**DETERMINATION OF COMMUNITY DEVELOPMENT POLICIES USING URBAN RESILIENCE AND SYSTEM DYNAMICS SIMULATION APPROACH**

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**Abstract**

As our world becomes predominantly urban, cities are increasingly emerging as the field where the main challenges for sustainable development are seriously considered and resolved. The recognition of the importance of the concepts of risk reduction, disaster prevention and the sustainable development of urban areas has been broadly accompanied by a growing global interest in cities from the resilience perspective. Since its origins in ecological systems thinking in the 1960s and early 1970s, resilience thinking has progressively gained prominence. Owing to the concept’s various definitions and flexibility, it has been adapted to a diverse range of disciplines including: engineering, ecology, physics, geography, business management and psychology. *Urban resilience* is specified as a dynamic and inherently contextual concept, the capacity of which depends on the urban system in its entirety; as well as on the interconnections featuring both across city elements and beyond the urban boundaries. The paper presents a conceptual idea of definition of system archetype in the field of urban policy, based on the system and resilience thinking. The basic idea is to point at the analytical potential of the resilience concept in urban planning by using the simulation approach. We will use the System Dynamics (SD) simulation approach, which can provide an insight into dynamic processes of changes in the system and interaction of elements that define the activities pertaining to urban development. The SD model is represented as a Causal Loop Diagram (CLD) showing the cause-consequence relations between urban system elements. Through computer simulation, the model developed using the CLD enables analysis of various scenarios as a basis for evaluation and decision making support in the field of urban planning.

*Keywords: urban planning, policy development, resilience, system dynamics*

**INTRODUCTION**

The world is undergoing the largest wave of urban growth in history. More than half of the world’s population now lives in towns and cities, and by 2030 this number may reach 5 billion. (UNFPA, 2017)

Complex as they are, urban systems and public policy problems have numerous characteristics that inhibit both the making and implementation of effective policies. In this paper, we argue that system dynamics models and resilience approach can play an important role in overcoming those issues. The paper presents a conceptual idea of definition of system archetype in the field of urban policy, based on the system & resilience thinking.

 The basic idea is to point at the analytical potential of the resilience concept in urban planning by using the simulation approach. We will use the System Dynamics (SD) simulation approach, which can provide an insight into dynamic processes of changes in the system and interaction of elements that define the activities pertaining to urban development. The SD model is represented as a Causal Loop Diagram (CLD) showing the cause-consequence relations between system elements. Through computer simulation, the model developed using the CLD enables analysis of various scenarios as a basis for evaluation and decision making support in the field of urban planning.

**RESILIENCE – PRINCIPLES, DIMENSIONS, DETERMINANTS, STRATEGIES**

The importance of the risk reduction, disaster prevention and sustainable development concepts of urban areas has been broadly recognized and accompanied by a growing global interest in cities from the resilience perspective. We refer to resilience as the ability of a system to maintain key functions and processes in the face of adversity, by either resisting or adapting to change. There are two main components of resilience: the ability to absorb or resist the impacts of stresses and the ability to recover quickly from them. Resilience principle can be applied and integrated into management of any natural system as well as social systems.

Social resilience focuses on the resilience of communities in adapting to and withstanding institutional, environmental and economic changes in their location. Occasionally these changes take the form of policies and regulations that alter long standing local habits and practices with more resilient communities more likely to comply and sustain change. Resilience of social systems is often related to three different characteristics:

1. The magnitude of shock the system can absorb and remain stable

2. The degree to which the system is capable of self-organisation

3. The degree to which the system can build capacity for learning and adaptation.

Depending on the domain of application (socio-economic systems, technical systems, IT, psychology etc.) various classes of resilience principles can be defined. In the domain of socio-ecological systems and spatial-urban planning, generally seven basic resiliency principles are used: Maintain diversity and redundancy, Manage connectivity, Manage slow-delay variables and feedbacks, Foster complex adaptive systems thinking, Encourage learning, Broaden participation and Promote polycentric governance (Stockholm Resilience Centre, 2015).

Normally, three general resilience capacities are mentioned in the literature – absorptive, adaptive and restorative, whilst some also add the predictive capacity. Absorptive capacity is the degree to which a system can automatically absorb the impact of system perturbations and minimize consequences with little effort. Adaptive capacity is the degree to which the system is capable of self-organization for recovery of system performance levels. Finally, the restorative capacity is the ability of a system to be repaired easily – either to its original, pre-event state, or to a completely new state that anticipates future system requirements (Keković et al, 2014).

Furthermore, a lower layer of resilience assessment – resilience capacity features (such as redundancy, robustness, segregation etc.) the existing design implementations that contribute to one or more of the system capacities may be used for reaching more precise conclusions about the state of the system in accordance with its dimensions and indicators. The highest layer of resilience assessment - dimensions (the aspect that answers to the question “What elements should be judged by their resilience capacities (and features)?”) is thought to depend on the domain it is applied to.

For instance, the City Resilience Framework (CRF), developed within the 100 Resilient Cities project, describes the essential systems of a city in terms of four dimensions of urban resilience: **Health & wellbeing; Economy & Society;  Infrastructure & Environment;** and**Leadership & Strategy**. Each dimension contains “drivers”, which reflect the actions cities can take to improve their resilience (100 Resilient Cities, 2017).

An open issue is the identification of resilience determinants, that is, the factors that influence the evolutionary dynamic process of robustness and adaptability registered in particular places. Policymakers can play an active role in sustaining resilient urbanisation by addressing resources and efforts in the right policy areas without waiting for crises. The determinants of resilience are different depending on the indicators used, among which territorial factors are particularly important. Urban development attributes of wealth (e.g., land tenure, housing, stable income, infrastructure) and capacities (e.g., education, reliance on community support) are fundamental determinants of resilience across cities worldwide and represent key determinants of urban resilience of social and economic structure. The determinants of urban resilience are most often rooted in a city’s history, geography, and other inherited traits, and as such not easily amenable to local policy intervention.

Resilience strategies are core policy tools that propel socio-ecological systems through the process of building resilience. Resilience strategies foster interagency and public-private collaboration for identifying common-sense solutions, strategic opportunities and catalytic projects, in order to advance lasting solutions. Also, they provide technical assistance and strategic advice to public, private and non-profit clients on: integrated planning, policy development, stakeholder engagement, securing funding, implementation of policies and programs, performance evaluation, and capacity building. Rather than a static road map, the resilience strategy is a living document that should be continuously fine-tuned as priorities are addressed and initiatives are implemented. Understanding that cities function as complex, interdependent and integrated social-ecological systems, or even systems of systems, is crucial to understanding how resilience-based planning, development and management can protect life, assets and maintain continuity of functions through any plausible shock or stress. (UN Habitat, 2017)

**Urban resilience and Adaptive capacity**

Within the development realm there is an emerging trend to produce quantitative tools, indicators and international standards to measure resilience at the urban scale. (UN Habitat, 2017) The urban risk index may include such risks as drought, earthquake, flood, freeze, heat-wave, human pandemic, cyber-attack, market crash, nuclear accident, oil price shock, power outage, plant epidemic, solar storm, terrorism, tsunami, volcano eruption, windstorm, commodity price hikes, social unrest, political, interstate and separatism conflict, refugees and migrations. (100 Resilient Cities)

Linked systems of people and nature, especially with the extent and interconnections of today’s populations, technologies, and human activities, behave as complex adaptive systems. Adaptive capacity is the ability of a social-ecological system to cope with novel situations without losing options for the future and to reconfigure themselves with a minimum loss of function. In human social and urban systems it is demonstrated by the stability of social relations, the maintenance of social capital and economic prosperity. Adaptive capacity is closely related to learning, and learning is central to the notion of adaptive management. In social and urban systems, the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups play an important role in adaptive capacity. Systems with high adaptive capacity are able to re-configure themselves without significant declines in crucial functions in relation to primary productivity, climate cycles, social relations and economic prosperity.

The resilience strategies envisioned by the organizations and actors are intended to be coordinated, balanced, integrated and sustainable, with the long-term scope of enhancing the adaptive capacity of cities, neighbourhoods or buildings.

**Urban dynamics**

Urban dynamics theory views the city as a complex social and economic system formed by the interactions of individual efforts to achieve personal goals. Many individuals can take actions that appear to satisfy their own objectives; the aggregation of these efforts constitutes a complex social system. Urban dynamics provides a theory that embraces a conceptual understanding of the city as a whole. It can facilitate analysing the city's various activities as interrelated functions. Therefore, it is a convenient management tool for urban policy analysis.

Through simulation analyses of urban dynamics models, it is possible to study the effects of alternative programs and policies on the city as a whole. The model then allows us to analyse the system's response to programs and reach conclusions about policy decisions. An urban dynamics model permits computer simulation of alternative policies to improve city management. A fuller understanding of how to use urban dynamics may be explored by additional modelling and the analysis of policies in specific cities. Policy testing can help to achieve goals for growing cities and to revive declining cities.

System dynamics approach presents a model describing the major internal forces controlling the balance of population, housing, and industry within an urban area. This model simulates the life cycle of a city and predicts the impact of proposed remedies on the system. According to that System dynamics approach became the basis of a major research effort that has influenced many government urban-policy decisions (Forrester J.W. 1969).

**System dynamics model and Causal Loop Diagram (CLD) in Policy Design and Analysis**

Public policy problems have several characteristics that impede resolution using traditional non-simulation approaches. These characteristics are policy resistancefrom the environment, the need for and cost of experimentation with proposed solutions, the need to achieve consensus between diverse stakeholders regarding the merits of a particular approach, overconfidence among expert decision and policy makers, and the need to have an exogenous and endogenous perspective of the problem. Public policy problems have numerous characteristics that complicate both development and implementation of effective policies. System dynamics models can play an important role in overcoming the above issues. An approach in community development policy creation in the field of urban planning represents the use of system thinking principles with the application of System Dynamics tools. This approach can be used for developing a computer simulation that can provide an insight into dynamic processes of changes in the system and interaction of elements that define the activities pertaining to urban development. According to that System dynamics approach may became the basis of a major research effort that has influenced many government and community urban-policy development (Lynam, 2006).

Invented in mid 1950s by Jay Forrester of the Massachusetts Institute of Technology (MIT), System Dynamics (SD) is defined as a "computer simulation of continuous, non-linear feedback systems, emphasizing an endogenous point of view". System Dynamics is an approach applicable to policy analysis and design, based upon feedback principles and computer simulation. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems – i.e. any dynamic systems characterized by interdependence, mutual interaction, information feedback and causality. SD can deal with dynamic policy problems of systemic, feedback nature, which can arise from the interactions between system variables and from the feedbacks between the managerial actions and the system’s reactions. The purpose of a system dynamics study is to understand the causes of a dynamic problem, and then search for policies that alleviate/eliminate them (Forrester J.W. 1961).

Feedback thinking is a central concept in the SD approach. This means that there is a closed causal chain, a closed loop of mutual cause-and-effect, so that an effect perpetuates until it influences back to its initial cause, after having passed one or any number of variables before. A feedback loop can be positive or negative. Positive loops tend to reinforce or amplify whatever is happening in the system. Negative loops counteract and oppose change, so they are also termed as balancing or counteracting loops.

The second key concept refers to the important status of stocks and flows. As soon as SD models are used for simulation it needs to be identified whether a variable is a stock or a flow variable. Stock variables are accumulations and indicate the status of the system through time, whereas flows represent the rate of change: they increase or decrease a stock over some time interval, being either inflows or outflows. A stock can only be changed and thereby managed by a flow.

The objective for creation of a SD model is to develop a hypothesis, a theory that explains the causes behind the problematic dynamics. In the first step, this must be an “endogenous” explanation. Later, this hypothesis is converted to a formal simulation model and the validity of the hypothesis can be tested.

The key step in generating a conceptual model is the construction of a *Causal Loop Diagram* (CLD). The SD conceptual model for community development policiesis represented as a Causal Loop Diagram showing the cause-consequence relations between urban system elements (Figure 1). The CLD model presents a conceptual idea of definition of system archetype in the field of urban policy, based on the system and resilience thinking. The basic idea is to point at the analytical potential of the resilience concept in urban planning by using the simulation approach.

On this CLD we singled out two domains that play important roles in urban development policy making - *Security* and *Resilience*. On the basis of *Security assessment* and *Resilience assessment*, as well as on the urban environment’s projected security level, the decision on change of urban policies is made with the object of achieving and maintaining the required security level. Taking into account that the security aspect is among key factors for the stability of an urban system, the *Decision making* (DM) sector is used for security management. This sector, with the assistance of the separate *Emergency warning system* block (EWS), for identification of emergency situations, threats and crises, together with the application of all other parameters in the system, brings about decisions on security management aimed at the maintenance of security stability. After the detection of the surpassing of critical values of those indicators by the EWS, a signal is sent to the Decision Making System for an urgent reaction with the aim of removal of consequences caused by serious disturbances. In addition, the EWS warning signals can lead to the change of the policies of urban planning and development.



Figure 1: Causal Loop Diagram of the System dynamics conceptual model for community development policies.

Several closed loops can be observed on the diagram, on whose basis the influence of different factors on urban security can be assessed. For instance, by applying the SD principles it can be concluded that the loop R1 (*DM – Emergency control – Threats – EWS – DM*) has stabilizing character. On the contrary, the loop R2 (*Urban policy – Urban resilience assessment – Request for policy change – Urban policy*) has a destabilizing influence. Other loops in the CLD can be analysed in a similar manner. Consecutively, we can conclude that security stability is influenced by timely and adequate security control and decision. In other words, the delay in adopting adequate urban policies can lead to security instability and even insecurity.

Time delays often play an important role in the dynamics of systems. Significant time lags may intervene between causes and their effects. There are two general categories of time delays in system dynamics: *material/financial* delays and *information* delays. An important consequence of having delays in structures is that they are potential sources of oscillatory or unstable behaviour. Due to that reason, depending on expected and realistic disturbances and threats, Decision making sector plays the main role in the security stabilization of the urban environment, by adoption of predictive and timely security measures.

The showcased methodology, based on the SD principles, can be operationalised for the use in real conditions via adequate software tools for simulation of dynamic systems. This software tool enables the direct formation of simulation model on the basis of *Causal Loop Diagram* (CLD) that aids in visualizing how different variables are interrelated in the system.

Starting from the conceptual CLD model (Figure 1), the software internally realizes all mathematical relations of the model and forms a simulation model. Also, this software tool generates the system of complex nonlinear differential-integral equations, which represent a mathematical model of the analysed dynamic system.

Generally, all equations in the model have the form of complex mathematical expressions that represent dependence of certain system variables on different factors and time. (Keković et al, 2017) For instance, the variable Security\_assessment, taken from the CLD model, can have the following general form:

***Security\_assessment(t)=f(level of crime, socio/economic factors, spatial characteristics…, t)***

Also, all factors and variables *Vi* are expressed in the following equation form:

*Vi = F1* $\*$ *c1 + F2* $\*$ *c2 +…. Fn* $\*$ *cn* ; *Fa(t)* are non-linear functions or coefficients representing system components, which can be time dependant; *ca* represent weighting parameters.

Determination of factors and parameters of a concrete urban system is done on the basis of the system analysis, statistical data, empirical and expert knowledge. Also, the weights parameters are adjusted during experimental testing of the model using the standard calibration procedure. For that reason, data may be collected from different sources and real world events and compared with the outcome of the model simulations. For instance, the outcomes closest to the observed historic data are selected and used in the model for further experimental simulations.

The whole quantification process, i.e. the transformation of the conceptual into simulation model with real parameters, consists of complex activities and requires expert and team work, with the participation of many actors with different profiles and backgrounds. On the basis of the real model, the same approach can be used for assessment of various urban environment protection scenarios from different threats and hazards, as an aid in decision making about the choice of an optimal strategy. (Simonović, 2011) In addition, urban resilience and system dynamics simulation approach may be dominantly used for determination of Community development policies.

**Conclusion**

Despite the high applicability to public policy problems, system dynamics is currently underutilized in government policy making. However, system dynamics models are unique in their ability to capture important and often counterintuitive insights relating behaviour to the feedback structure of the system without sacrificing the ability for policymakers to easily understand and communicate those insights. Also, for many public policy problems such models are sufficient to explain problems behaviour and build intuition regarding appropriate policy responses.

The paper presents a conceptual idea of definition of system archetype in the field of urban policy, based on the system and resilience thinking. The basic idea is to point at the analytical potential of the resilience concept in urban planning by using the simulation approach. We used the system dynamics (SD) simulation approach, which can provide an insight into dynamic processes of changes in the system and interaction of elements that define the activities pertaining to urban development.

The SD model is represented as a Causal Loop Diagram (CLD) showing the cause-consequence relations between urban system elements. A specific simulation model can be developed with CLD and software simulation tools. Determination of factors and parameters of a simulation model for concrete urban system is done by quantification process on the basis of the system analysis, statistical data, empirical and expert knowledge. Through computer simulation, the developed simulation model enables analysis of various scenarios as a basis for evaluation and decision making support in the field of urban planning.

In his Nobel Prize lecture, Phillip Anderson stated that “The art of model-building is the exclusion of real but irrelevant parts of the problem, and entails hazards for the builder and the reader. The builder may leave out something genuinely relevant; the reader, armed with too sophisticated an experimental probe or too accurate a computation, may take literally a schematized model whose main aim is to be a demonstration of possibility.” However, models can serve a specific purpose for analytic and experimental research in the field of urban planning and community development policies. We believe that using urban resilience and system dynamics simulation approach may serve as a decision making vehicle for policy makers, urban planners and community developers.

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