An Optimization Algorithm for the Selection of Investment Projects in Smart Cities

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Abstract

Cities and territories are being called upon to face the strategic challenges involved by sustainable development, based on the complexity of the interactive perspectives, in line with stakeholders' interests and constraints about the limited financial available resources. In this context, the integrated approaches for decision making relating in particular to urban planning and design in accordance with guidelines for Smart Cities, provide for a resolution of different scenarios having a complex nature thus helping to define programming procedures designed to return a model of a smart city based on the best use of the funds. The paper proposes a multi-criteria economic analysis model for a selection of investment projects that considers not only financial but also social, cultural and environmental parameters in order to examine the real sustainability of initiatives to be taken in urban areas. The model is defined in a mathematical programming language (AMPL) with the optimization algorithms typical of Discrete Linear Programming and it is tested on case studies.

Keywords: Economic Evaluation; Optimization Algorithms; Multicriteria Models; Sustainability; Smart City.

1. Technological innovation and smart planning

In a time of diffused economic crisis, marked by the growth of population and the lack of available resources, the phenomenon of urbanization has been assuming an antagonistic role for the sustainable development of the territory (De Santis R., Fasano A., Mignoli N., Villa A., 2013). This has pushed local authorities to take planning actions that aim to improve citizens' quality of life, to reduce pollutant emissions in the atmosphere and to promote local development, based however on a decisional system that is really fragile and less sensitive to the changes of the contemporary city (Chan E.H. and Yung E.H.K., 2004; Yi-Kai J., Ropper K.O., Castro-Lacouture D., Ha Kim J., 2010). From this point of view the use of integrated approaches underpinning decisions, relating in particular to urban planning and design, is the solution for complex and different scenarios implementing project actions designed to define a Smart City model based on the balance between the use of new technologies and territorial planning (Allmendinger & Tewdwr-Jones, 2006). The present widespread inability to create efficient and intelligent forms of urban areas' government is due to the:

- marginalization of the relationship between city and technological innovation in the urban debate;
- business matrix of the intelligent planning model, where the implementation of innovative techniques, that are difficult to adapt in urban areas, is privileged (Fistola R., 2013).

The methods and the canon tools of planning are therefore inappropriate and it is necessary to apply instead sentient analysis models to support a sustainable urban development through concrete actions of investment projects which take into account not only financial criteria, but also social, cultural, and environmental aspects (Barbier E.B., 1987; Cooper *et al*., 2001; Bentivegna V., 2009; Amato F., Maimone B.A., Martellozzo F., Nolè G., Murgante B., 2016). Just on the basis of the paradigm of the sentient city, the urban areas regain their multi-dimensional character through the skillful use of tools that reconfigure the town in the idea of optimization among technological advance and sustainability of a scenario characterized by limited resources. From this point of view the basic principles of the Smart City, where «investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance» (Caragliu A., Del Bo C. and Nijkamp P. 2011, p. 50), are of great importance. This paper highlights the multidimensionality of urban planning processes conducted in line with the logic of the Smart City. From the study of the Operational Research instruments, the outcome of the work indicates that the Discrete Linear Programming (DLP) can be an effective tool for the selection of investments aiming to achieve the financial, social, cultural, and environmental sustainability. A multi-criterial approach for optimal allocation of scarce resources is thus proposed. The model written in the logic of DLP using A Mathematical Programming Language (AMPL) is tested for defining an investment programme aimed to the smart growth of a wide area.

2. Smart City and multi-dimensionality in the land-use planning

The coexistence of many and heterogeneous problems makes the city an ideal platform for the development of innovative management models that could cope with the growth of the territory according to multi-criterial principles. The paradigm of Smart City develops in accordance with a systemic approach in which social, cultural, and environmental dimensions of the urban area are compared with the purely financial progress. This recommends the application of economic evaluation techniques based on a renewed attention on urban sustainability issues. In particular, the relationship between organization, technology, and policy defines different analysis models among which:

- the British Standard Institute model;
- the model of the City of Santander in Spain;
- the SACERT system.

These offer a systemic view of the territory including either financial or extra-monetary dimensions, according to an integration logic supported by Information and Communication Tecnology (ICT). Specifically, the SACERT system, that goes back to The Smart Cities Wheel model proposed by the American Society Fast Company in its report Smart City ranking 2012[1], identifies among the essential dimensions useful to the city's smart growth, the economic (Smart Economy), the environmental (Smart Environmental) and the social (Smart People) nature, in addition to the sectors relating to Governance, Living and Mobility. Three factors, which are the criteria useful to define the meaning of smartness enshrined in the contemporary city, shall be determined for each of these urban dimensions, as Figure 1 below shows.

SMART CITY	SMART ECONOMY	*Productivity* *Local & Global Interconnectedness* *Entrepreneurship & Innovation*
	SMART GOVERNANCE	*Enabling supply & demand side policy* *Transparency & open data* *ICT & e-gov*
	SMART LIVING	*Culturally vibrant & happy* *Safe* *Healthy*
	SMART MOBILITY	*Mixed-modal access* *Prioritized clean & non-motorized options* *Integrated ICT*
	SMART PEOPLE	*21st Century education* *Inclusive society* *Embrace creativity*

Figure 1. "The Smart Cities Wheel" Source: Smart City ranking, Fast Company, 2012

[1] See: http://www.fastcoexist.com/1680856/the-top-10-smartest-european-cities#1.

All these realities individualize the framework of a city that is «the organic and multiform whole of the economic, intellectual and social capital» (Giffinger *et al*., 2007, p. 21), in addition to being technologically advanced. A territory assumes therefore the qualification of Smart City when the investments to be implemented are combined with communication infrastructures and with sustainable economic development instruments, as well as with high-quality of the life and optimal management of resources thanks to participatory governance. Consequently, the territory must be planned according to multi-criterial logic through the following stages:

1) identification of the financial, social, cultural, environmental objectives to be achieved through projects implementation;
2) definition of the criteria that are able to measure the capacity of interventions to pursue different objectives. The criterion is «a principle or standard by which anything can be judged» (Lim C.S. & Mohamed M.Z., 1999, p. 243). Similarly, the criteria are «the lens through which to determine if the project is a success or a failure» (Ika L.A., 2009, p. 7);
3) assignment of a performance indicator to each criterion.

Of course, a good selection of investment projects is essential. For this purpose, the optimization algorithms are very useful because they contemporarily bring different evaluation criteria through the writing of a mathematical expression that represents the *objective function*. As reported, the Operational Research uses alphanumeric tools to build analysis models that are easily adjustable according to different aspects of the Smart City.

3. Optimization models for projects of Smart City

The use of Operational Research techniques allows to treat the multiple dimensions of the Smart City through mathematical formalisms sensitive to change of the real world (Shapiro J.M., 2005; Lazaroiu G.C. & Roscia M., 2012). It is useful to implement the linear programming techniques with regard to the selection problems among projects aimed to smart planning of the city. This makes it possible to manage the multi-dimensionality of the territorial planning with relative simplicity, according to the real functional relations between the variables that rule the system.

In the construction of analysis mathematical model, the decision is formalized as optimization problem such as:

$$\begin{cases} \max \text{ (or min) } C(x_1, \ldots, x_n) \\ \varphi_m (x_1,\ldots,x_n) \leq b_m \\ x \in X \end{cases}$$

in which the objective function C(x), the system of constraints (φ_m) and the set of variables x appear (Korte B., Fonlupt J. Vygen J., 2010).

It is possible to distinguish:

1. linear programming problems, if the objective function as well as the functions that define the constraints are of linear nature, and in

2. non-linear programming problems, if at least one of the functions that define the problem is not linear.

In turn, linear programming problems may be classified as follows:

a. continuous optimization, if the vector x assumes values in $\mathbb{R}^n$;
b. whole (or Discrete) optimization, when the considered variables assume values in Z^n;
c. mixed, when the variables assume both whole and continuous values.

In the field of discrete linear programming, the problem can be of two kinds:

1. pure whole linear optimization, when the variables of decision x must assume values in Z+;
2. binary or Boolean optimization, when the condition of entirety $x \in Z_+^n$ is more restrictive and it imposes that the variables assume only values 0 and 1, i.e. $x \in \{0,1\}$, with the meaning of select {1} and not select {0}.

In all cases, it has to be selected the problem-solving algorithm. Within the entire linear programming context, the more used algorithms of resolution are those of dynamic programming, implicit enumeration such as Branch&Bound (B&B), the cutting plane algorithms, the Brunch & Cut algorithm (Ventura P., 2003; Vercellis C., 2008). The selection problems can often be resolved on the basis of mathematical models with simple algebraic structure, particularly in urban planning and design, because they are characterized by entirety constraint on decision variables ($x \in \{0,1\}$). As an example, the know knapsak problem, according to which the objects are chosen depending on their value and knapsak's capacity. With the aim of pursuing *m* objectives of Smart City, with $m > 1$, the question arises of selection among *n* projects, not all feasible due to budget constraints. Since the single projects cannot be subdivided (Thusen G.J. and Fabrycky W.J., 1994), Discrete Linear Programming algorithms (D.L.P.) can be implemented. The aforementioned Branch & Cut algorithm, that combine cutting plane method with that of Branch & Bound, is selected among these. In the following section, a rational model, which is easy to implement, is written according to the syntax of AMPL with the aim of purposing the best distribution of the money to be allocated in investments for Smart City.

4. An economic evaluation model for the smart planning of the city

The model in Table 1 is written with AMPL (Bruglieri M., Cordone R., Liberti L., Iuliano C., 2010). CPLEX is used as solver of the problem. The optimization algorithm of Brunch&Cut (B&C), which allows to resolve discrete linear programming problems, is implemented. The *n* projects for urban area (set PROJECTS), which are separate in *k* fields of action (set PROJECTS_TYPE), are assessed according to *m* sustainability indicators (set EVALUATION CRITERIA). In the division PARAMETERS there are the numeric values that characterize the proposed selection problem. They are:

- the available budget (param BUDGET),
- the multi-criterial matrix (param INDICATORS_UNIT {PROJECTS, EVALUATION CRITERIA}) and
- the vector that includes the investment cost for each project (param COST {PROJECTS}).

The unknown values of the problem (var *x* {i in PROJECTS} binary) are binary variables, namely $x \in \{0,1\}$, with regard to the nature of the selection problem to solve. The objective function is written in the following form:

maximize (or minimize) objective: sum {i in PROJECTS, j in EVALUATION CRITERIA} INDICATORS_UNIT[i, j]**x*[i]. The system of constraints takes into account both available budget:

s.t. vinc_0: sum {i in PROJECTS} COST[i]**x*[i] <= BUDGET,

and the need to ensure at least the implementation for each group of projects with the following expression:

s.t. (subject to) constraints_*m*: sum {j in PROJECTS_TYPE K} l [h] >= 1

Table 1. Projects Portfolio Selection Problem

Sets
set PROJECTS ;
set PROJECTS_TYPE 1;
set PROJECTS_TYPE 2;
⋮
set PROJECTS_TYPE *k* ;
set EVALUATION CRITERIA;
Parameters
param BUDGET;
param INDICATORS_unit {PROJECTS, EVALUATION CRITERIA} ;
param COST {PROJECTS} ;
Variables
var x{i in PROJECTS} binary ;
Objective Function
maximise (or minimise) objective: sum {i in PROJECTS, j in INDICATORS} INDICATORS_unit[i, j]*x[i];
Constraints
s.t. (subject to) constraints_0: sum {i in PROJECTS} COST [i]*x[i] <= BUDGET;
s.t. (subject to) constraints_1: sum {j in PROJECTS_TYPE 1} y [f] >= 1;
s.t. (subject to) constraints_*m*: sum {h in PROJECTS_TYPE *k*} l [h] >= 1;

In practice, the use of AMPL makes it possible:

- to build a parametric model through the file .mod ;
- to write the data of the problem with a file .dat separated from the corresponding file .mod;
- to characterize the components of the system such as series of objects (set);
- to establish the unknow values, namely the projects to be selected (var *x* binary);
- to express the objective function such as linear algebraic expression that maximize the capacity of investments in pursuing differing aims of sustainable urban planning.

5. Case study

A set of 30 projects has been proposed for public financing and for urban planning of a vast area on principles of smart planning. Due to the limited monetary resources, which can't finance all the actions, the aim is to select those projects which are able to determine the best financial, social, cultural and environmental benefits for the territory. The inherent characteristics of the interested area lead to the assessment the *i*-th project according to the following objectives:

a) financial impact;
b) effects on employment;
c) reduction of pollutants in atmosphere, also through the use of renewable energy sources;
d) implementation of new technologies for a better use of services for the city;
e) urban equalization.

As corresponding performance indicators are used:

a) the Internal Rate of Return (IRR);
b) the number of new employees that the project produces (N° OF WORKERS);
c) the lowest CO_2 emissions in atmosphere, in terms of thousands of tons per year[2];
d) the number of informative digital services offered by project for the use of service (ICT);
e) the geographic location of the project. An indicator (IMPA), which is expressed through a numerical ordinal value of Saaty scale[3], is selected. This value is increasingly attributed on the ability of the project to create new wealth in districts with high degradation levels that have need of actions useful for pursuit the highest urban standards typical of other areas of the city. The values of each parameter recorded for the 30 projects are presented in Table 2.

As for the comparison of projects' attribute, a common measurement scale is defined by standardizing every attribute through the following equation:

$$z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j}$$

where x_{ij} identifies the value taken on by the assessed i-th project according to the j-th indicator, μ_j states the arithmetic average of the values assumed by the assessed n projects according to the same j-th indicator, σ_j represents the standard deviation of the values x_{ij} corresponding to the j indicator.

The mathematical model proposed in preceding paragraph is implemented using normalized data. The priority for the projects is constructed by linking the binary value {0,1} to each one, according to whether the *i*-th investment is selected (value 1) or not (value 0). Resorting to the mathematical formalism, this model about selection problem can have the following form:

$$\begin{cases} \max \sum_i (\text{IRR}_i + \text{N° OF WORKERS}_i + (-\text{EMISSION})_i + \text{IMPA}_i + \text{ICT}_i) * x_i \\ \sum_{i=1}^{30} C_i * x_i \leq \text{BUDGET} \\ \sum_{i=1}^{8} x_i \geq 1 \\ \sum_{i=9}^{18} x_i \geq 1 \\ \sum_{i=19}^{24} x_i \geq 1 \\ \sum_{i=25}^{30} x_i \geq 1 \\ x_i \in \{0,1\} \ (i=1,\dots,n) \end{cases}$$

in which the objective function, the constraint regarding the available capital allocation and the necessity to ensure the selection at least one project for each Smart Sector are reported. In the AMPL, the .dat file (Table 3), that includes the multi-criteria analysis data performed for each of the 30 projects in Table 2., is associated with the .mod file in Table 1. At this point the .mod and .dat files are entered into the AMPL command line, specifying the solver that implements the Branch & Cut algorithm:

```
ampl: reset;
ampl: model FILE.mod;
ampl: data FILE.dat;
ampl: option solver cplex;
ampl: solve.
```

The resultant optimal combination is made up of the projects:

1 - 2 - 3 - 4 - 9 - 12 - 13 - 15 - 16 - 17 - 24 - 27.

The corresponding objective function value is 23.67 and the total cost of investment is 32,768 thousands of Euro. The available budget of 33,500 thousands of Euro is almost entirely used. Having a pre-conceived preference for an approach to solve multi-objective problems, in which the decision-maker has the possibility to choose the nearest solution to its decision-making policies, with an ε-constrained type algorithm, a further constraint can be imposed to the problem:

objective i <= objective (i – 1) - ε

so as to extrapolate, with ε = 1‰, the list of the best combinations of projects. The Table 4 shows the first five combinations, each of which has the objective function value and the investment cost.

[2] The numerical values are positive – which are detrimental to the selection purposes – in case of CO_2 emissions, while they are negative where the project determines the destruction of CO_2, such as initiatives for urban recovery which create new green areas.

[3] The evaluation is conducted attributing the scores 1, 3, 5, 7 and 9, according to the physical and social disadvantages, which define the urban area of intervention, and the more general capacity of the project to pursue urban equalization objectives.

Table 2. Multi-criteria analysis matrix

SMART SECTORS		PROJECTS	COST (thousands of €)	IIR (%)	N° OF WORKERS	CO_2 (thousands of t/year)	IMPA	N°. ICT
SMART ENVIRONMENTAL *ENERGY*	**1**	Monitoring Systems of the Urban Energetic Consumption	1,000	6.70	2	2	7	3
	2	Alternative Energies for Scholastic Buildings	4,300	8.14	10	3	5	6
	3	Employment of Photovoltaic Panels	3,800	4.08	15	5	3	6
	4	New Treatment Plant	5,000	5.14	18	7	7	0
	5	Geothermal Systems for Public Buildings	4,850	6.05	6	4	5	5
	6	Improvement of City's Electronic Grid	3,000	5.20	8	3	1	5
	7	New Plant of Public Illumination	3,150	8.30	5	4	3	2
	8	Systems Of Alternative Energy For Residential Housing	7,125	9.10	20	3	3	2
SMART LIVING *LIFE & HEALTH*	**9**	Air Quality Control Systems	2,000	5.10	13	4	5	0
	10	Sensor Networks for Environmental Emergencies	5,210	6.23	15	2	7	4
	11	Intervention of Sustainable Urban Renewal	5,748	6.30	0	-4	3	2
	12	Actions of Alternative Tourism	1,300	5.00	16	0	9	7
	13	Digital Enhancement of Cultural Heritage	1,838	11.23	18	2	7	5
	14	School Canteen with Low Emissions	5,370	8.36	5	3	1	3
	15	Realization of Integrated Ecological Systems	2,200	7.33	4	2	7	0
	16	Cyber-Cultural Pole	2,850	8.00	12	3	3	5
	17	Actions for Healthy Lifestyle	2,110	5.40	4	0	3	4
	18	Care Activities for The Elderly	3,700	6.00	15	0	5	0
SMART MOBILITY *ALTERNATIVE SYSTEMS*	**19**	Alternative Mobility İniziatives	2,160	19.50	40	0	9	8
	20	Bike-Sharing Systems	1,617	11.56	25	0	5	3
	21	Actions for Elecrtical Mobility	5,895	6.60	16	2	3	5
	22	Improvement of Distribution of Commodities	9,200	6.75	8	3	5	4
	23	Mobility Management Services	8,000	16.20	20	0	1	6
	24	Info-Mobility Tools	7,116	5.26	25	0	3	6
SMART PEOPLE *INCLUSION*	**25**	Care Activities for Disabled Persons	8,125	8.160	41	0	9	5
	26	Construction of Social Structures	7,800	14.58	60	4	7	2
	27	Open-Data Tools for Integrated Planning	1,110	9.45	32	0	9	4
	28	Creation of Social Enterprises	4,860	5.17	28	5	3	2
	29	New Cultural Center	6,750	11.20	17	0	5	9
	30	Welcome Structure for İmmigrants	5,110	9.85	18	2	7	0

Table 3. .dat file written in AMPL

set PROJECTS := 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30;

set INDICATORS := IRR N.W. CO2 IMPA ICT.;

param INDICATORS_unit : = **param** COST : =

	IRR	N.W.	CO2	IMPA	ICT	
1	0.34	0.03	0.29	0.78	0.33	1,000
2	0.42	0.17	0.43	0.56	0.67	4,300
3	0.21	0.25	0.71	0.33	0.67	3,800
4	0.26	0.30	1.00	0.78	0.00	5,000
5	0.31	0.10	0.57	0.56	0.56	4,850
6	0.27	0.13	0.43	0.11	0.56	3,000
7	0.43	0.08	0.57	0.33	0.22	3,150
8	0.47	0.33	0.43	0.33	0.22	7,125
9	0.26	0.22	0.57	0.56	0.00	2,000
10	0.32	0.25	0.29	0.78	0.44	5,210
11	0.32	0.00	-0.57	0.33	0.22	5,748
12	0.26	0.27	0.00	1.00	0.78	1,300
13	0.58	0.30	0.29	0.78	0.56	1,838
14	0.43	0.08	0.43	0.11	0.33	5,370
15	0.38	0.07	0.29	0.78	0.00	2,200
16	0.41	0.20	0.43	0.33	0.56	2,850
17	0.28	0.07	0.00	0.33	0.44	2,110
18	0.31	0.25	0.00	0.56	0.00	3,700
19	1.00	0.67	0.00	1.00	0.89	19,500
20	0.59	0.42	0.00	0.56	0.33	11,560
21	0.34	0.27	0.29	0.33	0.56	6,600
22	0.35	0.13	0.43	0.56	0.44	6,750
23	0.83	0.33	0.00	0.11	0.67	16,200
24	0.27	0.42	0.00	0.33	0.67	5,260
25	0.42	0.68	0.00	1.00	0.56	8,125
26	0.75	1.00	0.57	0.78	0.22	7,800
27	0.48	0.53	0.00	1.00	0.33	1,100
28	0.27	0.47	0.71	0.33	0.22	4,860
29	0.57	0.28	0.00	0.56	1.00	6,750
30	0.51	0.30	0.29	0.78	0.00	5,110

param BUDGET := 33,500 ;

Table 4. List of the best combinations of projects according to analysis model

	COMBINATION PROJECTS	OBJECTIVE FUNCTION	COSTS (in thousands of €)
1	1-2-3-4-9-12-13-15-16-17-24-27	23.67	32,768
2	1-2-3-6-7-9-12-13-15-16-22-27	23.56	33,298
3	1-2-3-9-12-13-15-16-24-26-27	23.53	33,458
4	1-3-4-5-9-12-13-15-16-17-24-27	23.52	33,318
5	1-2-4-6-7-9-12-13-15-16-24-27	23.51	33,008

The analysis so far conducted assumes that all evaluation criteria have same importance. It is also possible to attach different weight to various indicators

$$\max \sum_{i} (p1 * IRRi + p2 * N° \text{ OF PERMANENT WORKERS}i + p3*(IMPA)i + p4*(-EMISSIONI)i + p5*ICTi)* xi ,$$

writing the maximizing function which takes the following form

where $p_1, \ldots, p_5$ are the coefficients able to “weigh” the five indicators between them.

6. Discussion of the results

The Smart City represents the new urban dimension defined by the aware inclusion of technological innovations into systemic structure of the city. This supports the efficient use of available resources, the use of alternative energies, the functional virtualization geared toward intensity reduction of land use, the widespread promotion of alternative secondary mobility system. The model of *senseable city* reflects the multidimensional character of the urban environment by finding multiple levels on which we can make surveys and studies. With regard to funding process of investment projects, the need to use economic multicriterial evaluation techniques is all the more necessary. The present work proposes a model built according to Operational Research’s rules. The model allows to select the best combination of projects to finance in view of sustainable development for urban territories, so that an investment program able to pursue multiple objectives is established in consistent manner. Data from multicriteria analysis must be associated to evaluation protocol written in A Mathematical Programming Language. Objective functions and conditions of constraints are expressed within the terms of Discrete Linear Programming. The case study, which concerns the selection of projects for Smart City, demonstrates the efficacy and ease with which the analytical system is implemented. It is useful to define the best combination of the actions able to maximise the value of objective function. This value depends on the baseline indicators and system of imposed constraints. The construction of lists of priorities for projects combinations and the possibility of introducing factors p_j in order to weigh the criteria in the maximized function make the model adaptable to different case studies.

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