

Smart City and Modelling of Its Unorganized Flows Using Cell Machines

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Abstract

The evolution of the digital economy requires the appropriate infrastructure for administrative management and support of "Smart City". All this makes it possible to look at the problems of the city in a new way. SMART-city is an integrated infrastructure, an environment for improving the comfortable life and work of all citizens. In urban traffic flows, there are obstacles in place where traffic flow is not organized. In these places, special solutions, management measures and safety criteria are required. Such flows and situations should be simulated. This problem is solved based on flow-intensive management criteria using situational scenarios. The efficiency of flow management on busy highways requires the consideration of critical factors. In the present work, such a task is investigated using cell machines, which showed efficiency in streaming tasks of gas dynamics. A purpose of work and its result is a decline system's complexity and dimension by means of linearization and reduction of algorithmic complexity. The field of cells is considered. If there's an obstacle in the cell then the direction by which the obstacle affects minimally is selected (Stochastic assessment has been used). System analysis of SMART-city problems is also carried out in this work. Adaptive IT infrastructure, security, virtualization, risk and the multi-criteria decision-making in an uncertain environment has been analyzed.

Keywords: Simulation; Safe Movement; Smart City; Infrastructure; Management.

1. Introduction

The modern city is the city not only with the developed city traditional infrastructure (Roads, Offices, Service Institutions, etc.), but also it is the city with the developed IT infrastructure, life activity and comfort. The city which creates conditions to evolution of digital economy and digital business, health care, municipal management, educations – "the smart city (SMART-city)" [1], intelligent city. SMART – an abbreviation target words: Specific, Measurable, Achievable, Relevant, and Time bound ("time limited"). The philosophy of "SMART-city" is necessary in the metropolis, and also it will provide flexible, technological controllability of the city, its infrastructure [2]. Criteria of the "smart" city are:

- 1) Digital Technologies;
- 2) Intellectual Systems;
- 3) Subsystems of the Electronic State, Government, City Administration;
- 4) New Interactions, Communications, Intellectual processes of the city structures and "Clever Citizens" susceptible and ready to innovations of city life.

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What city systems should be connected to SMART-city? – All transport logistics, infrastructure, power, police, ambulance, fire, banking, educational and medical systems, and employment services. Continuous access in the Internet is necessary.

This definition is widespread, but not the only thing for studying of SMART-city. There are also options: "intellectual city", "digital city", etc. All of them are closely connected with category "Internet of Things: (IoT)". IoT is a new stage of society informatization at which practically all objects have access to networks. Networks G5 are developed for high-quality growth of web connections. The smart home system should be under construction on 3D-connections "all (x), everywhere (y), at any time (t)". According to forecasts the number of the devices connected in 2020 will exceed 50 billion.

The novelty of this article is to consider unorganized flows with obstacles in the cellular space of a smart city, to build and study a model of managing such flows using situational scenarios that take into account critical factors (flow intensity, risk situations, poor visibility, etc.).

2. Research Methodology

IT components and the principles of management of SMART-city are underlain at design, planning of city infrastructure [3]. "Smart subsystems" of SMART-city allow authenticated citizens to participate in self-government of the city (health care, education, safety, etc.). Except executive power, it's possible to include subsystems to them "Clever citizen", "Smart building", "Smart infrastructure", "Smart distribution (smart accounting)", "Smart document flow", etc. Smart-city Data Base – DPC, situational and call centers, the developed monitoring and adaptive analytics, etc.

The purpose of subsystems – increase in management efficiency and evolution, decrease in expenses, providing digital services [4]. For example, signing up in polyclinic, the electronic diary of children, public city transport on the basis of Wi-Fi, GPS and flexible management of it, optimization and management for energy consumption. Safety of citizens and city structures provide the intellectual video analysis (CCTV), the systems of personal, public and corporate security. "Smart" security policy, prevention of threats, development of preventive protective measures is necessary (especially, in places of accumulation of citizens in the city).

SMART infrastructure of the city leans on IT, "clouds" and a Blockchain, Big Data, Social Mining, Data Mining, and etc. They do the city "more smart", as well as citizens. For example, the Safe Region system of Ramensky district of Moscow uses 611 video cameras (mass, transport or social assignment). Evolutionary innovations – "intellectual flows", IT tracking, Eye-tracking (the computerized tracking of a look), neurosystems, bases and the systems of knowledge, supports of solutions, the chat bots, "talking heads" answering questions of the class FAQ in a natural language. There are basic concepts of SMART city management:

- 1) The centralized system – actually one server, it's cheaper, but it is less safe (in the 2016th "dropped" Twitter, Facebook, PayPal, Amazon because of the DDoS-attack of the cracked coffee-machines);
- 2) Sets of the interconnected and interdependent servers;
- 3) Sets of the connected, but almost independent servers, for example, the center of the DPC distributing data to other systems.

The smart city – evolutionary category, it integrates information systems of the city which quickly, becomes hi-tech, self-governed thanks to digital technologies. Electronic procedures, functionality of participation in administration, discussion of city problems and decision-making are available to citizens. Since 2014 there are new standards of management quality [5, 6], which are quite demanding. The main advantages of "smart city" are:

- 4) Transport - mobility, reduced travel time;
- 5) Health care - efficiency of information and reduction of costs;
- 6) Energetic - comfort and safety;
- 7) Educational - openness, mobility, individuality;
- 8) Medical - simplification of access, improvement of quality and information value, quality control;
- 9) Financial - simplification and improvement of transaction security, variety of systems;
- 10) Environmental - environmental management, information content for the case;
- 11) Production and construction - optimization (rationalization) of production, expenses, etc.

The role of SMART-city infrastructure in the development, design of urban infrastructure has so far only been identified. System analysis and simulation is required [7]. One of the interesting tasks of modeling a transport task for SMART-city has been considered. It's necessary to develop a policy of safe movement in unorganized high-intensity

flows of the metropolis. Flow-based management has been used. In Malinetsky and Stepanov (2004) study [8] similar task is modeled by gas-dynamic task, using the apparatus of cell machines [9], which allows to "escaping" nonlinear descriptions. Dynamic simulation models are also important [10, 11]. Improving the efficiency of flow management is a pressing problem on busy urban ways. The measure of the intensity of transport flows is difference, and the effect of transport is increasing. Reliability of the system, reduction of risks of delivery delays, accidents, non-optimal traffic parameters are our problems. Traditional economic-mathematical models cannot take into account the dynamism, complexity, system of risks and uncertainties. Critical factors [12] are often not taken into account:

- 1) Non-stationary environment (traffic intensity);
- 2) Heterogeneity of transport conditions;
- 3) Complicating transport company interactions;
- 4) Risks of extreme and emergency situations;
- 5) Dynamic adaptation of transport characteristics;
- 6) Necessity of simulation calculations of motion parameters taking into account probabilistic data (wind, visibility, and etc.) [13].

The task using cell machines will be formalized. The field where the movement of unorganized objects takes place is a cellular. There are insurmountable obstacles on the cell field. The field is defined by an orthogonal grid. In each cell it's possible to find a driving transport or stationary obstacle, as well as movement (if there's no obstacle) "left", "right", "down", "up" strictly in one direction. If there's an obstacle in the cell, affects minimally may be evaluated in a stochastic way. Let τ be the "view" distance or depth of analysis of the situation in the flow, as well as the choice of direction with the minimum number of vehicles or obstacles. The field is identified with a pair of matrices (F, V) , where;

$$F = \| f_{ij} \|, i, j \in Z, f_{ij} \in \{0,1,2,3,4\}, V = \| V_{ij} \|, V_{ij} \in \{0,1\}, \tag{1}$$

Where; "0" is the absence of transport (F) or obstacle (V), and "1" is the presence of transport. We consider the vicinity of the von Neumann automata type: neighboring cells (i, j) are considered cells "left" – $(i-1, j)$, "right" – $(i+1, j)$, "top" – $(i, j+1)$ and "bottom" – $(i, j-1)$. In Figure 1, arrows mark the direction of movement into said cells from the current cell with coordinates (i, j) . Of course, other rules can be adopted, including adaptively customizable movement moves.

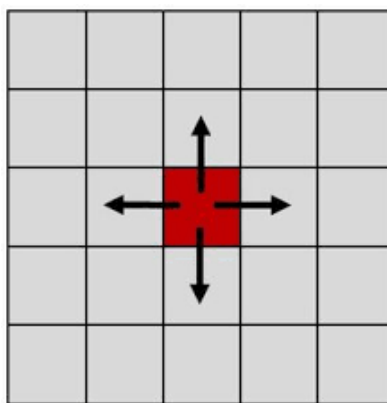


Figure 1. Directions of motion to adjacent points from coordinates (i, j)

Point (cell) (a, b) we'll designate A , then \bar{A} – inversion of this point, change of the direction on opposite, for example:

$$C = (i, j), \bar{C} = (i, j), W = (i - 1, j), \bar{W} = (i + 1, j). \tag{2}$$

Similarly;

$$E = (i + 1, j), \bar{E} = (i - 1, j), S = (i, j - 1), \bar{S} = (i, j + 1), N = (i, j + 1), \bar{N} = (i, j - 1). \tag{3}$$

At the same time, conditions are correct for neighboring cells:

$$f_{i-1,j} = f_{ij}(W), f_{i+1,j} = f_{ij}(E), f_{i,j-1} = f_{ij}(S), f_{i,j+1} = f_{ij}(N), f_{ij} = f_{ij}(C). \tag{4}$$

Similarly for elements of matrix V :

$$V_{i-1,j} = V_{ij}(W), \tag{5}$$

$$V_{i+1,j} = V_{ij}(E), \tag{6}$$

$$V_{i,j-1} = V_{ij}(S), \tag{7}$$

$$V_{i,j+1} = V_{ij}(N), \tag{8}$$

$$V_{ij} = V_{ij}(C). \tag{9}$$

It's necessary to set rules of neighborhood and movement through cells [14-15]. We'll define these rules as follows;

1. It's prohibited to move to a busy cage. Let $P_{ij}^{(1)}(A)$ be the probability of moving to $A \equiv (W, E, S, N, C)$. Then:

$$P_{ij}^{(1)}(A) = \frac{(1-V_{ij}(A))(1-V_{ij}(A))}{4}. \tag{10}$$

2. Analysis of surrounding cells by transport (driver) in the stream. If the adjacent cell is occupied, a ban on advancing into that cell (according to p.1). The remaining cells are viewed "deep" at the distance τ : we sum the number of cells, in this direction in the state 1 at the distance τ and, if there's a cell with an obstacle among them in the direction, it and the following cells are considered occupied (prohibition of advance). Probabilities are given by formulas:

$$P_{ij}^{(2)}(N) = (1 - \frac{1}{\tau} (\sum_{k=1}^{d_{ij}} f_{ij+k} + \tau - d_{ij})) P_{ij}^{(1)}(N), \tag{11}$$

$$P_{ij}^{(2)}(S) = (1 - \frac{1}{\tau} (\sum_{k=1}^{d_{ij}} f_{ij-k} + \tau - d_{ij})) P_{ij}^{(1)}(S), \tag{12}$$

$$P_{ij}^{(2)}(E) = (1 - \frac{1}{\tau} (\sum_{k=1}^{d_{ij}} f_{ij+k} + \tau - d_{ij})) P_{ij}^{(1)}(E), \tag{13}$$

$$P_{ij}^{(2)}(W) = (1 - \frac{1}{\tau} (\sum_{k=1}^{d_{ij}} f_{ij-k} + \tau - d_{ij})) P_{ij}^{(1)}(W), \tag{14}$$

Where d_{ij} is the distance from the cell in question to the nearest obstructed cell in that direction, $P_{ij}^{(1)}$ is the probability of movement (p.1).

3. Movement in flow. We set the flows, increasing the probability of movement in the desired direction. For example, for the N direction:

$$P_{ij}(N) = P_{ij}^{(2)}(N) + a \min\{1 - P_{ij}^{(2)}(N), P_{ij}^{(2)}(S), P_{ij}^{(2)}(W), P_{ij}^{(2)}(E)\}, \tag{15}$$

$$P_{ij}(S) = P_{ij}^{(2)}(S) - \frac{1}{3} a \min\{1 - P_{ij}^{(2)}(N), P_{ij}^{(2)}(S)\}, \tag{16}$$

$$P_{ij}(E) = P_{ij}^{(2)}(E) - \frac{1}{3} a \min\{1 - P_{ij}^{(2)}(N), P_{ij}^{(2)}(E)\}, \tag{17}$$

$$P_{ij}(W) = P_{ij}^{(2)}(W) - \frac{1}{3} a \min\{1 - P_{ij}^{(2)}(N), P_{ij}^{(2)}(W)\}, \tag{18}$$

Where $0 \leq a \leq 1$ – aspiration coefficient to advance in this direction in a stream.

4. Configured the field. The configurations of the cell-automatic field are set recurrently:

$$F_{n+1} = \varphi(F_n), \tag{19}$$

$$\varphi = \varphi_2 \circ \varphi_1 \tag{20}$$

3. Results and Discussion

The main result of the work is the procedure of situational modeling using the cell machines space of a smart city defined above. Let's describe this procedure. In composition we will set;

$$\varphi_1(f_{ij}) = \sum_{\alpha} g_{ij}(\alpha), \quad (21)$$

$$g_{ij}(\alpha) = \begin{cases} f_{ij}^{(\alpha)}, \beta_{ij}(\alpha) = \bar{\alpha} \\ 0, \beta_{ij}(\alpha) \neq \bar{\alpha} \end{cases}, \quad (22)$$

Where $\beta_{ij} \equiv N, W, C, E, S$ if $f_{ij} \equiv 1$, the distribution law is also set, or:

$$P(\beta_{ij} = \alpha) = P_{ij}(\alpha), \quad (23)$$

$$P(\beta_{ij} = C) = 1 - \sum_{\alpha \neq C} P_{ij}(\alpha) \quad (24)$$

(The case of a "slow" driver), or:

$$P(\beta_{ij} = \alpha) = \begin{cases} 0, P_{ij}(\gamma) = 0, \forall \gamma \\ P_{ij}(\alpha) \left(\sum_{\gamma \neq C} P_{ij}(\gamma) \right)^{-1}, P_{ij}(\gamma) \neq 0, \exists \gamma \end{cases} \quad (25)$$

(Case of "restless" driver). Here $\alpha \neq C$.

The function φ_1 reflects the movement to free cells (up to 4 "applicants" per free space), φ_2 - resolves a problem of "Overpopulation" of cages, this function is set by an algorithm ($\forall_{i,j}$):

- 1) If $\varphi_1(f_{ij}) \leq 1$, then go to p.5;
- 2) If $V_{ij}^{(\alpha)} \varphi_1(f_{ij}^{(\alpha)}) \neq 0$, then $\alpha = RND$;
- 3) Change the states of the field cells:

$$\varphi_1(f_{ij}^{(\alpha)}) = 1, \quad \varphi_1(f_{ij}) = \varphi_1(f_{ij}) - 1; \quad (26)$$

- 4) proceed to p.2;
- 5) to put:

$$\varphi_2(\varphi_1(f_{ij})) = \varphi_1(f_{ij}). \quad (27)$$

Each transport moves in the selected direction, bypassing obstacles in the direction that are most free to move. For example, as a conversion φ , it's possible to take turns or departures aside in case of danger of collision, etc.

The proposed procedure and its possibilities for formalizing and modeling unorganized flows in a smart city has been discussed. Smart city projects tend to be implemented by deeply integrated systems. They consist of subsystems with different functional components [16, 17]. In the future, the demographic situation, environmental and economic needs are taken into account. How smart a city should be is determined not only by the administration, but also by citizens. This is influenced by their interests, way of thinking, education, age, income [18]. For active activity, directions with significant connections are selected, forms of partnership, models of interactions (B2B, A2B, B2G and others), as well as the city IT-platform of public use and the system of assessment of cities are determined [19, 20]. Legal aspects are also taken into account, for example, in Belyaev (2019) and Pinchuk (2019) studies [21, 22]. The core of "Smart City":

- 1) Innovation in the real sector;
- 2) Secure IT infrastructure (for example, Big Data [23]);
- 3) Developed urban infrastructure (Transport, Utilities, Energy, etc.);
- 4) Integrated "transparent (Electronic)" control;
- 5) "Smart citizens";
- 6) Smart health care, etc.

For SMART-city, everything from health systems to utilities, from energy to energy consumption, from transport

to train stations, from personality safety to social safety, from responding to the darkness of lighting to effective design of energy consumption of highways, buildings in the city is automated. SMART-city is a near reality. Programs "Electronic Moscow," Information City, "Electronic Government of Moscow" have been implemented in Moscow, the program "SMART-city - 2030" of creation of "Smart Capital" by 2030 is being promoted [24]. Moscow is actively moving to uniformity of platforms, active feedback.

Russia is exploring the potential of "Smart Cities" in 164 medium and large cities (NIU "Higher School of Economics") [25]. Potential leaders - Moscow, Yekaterinburg, Sochi, Kazan, etc.

The consulting company McKinsey predicts the emergence of more than 600 smart cities in 2020, which will generate more than 67% of world GDP. Provided that the environment is preserved, energy and economy management. But it's necessary to provide forecasts with appropriate models, a base of up-to-date information on infrastructure. SMART technologies here are a means to achieve a well-equipped urban environment, dialogue the authorities with the population. "Clever Residents" - informative and creative creators. "Smart city" covers transport mobility, communal systems, healthcare, education, public safety, finance, trade, production and ecology. The Smart City Project for all kinds of situations such as those discussed in this work. Unlike other traffic flows modelling (e.g. [26, 27]), flows are considered unorganized in this study. For such flows, procedures similar to those we have proposed are effective.

4. Conclusion

The growth of flows and volumes of data of the modern city requires reliability, productivity of its infrastructure subsystems. For example, in the processing of commercial or housing and communal data, there may be losses in both directions ("Client-Company"). The advanced IT infrastructure here will benefit, among other things, with the help of visualization, virtualization and situational modelling. Into account the risks of a multi-criterion decision in conditions of uncertainty are needed. It's necessary to organize SMART city's infrastructure and assess the current situation, adaptive integration of systems and evolution's potential. The flow management in the city requires consideration of critical factors such as traffic intensity, adaptation of motion parameters, etc.

In the SMART city interaction of subsystems "Citizen", "Building", "Transport", "Logistics", "Housing and communal services", "Document circulation" and others are based on Big Data, Social Mining, Data Mining and adaptive analytics. It's necessary for audit the infrastructure of SMART-city to assess the current situation, integration of administrative solutions and systems, evolution of the city infrastructure. The digital economy is the evolutionary foundation of SMART-city and a knowledge-based society. By 2025, 5G networks should be deployed in most Russian cities. Universities will produce 100,000 IT specialists annually. They should support urban SMART-city infrastructure. The "SMART-city" paradigm is applicable in a metropolis and town. It is flexible, technological, "smart," effective. It is necessary to get rid of multicriterality, uncertainty (for example, due to unorganized flows of people and transport) in solving problems of "smart" city. Here, traditional mathematical (e.g., gas-dynamic) models are complex, requiring complex identification procedures. As in this article, non-classical methods should be used - cell machines, neural systems, fuzzy logic, situational stochastic modeling, etc.

5. Conflicts of Interest

The authors declare no conflict of interest.

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