Modeling, Optimization and Coordination of Decisions in a Smart City

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***Abstract*—The proposed approach for making complex decisions in terms of implementing smart city concept is based on the advantages of the method of universal coefficients, which allows different stakeholders, regardless of their level of education and training, to express their own preferences in their natural form and immediately see to what consequences their decisions lead to.**

Keywords— Multi-criteria analysis of complex decisions, smart city, method of universal coefficients.

I. Introduction

One of the most pressing challenges facing humanity in the age of increasing urbanization and smartization is the problem of sustainable development of cities based on the new opportunities provided by information technologies [1].

The managerial aspect includes making optimal decisions for urban development taking most rationally into account the socio-economic factors, true community needs diverse, partly conflicting interests and characteristics (the factor of resistance to changes among them) of various stakeholders. Moreover, it should be orientated towards interdisciplinary interaction, taking into account the ability to integrate administrative decisions at different levels to anticipate how changes in one urban system will affect others and socio-economic processes [2].

The key feature of decision making for the management of the smart city development is the scope of the term "decision maker". Although eventually it is personified in the responsible individual (e.g. the mayor of the city), in fact, this person only reflects the consensus reached between the public authorities, certain segments of the population and the disposers of the resources geared towards urban development. Therefore, the decision-making process should ensure the objective evidence-based reconciliation of interests of all of the stakeholders. The information base for this is the system of mathematical models relying on the data and the set of KPI. The organizational and methodological framework is provided by state-of-the-art ICT and formalized methods of multi-criteria evaluation.

II. General Characteristics of the Model and the Method

The authors have developed a mathematical model that formalizes the core entities used in mathematical modeling of the impact of new technologies on the urban economy and environment. A brief description is given below. The main requirements for an acceptable solution are:

1. Only one certain technology can be scaled up to the possible extent in a particular sector of the urban economy;
2. For the implementation the necessary technology should be mastered;
3. All of the supporting measures need to be executed to complete the activities;
4. Only one general contractor (hereinafter referred to as the contractor) may be engaged to implement a specific activity;
5. It is possible to entrust the execution only to the properly qualified contractor;
6. Contractor's disposable resources should be sufficient enough to carry out all of the assigned activities;
7. If accepted the project must include all of the activities proposed by the investor (a stakeholder that is ready to finance the implementation of the own set of measures as well as others at the discretion of the decision maker);
8. The project must be provided with funding.

For a valid solution, the model calculates the following performance characteristics:

- Total expected effect of increasing indicators' values in each of the spheres of urban activities.
- Total expenditure of resources of each type for the execution of the project.
- Main (without investors) resources allocated for the implementation of the project.
- Total available resources for the project implementation (main and investors).

In actual operation, the model, of course, can be improved with embedded additional modules that reflect the unique features of each specific situation.

Based on the values of particular criteria calculated by the model, all stakeholders, as a collective decision maker, will have to make the most rational decision on the level of project funding and the distribution of allocated resources between certain urban development activities.

Modern mathematical methods for making multi-criteria decisions, such as the following method of universal coefficients of the importance of criteria (MUC), allow to carry out this procedure not arbitrary in shouting matches, but on the basis of the above-described mathematical model - quite quickly, well-reasoned, and respecting the balance of interests of all stakeholders - from businessmen to the population,.

The preference for using this method is determined by the fact that, unfortunately, despite the existing tools (for example, [3], [4]), in most cases, the choice of solutions to urban problems is fragmented, not interconnected, made by

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"pushing" the interests of certain groups and individuals. And a follow-up comprehensive assessment of all the consequences of the set of decisions taken, much less its impact on the choice itself, are out of the question. The disadvantages of this approach are obvious.

Until recently, in our opinion, there were no mathematical methods to reconcile the interests of different categories of stakeholders in a sufficiently objective manner, since each of these methods relied on a system of provisions that led to unjustified subjectivity and was also often unfeasibly difficult for the decision maker [2], [5 -8].

The appeared lately [9 - 12] method of universal coefficients (MUC) is to the utmost devoid of subjectivity in making multi-criteria decisions.

It was able to show that at the completely natural assumption of a choice rule under uncertainty, the values of the coefficients of relative importance of the particular criteria depend not on the specifics of the problem being solved, but only on the number of particular criteria in it and how many of them belong to which importance groups. This initial assumption, which is understandable to any decision maker and is unlikely to raise doubts, is that if a huge number of equal in quality experts evaluates any solution, the final assessment should take the average of all estimates (the so-called averaged approach) or, in a critical situation, the worst of them (the so-called guaranteeing approach). Basically, instead of real experts, the MUC utilizes their mathematical models, which eliminates subjectivity. The essence of the mathematical model of the expert is simple: it is a set of randomly specified numbers - possible coefficients of relative importance of criteria that satisfy only two conditions:

- The sum of these coefficients is equal to one.
- The values of the coefficients meeting the more important criteria are greater than the values of the coefficients meeting the less important criteria.

Thus, each expert model is a point in space. The number of space dimensions equals the number of criteria in the problem under consideration, and the entire set of models is a certain figure in this space. With a small number of criteria it can be shown graphically.

For different variants of the distribution of particular criteria by importance groups, the corresponding sets of coefficients of relative importance of criteria can be calculated in advance and merged into universal tables that can be used in each specific decision-making case. This table can serve to solve any decision-making tasks with three particular criteria. At the same time, the decision maker fulfills the entitled role: forms a selection policy by classifying particular criteria to the corresponding importance groups. Afterwards, a computer program based on the initial data of the mathematical model outputs the optimal solution with a comprehensive assessment of each of the considered options.

III. An Example of the Consensual Choice of the Optimal Solution

The application of the described technology is illustrated in Table I by the fictional example of choosing the optimal project for solving a transport problem. Let it be necessary to choose one of five possible projects: P0 - P4. The effectiveness of each is evaluated by four particular criteria:

- Cr1 - the degree of decrease in the average waiting time of public transport during rush hours;
- Cr2 - the degree of decrease in the average downtime of personal vehicles in traffic jams;
- Cr3 - The relative value of the additional tax increase;
- Cr4 - The CO_2 reduction factor

The decision-maker in this example is collective and includes three categories of stakeholders representing the population of the city:

- S1- employed citizens who have personal vehicles
- S2 - employed citizens who do not have personal vehicles and use public transport
- S3 - remaining citizens, mainly housewives and retirees

Each of these groups has its own interests and, accordingly, will offer its own version of the selection policy based on three levels of importance of particular criteria:

- I1 - normal importance
- I2 - increased importance
- I3 - highest importance

It is clear that these policies are different. All citizens save money, consider the environmental effect to be important, although not decisive in comparison with their personal financial costs, but the other two criteria for different categories of citizens vary naturally.

The structure of the corresponding selection policies is shown in Blocks 1–2 of Table I. It appears to be the same (Block 2) for two categories of the population, although the selection policies themselves are different. The right side of the table shows the universal coefficients of importance of particular criteria that meet the relevant selection policies. They are taken from the universal tables given in [9].

TABLE I. Selection Policies of Different Population Groups

Population categories	**Particular criteria**				**Number of criteria in the importance group**			**Universal coefficients of the importance of particular criteria in the importance group**		
	Block 1				***Block 2***			***Block 3***		
	Cr1	***Cr2***	***Cr3***	***Cr4***	***I1***	***I2***	***I3***	***I1***	***I2***	***I3***
S1	I1	I3	I3	I2	1	1	2	0.062	0.146	0.396
S2	I3	I1	I3	I2	1	1	2	0.062	0.146	0.396
S3	I1	I1	I3	I2	2	1	1	0.104	0.271	0.521

After that, the simplest rules allow to calculate a comprehensive assessment of the effectiveness of different projects (as the sum of the products of the normalized values of the criteria by their coefficients of importance) from the perspectives of each category.

As shown in Table II, only for owners of personal vehicles (S1) the optimal solution found by their selection policy turned out to be consistent with the preferred one. Representatives of the rest groups can see that the optimal solution, even from their point of view, is a solution that does not at all correspond to the most important, in their opinion, particular criterion, but which best takes into account the full range of their preferences. At the same time, they have no reason to doubt the objectivity of the result, since the values of the coefficients of relative importance of particular criteria that defined it were not proposed by subjective experts, but were found by the rigorous mathematical method according to their own selection policy.

Now it is necessary to determine the final optimal solution that consensually meets the interests of all three categories of the population. To do this, it is enough to normalize, within the same range from zero to one, the complex estimates calculated under their selection policies (right three columns of Table I), and then take their average for each solution option (the sum of their values multiplied by a coefficient of 1/3), since all three categories of the population are equal in decision making. If, for some reason, they were recognized as unequal, for example, it was decided that the opinion of the employed was more important than the opinion of the nonworking, then this would only lead to the fact that their normalized estimates would be added, not multiplied by 1/3, but accordingly by 0.444, 0.444, 0.111 - the universal coefficients of importance from Table II for such policy.

The results are presented on the right side of Table II. In both cases, taking into account the opinions of various categories of the population, the optimal solution is the same - project P1.

TABLE II. INTEGRATED ASSESMENT OF PROJECTS FROM THE PERSPECTIVE OF DIFFERENT CATEGORIES OF THE POPULATION

Solution options	**The integrated effectiveness of the solution option in terms of selection policies**			**Integrated criterion taking into account the interests of all categories of the population**	
	Category S1	***Category S2***	***Category S3***	***Opinions of employed and nonworking are equally important***	***The opinion of employed is more important***
P0	0.605	0.605	0.479	0.779	0.926
P1	0.304	0.492	0.441	0.189	0.234
P2	0.420	0.446	0.434	0.232	0.310
P3	0.475	0.373	0.467	0.272	0.280
P4	0.569	0.424	0.566	0.699	0.599

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