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A SPATIO TEMPORAL SIMULATION MODEL FOR EVALUATING DELINQUENCY AND CRIME POLICIES

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ABSTRACT

System Dynamics, has been useful for a variety of disciplines; however, it has limitations in showing a geographical representation of the models under study. This paper proposes a methodology based on layered vectors which allows the use a city's census information to feed a Geographic Information System (GIS). The GIS objects implemented into System Dynamics and located at coordinates X.Y.Z become the entry parameters for the simulation.

The simulation outputs close an analysis cycle, by means of adding new layers which are represented in the GIS. Consequently, the simulation provides feedback for vectorial representation which we successfully used to simulate strategies that can be used to reduce criminality rates in the city under study.

1 INTRODUCTION

Over the last two decades, numerous modeling and simulation implementations have been used across a geographic dimension, to study crime in urban zones. An excellent representation of these developments is found in the *"Crime Mapping and Analysis Program"* (CMAP 2004) from the US Government Department of Justice. The program's main objective is to carry out an intelligent analysis of the information contained in digital maps, providing reports which enable the monitoring, identification and prediction of the most critical urban crime zones.

In concert with digital geographic representation, analytical research has been carried out in order to determine the existing relationships between the most significant factors which influence the makeup of a criminal act as a social expression phenomenon.

From an economic viewpoint, Massourakis et al in 1984 published one of the first studies on the existing relationships between unemployment, race and criminality indexes, based on United States data from years 1970-1981(Massourakis, Rezvani and Yamada 1984). Using the growing functionalities of Geographic Information Systems (GIS), the *"Simulating Crimes and Crime Patterns Using Cellular Automata and GIS"* study was published in 2003(Liang, Liu, Eck 2001). The study aimed to develop a simulation model for crime patterns via spatial and temporal representation using "ArcView" GIS software, combined with the implementation of Cellular Automata. The study used one of the most influential crime theories, the "*Routine Activity Theory*" (RAT) developed by Lawrence Cohen and Marcus Nelson.

2 OBJECTIVE

The present study draws upon a methodology which enables the evaluation of "social policies" required to reduce crime indexes in urban zones. In keeping with the same, a simulation model associated with a GIS was built which included the most significant variables affecting criminality indexes. The model behaves like an agent that produces a reaction in both time and space.

The study's steps were to:

- Determining what variables influence criminality rates within a city's population. The data was obtained from demographic and social census databases.
- Building a GIS as an interface for the time-space representation of social policy simulation patterns.
- Using the attributes selected from the databases, (SQL query) to implement social policies with a Systems Dynamic methodology. See Figure 1.
- Validating the simulation model in three sectors of a city which features significantly opposing socio-economic indexes.
- Proposing a "social policies" evaluation methodology, employing the procedures, models and simulation developed in the study.

The three most difficult aspects of achieving realistic simulation were:

- Identifying and selecting databases for the study. These databases needed to demonstrate what influence social policies have had over time in reducing criminality rates in selected urban areas.
- Building the cause and effect models among the most significant variables which enabled the explanation of high criminality rates, and carrying out tests to validate the models.
- Implementing a GIS to associate space and time data from the study area, with the attributes of the census statistical data and finally representing simulation outputs in a geographic environment.

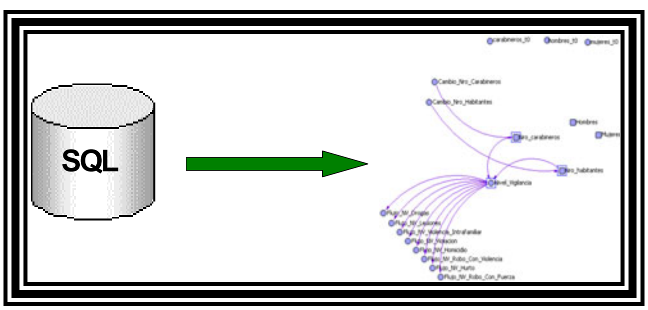

Figure 1: Database Feeds System Dynamics Models.

3 SELECTION OF VARIABLES

The determination of variables related to crimes of the greatest social relevance represents the essential elements for the eventual simulation of these variables in a Systems Dynamics environment. The input data was defined for: Environmental pertinence, Sex and Economic and socio-cultural variables of the subjects involved.

The determination of the above variables enables an approximation to the causes of criminal behavior. Since criminality is a problem with multiple causes, simplification is not recommended. *But, approaching all of a crime phenomenon is not required, nor is association of the risk factors studied here to other illicit behaviors which are beyond the objectives of this study.*

The creation of a simulation model which models all the crimes punished by a country's legislation would be too complicated and practically impossible. This is due to the large number of variables, the dynamic behavior of crimes, and the fact that these behaviors increase or change periodically with the addition of new types of crimes. Consequently, it was decided that only crimes with greater social and police connotations would be studied, since these have the largest impact and represent greater importance for personal safety in an urban context. See Table 1.

Table 1: Main Crimes Used in System Dynamics

• Robbery with Violence	• Robbery with Force	• Theft
• Injuries	• Homicide	• Rape
• Intrafamily Violence	• Drugs	

4 MODEL CONSTRUCTION

It is intuitive to realize that an increase in crime prevention should bring down criminality indexes. On the other hand, it is also valid to indicate that as crimes increase, individuals in charge of preventing these crimes will carry out more actions to reduce them. Both aforementioned relationships can be represented in the influence diagram. See Figure 2

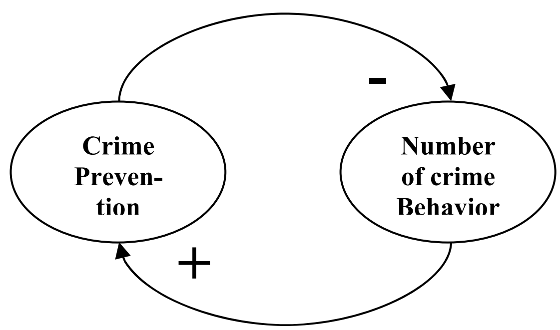

Figure 2: The Influence Diagram Shows the Balance Between Crime Prevention and the Number of Criminal Acts.

The method this study used to measure the general criminality rate is a function of the seriousness of the act committed or reported. Each type of crime was assigned weighting depending on the punishment stipulated in a country's current legislation. In order to calculate the value assigned to each type of crime, the measure was standardized. The result was that those crimes which generated greater fear for the population and in turn were more severely punished by legislation are those which had greater weight assigned to them. The values of these weights are indicated in Table 2.

Table 2: Weight Assigned to Crimes

CRIMES	WEIGHT
Homicide	3.56
Robbery with Violence or Intimidation	1.98
Drugs	1.42
Robbery with Force	1.19
Rape	0.63
Theft	0.41
Injuries	0.41
Intrafamily Violence	0.4

As consequence, it can be deduced that the general criminality index is related to the crimes in comment, as indicated by Figure N. 3.

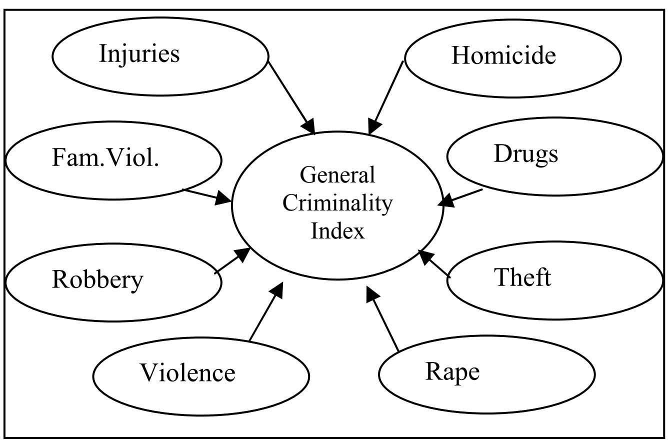

Figure 3: Crimes with Social and Police Connotations Influence the General Criminality Index

The influence of these crimes on the general index is given by a function which has a direct relationship on the weight assigned to each crime. Equation 1 shows the general criminality index.

$$y=(RwV)\cdot 1.98+(RwF)\cdot 1.19+(The)\cdot 0.41+(Inj)\cdot 0.41+ \\ +(Hom)\cdot 3.56+(Vio)\cdot 0.63+(IV)\cdot 0.4+(Drg)\cdot 1.42, \quad (1)$$

where:

- y : General Criminality Index
- *RwV*: Robbery with Violence or Intimidation
- *RwF*: Robbery with Force
- *The* : Theft
- Inj : Injuries
- *Hom*: Homicide
- Rap : Rape
- *IV* : Intrafamily Violence
- *Drg* : Drugs.

5 INFLUENCE VARIABLE

There are several variables that influence crimes and the value of these variables depends on the entry parameters and feedback with the rest of the model's variables. Starting with each of these variables, a flow is calculated going toward each of the crimes with the most serious social and police connotations. (System Dynamics model shown in Figure 4).

The following is a description of an influence variable. The *Surveillance_Level* is represented by a flow. The equation which governs its value is the following:

$$\text{Surveillance\_Level} = \frac{\text{Nr\_policemen}/\text{Nr\_inhabitants}}{\text{average\_policemen\_per\_person}} \quad (2)$$

The *Nr_policemen* ($X_{3,1}$) variable is a Stock, whose equations are:

$$\text{Initial Value} = policemen\_to \quad (3)$$

$$\frac{dx_{31}}{dt} = Change\_Nr\_Policem. \quad (4)$$

The equation for the *police_to* variable is a parameter which comes from interaction with the database. The *Change_Nr_Polic* variable is governed by the following equation:

$$\text{Change\_Nr\_Polic} = \frac{(\text{general\_index} - \text{general\_rate\_aa})}{\text{Change\_Policemen\_Rate} * 50} \quad (5)$$

where *general_rate_aa* is the value in the past period. The parameter *Change_Policemen_Rate* was introduced for modeling calibration purposes.

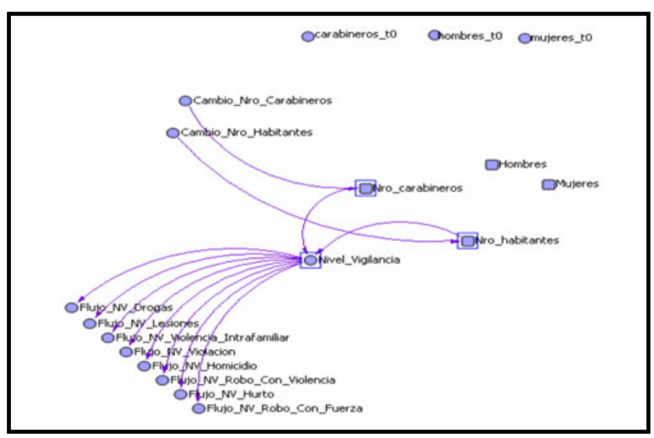

Figure 4: System Dynamic Model Implemented on AnyLogic™ Software.

6 INFLUENCE VARIABLE FLOW

Due to the fact that each variable has different influence over the crimes, a ratio modifying the flows between the stocks and variables was generated into the models. This ratio was calculated based on the crimes carry out in one sector of the city, which is the most representative in terms of the population and level of criminality. The percentage of annual crimes was calculated for the above mentioned sector according to historical values.

Each of the flows towards the crimes is the sum of 10 flows which depend on the level of the influence variables, pondered by the weights mentioned in Table. 2. This situation is reflected in Figure 5 which shows a Systems Dynamic diagram with the flows and the stock homicide.

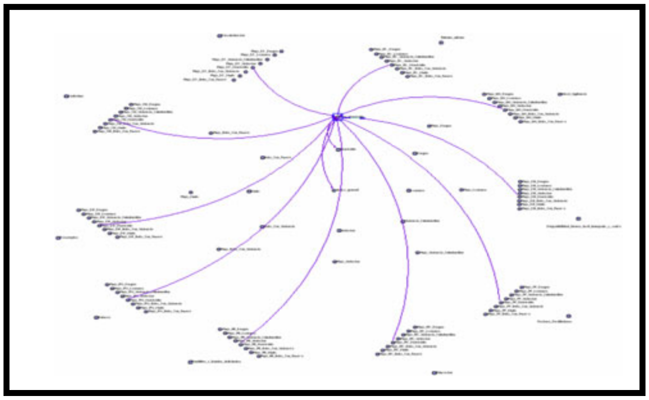

Figure 5: Relationship Between Homicide Flows and Variables

As an example, the *Homicide_Flow flow* represents the following sum:

Homicide Flow = *DI*_Homicide_Flow + *IN*_Homicide_Flow + *UE*_Homicide_Flow - SL_Homicide_Flow + *GA*_Homicide_Flow + *FF*_Homicide_Flow - *ED*_Homicide_Flow + *GB*_Homicide_Flow + *PO*_Homicide_Flow + *UN*_Homicide_Flow,.

where each variable means:

- DI_Homicide_Flow : Discrimination flow
- SL_Homicide_Flow : Surveillance level flow
- ED_Homicide_Flow : Education flow
- UN_Homicide_Flow : Unemployment flow
- IN_Homicide_Flow : Individual flow
- GA_Homicide_Flow : Availability flow
- GB_Homicide_Flow : Gangs criminal band flow
- UE_Homicide_Flow : Urban environment flow
- FF_Homicide_Flow : Facilitating factors flow
- PO_Homicide_Flow : Poverty flow.

The central part of the design relates crimes with the general index, is shown in Figure 6. This rate is a

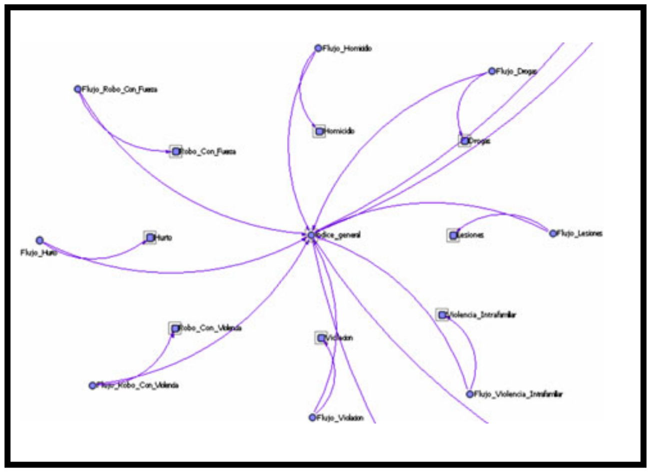

Figure 6: Design of Central Simulation Model

ponderation of the crimes according to values of Table 2.

The central portion included eight stocks which represent the total sum of each crime within the study period.

In addition to the above, two Timer components were added. The first *Timer* called *Export* enables the export of final data to the ODBC database. For this purpose this timer was programmed using Java language. The second *Timer*, called *Restrictions,* contains two model boundaries.

The first is the number of policemen with a higher rank than N, in order to avoid the sector under study being without this variable in the simulation. The second is that the number of inhabitants of the sector cannot be less than the historical base. The rule is the following:

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If (Nr policemen   < 1)Then Nr._ Policemen=1

If (Nr inhabitants < 0)Then Nr._ Policemen=0
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7 EXPERIMENTS BASED ON THE SIMULATION MODEL

Using the System Dynamics models, four experiments were created to enable the simulation of each social policy to be implemented:

- Policy 0 “Actual Policy”
- Policy 1 “Education”
- Policy 2 “Environment”
- Policy 3 “Unemployment”

The “Actual Policy” experiment enables simulation of the crime rate evolution without any change in the influence variables, which is to say that it shows what would happen if there were no improvement or inversion in the sectors.

The "Policy 1 Education" experiment simulates an improvement in the educational system which produces medium and long-term effects. "Policy 2 Environment" simulates an improvement in the City environment, its effect is reflected immediately in the crime rate. "Policy 3 Unemployment" simulates a reduction in the unemployment rate. This policy has short, medium and long-term effects. The outcomes from the simulation are useful for making sensitivity analysis or creating new layers in the GIS. See Figure 7.

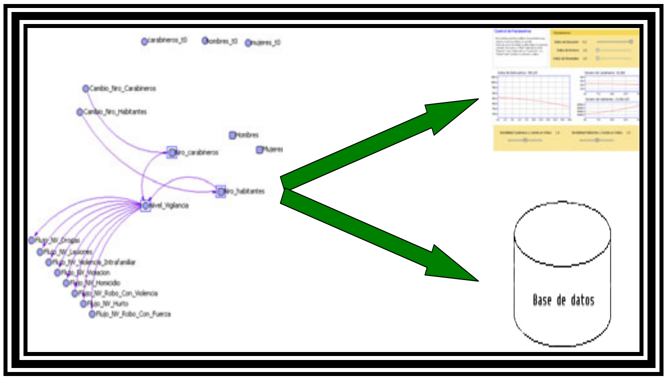

Figure 7: Outcomes from System Dynamics

8 GRAPHIC INTERFACE SENSITIVITY ANALYSIS

A graphic interface was created using tools provided by AnyLogic™ software to facilitate the sensitivity analysis of the model. This interface allowed the varying of interest parameters, as indicated in the Figure 8.

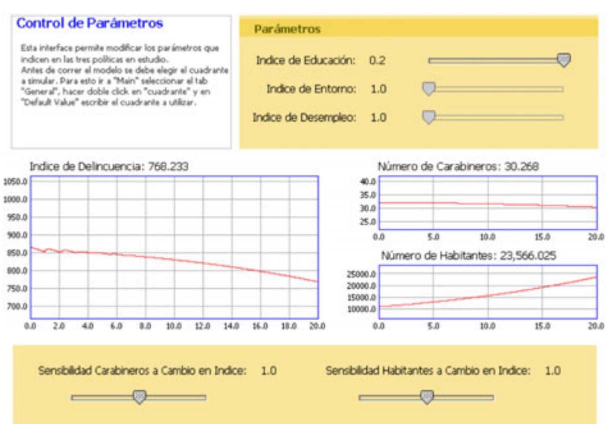

Figure 8: Sensitive Analysis with AnyLogic™ Interface

According to the interface, the parameters which can be varied are the following:

- Education Index
- Environmental Index
- Unemployment Rate
- Policy Sensitivity to Rate Changes
- Inhabitant Sensitivity to Rate Changes

The variation of these parameters can be performed at any point of the simulation, which is to say, they can be modified in time zero or over the space of a few years.

9 GEOGRAPHIC INFORMATION SYTEM AND SYSTEM DYNAMICS

During a first stage, ArcView software was used to geographically locate information taken from the City Census. It also included police information and the opinions of experts in crime and delinquency. The final parameters were provided by means of SQL sentences, and these were the base for making the vector digital layers performed on GIS tool.

Using the GIS's database, 36 parameters were selected and used to enter into the simulation model by means of a code programmed in AnyLogic™ simulation interface software.

Once the GIS was structured, *the crime makeup implication parameters* are sent to the System Dynamics models and it constitutes the initial data for simulating the defined stocks and flows.

After the simulation is performed using the AnyLogic software, the output data will create rows in a new database which contains the simulation output values. Figure 9 shows the general process.

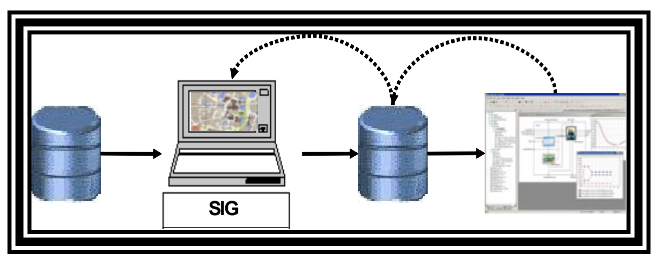

Figure 9: Sequence for Simulating and Collecting Data from System Dynamics Models

This data will constitute a new entry into the GIS software in which analysis can be performed using data generated from the experiment simulation and design. It will compare data from the real world with that generated using AnyLogic™.

An example which illustrates the projection of the general criminality index 20 years after the implementation of a certain policy is shown here to graph the above methodology. This index is represented by a greater density of color pixels in the quadrants where, due to initial layout and projection through the simulation model, the greatest number of crimes would be committed which are the product of reports or arrests by police agencies. Figure 10 shows the new layers which are a geographic representation of the outcomes obtained from the System Dynamics models.

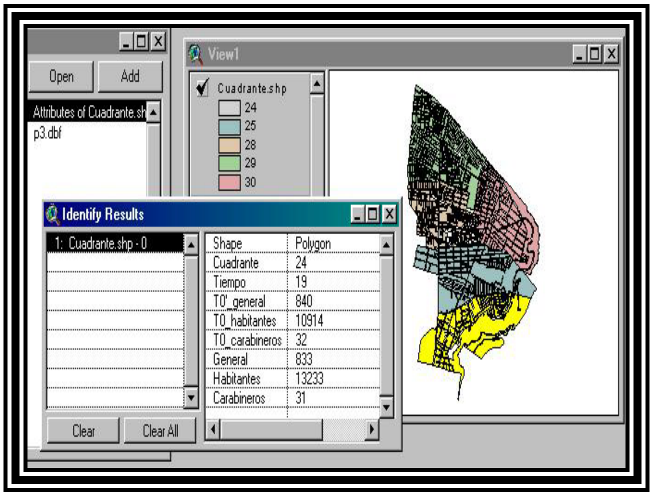

Figure 10: Layer Obtained from System Dynamics Models

10 CONCLUSIONS

The methodology created would support complex decision making and it is based on eight steps: Figure 11:

- Exploration and selection of data
- Information storage
- Definition of the phenomenon under study
- Preparation of initial data for the GIS and simulation model
- Interaction with the database
- Construction of a simulation model
- Evaluation of policies implemented
- Model data export and visualization in the GIS.

The identification and use of city census information corresponds to the information which feeds the simulation into System Dynamics and the GIS. Therefore it is fundamental that this be updated census data.

Cartography in a vectorial format with essential elements such as points, lines and polygons provide geographic localization to the flows and stock modeled in System Dynamics, creating a hybrid simulation environment which is extremely difficult to obtain using other techniques.

The overall structure of "AnyLogic™" models is made up by fundamental units called "ActiveObjects" which represent the model's real objects. These elements are directly associated with classes and objects implemented in Java programming language, with which functionality can be increased by adding a code according to certain rules.

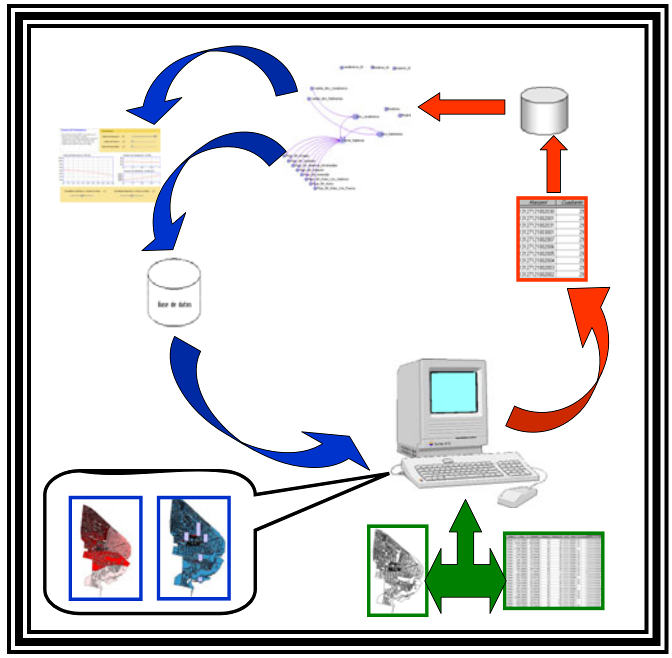

Figure 11: Cycle Census Data GIS and System Dynamics

Incorporating the parameters which influence criminality rates as well as cause and effect relationships between the different variables which interact in the system, the entire model predicts the development crime levels will have in the sector under study over time.

By employing linear cause and effect relationships and the use of feedback cycles, non-linear results can be achieved which are impossible to predict without the use of computer tools.

There are different software configurations which can be used to implement the System Dynamics methodology. However, we used AnyLogic™ based on the possibility of employing Java incrusted into the software code, thus the simulation model was programmed so that it could import the inputs and export its outputs to an external database.

The methodology employed implies exhaustive initial work regarding causality diagrams in which positive and negative polarity cycles can be identified beforehand, since these are what will determine the model's behavior.

The system designer's capacity to identify stocks and flows becomes fundamental when it comes to obtaining results which effectively represent the modeled reality.

The non-linearity of models was achieved through random and feedback cycles incorporated through the functions used in the elements which make up the System Dynamics annotation.

Delays were employed in the model in order to produce a differentiation in variable times in terms of intensity. This function was used in the study so that the general criminality rate could influence the assignation of the number of policemen for the following period. For example, in case the crime rate of a named sector increases with respect to the previous period, the number of policemen estimated for the next stage will be greater, directly influencing increased levels of surveillance.

Three social policies were selected to simulate which have a positive effect on the reduction of criminal activity:

- The first policy chosen was Education, here the model simulates an annual improvement in the level of education for the time period under study, which represents long-term of improvements in education.
- The second policy chosen was to increase the number of policemen. In contrast with the first policy, this has an immediate effect on the model. It also has a positive effect on the level of criminality which is reflected as of time zero.
- The third policy chosen was the improvement of the sector's environment, which is to say the state of street lighting, public squares, etc. As in the increase of policemen, this has an immediate effect which leads to a lower criminality rate as of time zero.

The "education policy" has no effect on initial time but its effect is long term. The "environment policy" any affects the beginning of the simulation and not the rest of the period. Lastly, the "unemployment policy: has an initial effect as well as during the study period, since this implies an increase in education and easily sold and transported goods over the medium and long term.

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