suggested to be made by teamwork and strong participation of experts and relevant stakeholders (Godet 2000). Once the grading is done for all variables it is possible to observe that the row sum for each variable will tell the influence level; similarly, the columns sum will tell the dependency level.

Once this matrix of direct impacts is built, the indirect impacts could be established using the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC), which was consolidated between 1972 and 1974 by Michel Godet in collaboration with J.C. Duperin (Godet 2000). MICMAC multiplies the graded direct impact matrix with itself several times. For each run, it calculates the sums of columns and rows and does so until these values show stability.

2.3.2 Graphical representation

Both direct and indirect influences can be represented in a grid (Fig. 1) where the direct and indirect matrix impacts are used. For each variable it is possible to locate a place into the grid from a couple of *x,y* coordinates obtained from the row and column sum of the direct or indirect matrix (Table. 1). For example for Variable 1 the (x,y) coordinates correspond to (Var 1,2+Var 1,3+…+ Var 1,i , Var 2,1+Var 3,1+Var j,1)



------------ Mean influence score
-·-·-·-·-·-·-·- Mean dependence score

Figure 1. Impact activity scheme. Adapted from Scholz and Tietje (2002)

The grid is divided in four quadrants representing four types of variables. The differences between the variables lie in the value for the influence and dependence. The influential variables represent input variables; the dependent variables represent output variables. Buffer variables are the less important variables in terms of dependency and influence. Ambivalent variables are important because they have both influence and dependence in the system and they could change to be input or output variables.

2.3.3 Selection of Key variables

From the results of grading and its graphic representations, it is possible to compare and evaluate the results from which the key variables of the system will be obtained. These variables will be those that occur simultaneously or not simultaneously in the upper left quadrant of influential variables or in the lower right quadrant of dependent variables, for both direct and indirect matrices. Ambivalent variables also must be taken into account

These results will show the key variables of the system but will not exclude the rest of variables that work in the system. It is just telling that those “key variables” are the variables on which greater attention should be placed.

3. Illustrative example. Solid Waste Management (SWM)

Environmental systems such Solid Waste Management (SWM) systems are complex systems generated by human activities interacting with the environment exhibiting emergent properties evidenced by their patterns of behavior (Ford 1999; Deaton and Winegreake 2000). They can also be interpreted as embedded systems, where one of the most relevant characteristics is that they lead to counterintuitive results. This type of systems can be studied with system dynamic models, where different dimensions of the system (social, financial, political, technical, etc.) can be included.

We are currently developing a SWM project for a Colombian small municipality. The purpose of this project is to develop sustainable policies that account for the complexity of the interaction of people, waste, information, resources and environmental factors. One of the first steps in this project was to develop a first conceptualization that should drive the discussion and the construction of a solid system dynamics model. This first step is summarized in this section.

3.1 Problem Identification

Colombian established in 1997 as a national priority to develop integral solid waste management systems. This was a logical call since the accelarated population growth, its massive solid waste generation through the years, and the need to handle large quantities of residues that the country was not prepared to handle, demanded national action.

This policy established several goals such as the reduction (or even avoiding) of source generation and consistent and sustainable processing and treatment in order to reduce the waste quantity going to final disposal. As a result, a concern for the adequate and controlled final disposal in sanitary landfills emerged because they were misused or dominated by uncontrolled open dumps. Also there were practices of disposal in water bodies, open burnings and burials. Over time, Colombian data has shown that integral solid waste systems have worked better for large municipalities and cities with high density populations. It is presumed that this sistuation occurs because environmental authorities have a better understanding of the operation of such systems in those kinds of municipalities. For example, in 2008, Colombia had 1088 municipalities generating approximately 25 tons day of solid waste. A 41% from the total were from 4 big cities (Bogotá, Medellín, Cali and Cartagena), an additional 19% from 28 capital cities and the remaining 40% were from 1056 small municipalities (Superintendency 2009). The big cities and some municipalities have been able to improve their performance in the public solid waste management service. However, minor municipalities have technical, institutional and financial troubles to improve their performance.

To improve the understanding of the situation, our project started a first conceptualization to understand how waste management works in minor municipalities in Colombia.

3.2 Pre-selection of Variables

In order to establish a first set of relevant variables primary basic information was consulted, i.e. national laws, decrees, national and departmental policies and studies, municipal performance reports and experience sharing of institutions, enterprises and experts. 46 variables were identified (Table 2).

Variable N°	Long Title	Short title
1	Per capita solid waste generation	Var01
2	Household users	Var02
3	Household composition	Var03
4	Population	Var04
5	Population Density	Var05
6	Source sorting	Var06
7	Waste composition	Var07
8	Desired waste collection (Coverage)	Var08
9	Collection rate	Var09
10	Waste recovery	Var10
11	Profit of waste recovery	Var11
12	Recovery rate	Var12
13	Waste treatment	Var13
14	Average distance between rural households	Var14
15	Total waste to be transported	Var15
16	Distance to final disposal site	Var16
17	Transportation cost	Var17
18	Type of transport	Var18
19	Sanitary landfill reception capacity	Var19
20	Area availability for solid waste final disposal in sanitary landfill	Var20
21	Sanitary landfill capacity	Var21
22	Lecheate production	Var22
23	Average employment generation	Var23
24	Final disposal costs	Var24
25	Fraction of waste disposal	Var25

Variable N°	Long Title	Short title
26	Negative Impact of waste disposal	Var26
27	Hoseholds Affordability for the sanitation service	Var27
28	Average charge	Var28
29	Billing collection efficiency	Var29
30	Financial resources availability	Var30
31	Infrastructure investment	Var31
32	Mortality rate	Var32
33	Birth rate	Var33
34	migration rate	Var34
35	Population average educational level	Var35
36	Environmental education	Var36
37	Purchasing power	Var37
38	Employment rate	Var38
39	Consumption pattern	Var39
40	waste generation avoidance	Var40
41	Perception of solid waste management quality	Var41
42	Industrial Growth Rate	Var42
43	Industry Productivity	Var43
44	Industrial waste avoidance	Var44
45	Sanitation service regulation	Var45
46	Life quality	Var46

Table 2. Pre-selected Variables

3.3 Stakeholders identification

Various stakeholders were identified:

- Households, waste generators
- Municipal Government (Office of the Mayor)
- Departmental Government (Office of the Governor)
- National Government (Ministry of Environment, Housing and Territorial Development, and National Planning Department
- Environmental authorities (Autonomous Regional Corporations)
- Institutional Regulator (Public Services Superintendency)
- Economic Regulator, pricing functions (Regulatory (National Commission for Water and Sanitation)
- Local Industry
- Solid waste service providers, municipal or prívate.

3.4 Identification of Key Variables

After the variables identification, an impact matrix was constructed and graded.

The results from the use of the MICMAC software (developed by the Strategic Prospective and Organization Laboratory) permits to establish direct (Figure 2) and indirect (Figure 3) relations between variables into grids. Matrices are not shown because of their size.

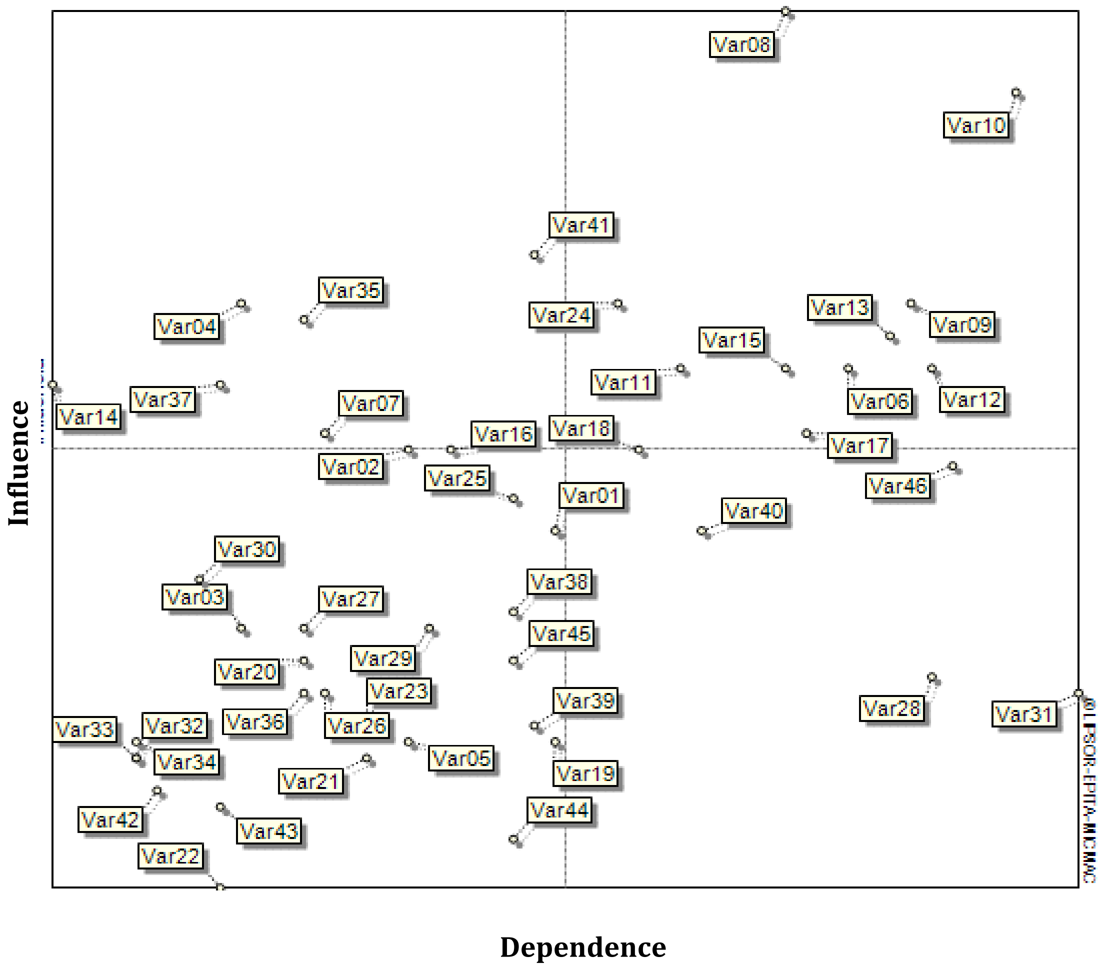


Figure 2. Direct Impact Activity Grid

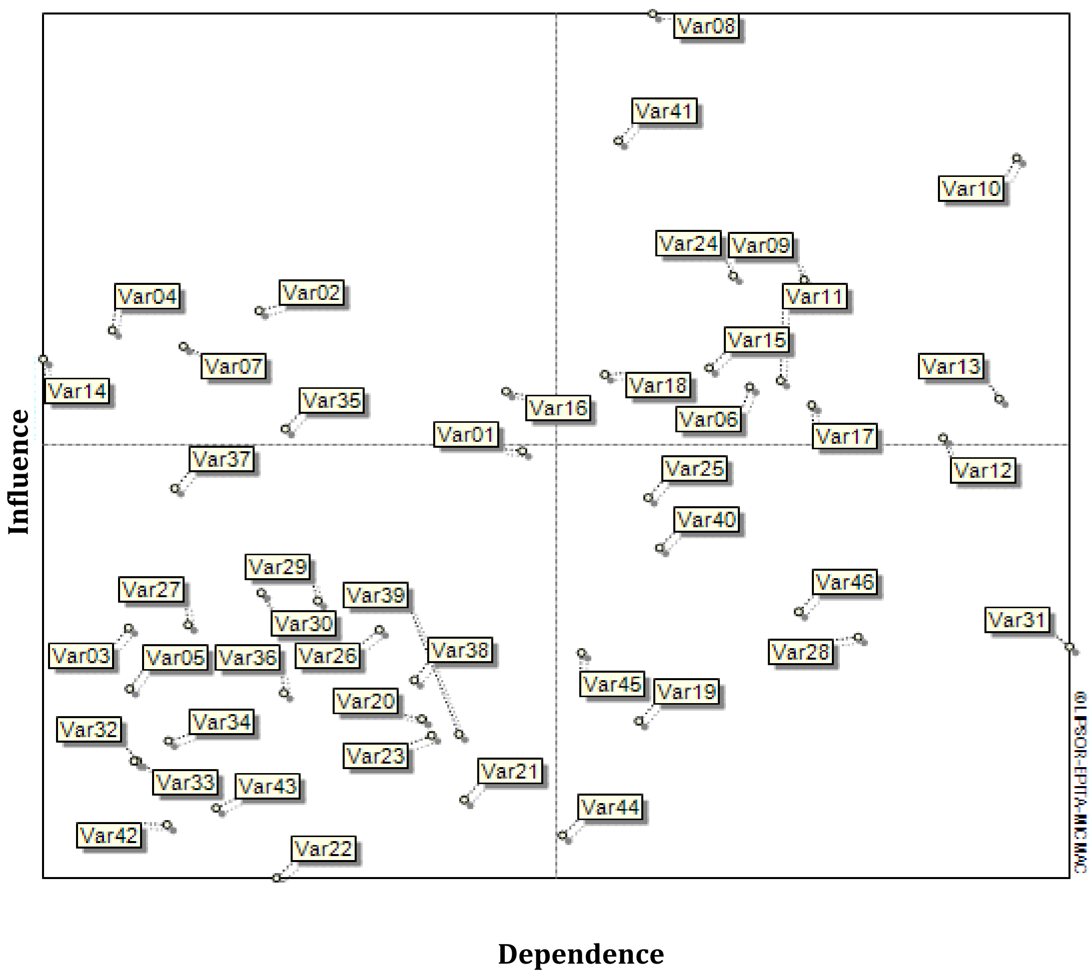


Figure 3. Indirect Impact Activity Grid

Once the direct and indirect activities grids were done, overlapping them was possible to determine whether there was a displacement of the variables between the grids. That displacement can be understood as the variation of the influence-dependence of the variables associated to the type of impact, either direct or indirect.

After contrasting the direct and indirect grids and determining the variables displacement, it was possible to notice that the input variables are not very strong compared to the output or ambivalent variables. Although the input variables are very important they were not selected as key variables. Only 6 from the 46 pre-identified variables were stablished as key variables for the model construction based on their displacements between grids and their location within them. Three variables from the six were ambivalent; the three remaining were output variables for the system.

Ambivalent variables:

- Variable 8, which is the desired waste collection in terms of public waste collection coverage.
- Variable 10, related to solid waste recovery.
- Variable 41 associated to the perception of solid waste management service quality

Output variables:

- Variable 28 which is the average charge fee to households (users)
- Variable 31: Infrastructure investment for the solid waste management service
- Variable 46 related to the life quality improvement in the minor municipalities population, associated to the sanitation enhancement for solid waste management activities

The variable 46 showed interesting properties from the indirect activity grid. This fact was impossible to notices just with direct impacts grading in a matrix or with a causal-loop diagram.

From the MICMAC software, direct and indirect relation graphs are optional to be generated. In this graphs, the high influences among variables are represented. For the direct impact the influences scored with 3, as described in section 2.3.1, are shown (Fig. 4). For the indirect impacts the values obtained from the matrix multiplication are use to establish the influences (Fig. 5).

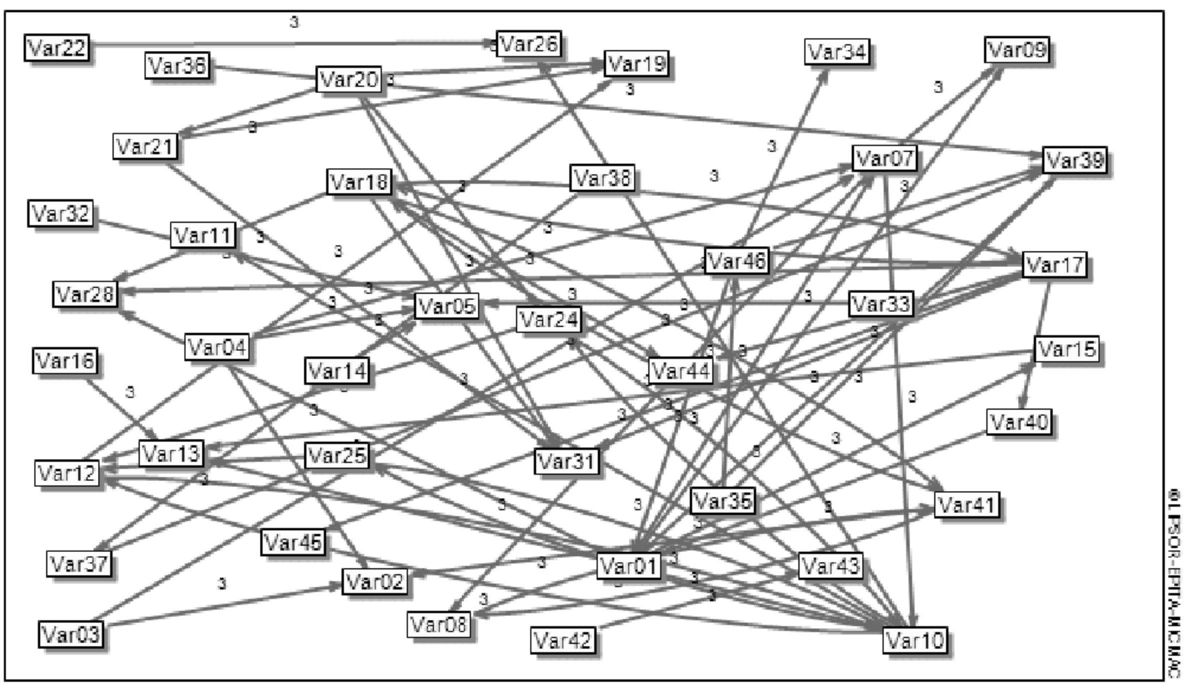


Figure 4. Direct influences graph

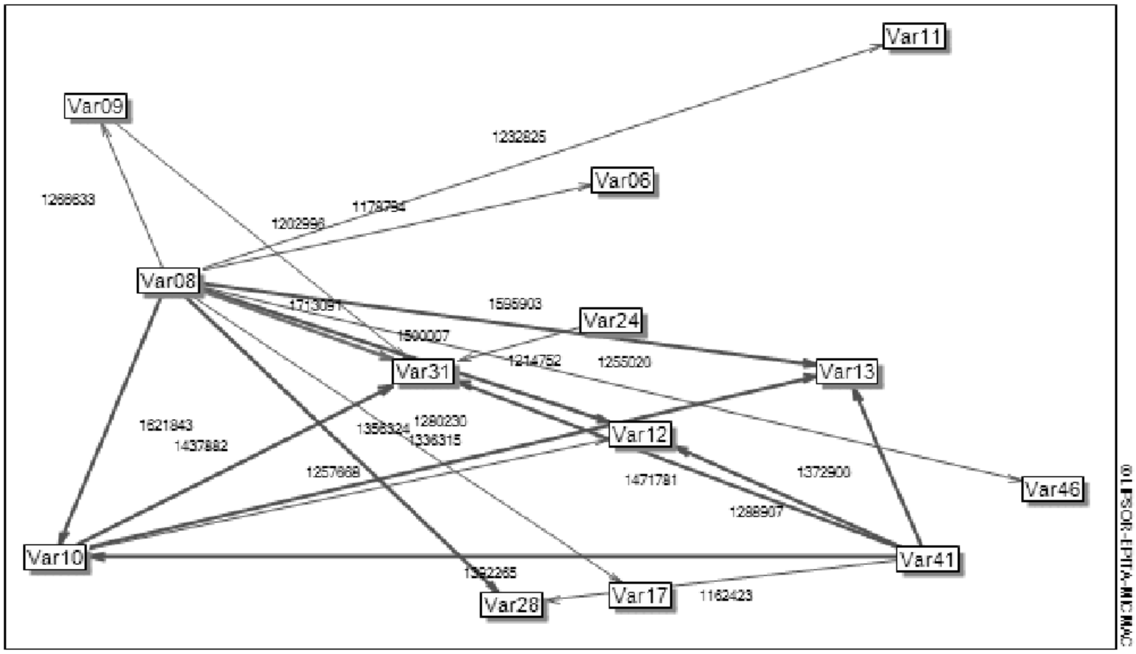


Figure 5. Indirect influences graph

The direct and indirect relation graphs work as a reference for Causal Loop Diagrams (CLD) construction. In this way, the process of constructing the CLD is a task more ordered and less intuitive. The CLD that was built based on the generated graphs is shown in the Appendix 1. This is the base for developing further conceptualization and refinement for building a simulation model.

4. Outlook

The systemic conceptualization of a SWM system is possible to be done with the use of system dynamics models. However, the complexity of this task can be overwhelming. Cross-impact methods can help to guide this process. Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) is a useful tool to establish key variables selection and it can improve the understanding of both direct and indirect interactions.

We presented the way we have used cross-impact analysis to develop the first steps for conceptualizing a solid waste management system for small municipalities in Colombia. The complexity of the issue demanded a systematic method to simplify the number of variables without loosing important elements that may help to develop an accurate model of the situation. Although we share the view that conceptualization is more art than science, we believe that organized methods may also help to tackle complex issues, at least in a first step. The visualization of variables, the quantification of relevance, and the significance of the grade of impact of some variables over other ones, are elements that can be deal with in a systematic way. This approach can serve as a basis for addressing further complex issues such as feedback loop conceptualization, group model building processes and quantification of variables for developing simulation models. This disciplined thinking counter-balances the creative act of posing variables and relationships so as to have a balanced approach to model building. We think that this method can be valuable for system dynamics modelers in order to guide the complex and artistic task of building models.

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Appendix 1. SWM Causal Loop Diagram based on a MICMAC analysis