Simulation of Socio-Economic Processes on the Municipal Level

Martin Sobotka[1], Milan Půček[2], Lucie Sobotková[3], Radka Knězáčková[4]

The monograph elaborates on strategic management in selected priorities of municipal development in which system dynamics is being applied. The method enables quantitative capturing of relations between individual development actors, subjects or processes themselves that may occur during development of a municipality. It is then possible to explore causalities between individual elements of the whole municipal system. The main benefit of the system dynamics, however, is not only capturing of these simple causalities, but also understanding the feedbacks between the system elements. This means that one single element through its behaviour affects another one within the same system. But response of this second element has a loop influence on the initial one. System dynamics introduces a dynamic view, in this case applied on the topic of municipal development. The approach is applicable also in modern management systems. In that case it would be an application of the Balanced Scorecard method which is based on system dynamics principles described above. In addition this method recommends capturing the development through both financial and also non-financial indicators. This generates further possibilities of application of quantitative approach of system dynamics to processes of rather a qualitative character.

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AMS Classification: 68U20

1 Introduction

Management of any organization needs an approach that creates the order in its organization and determines the direction in which the organization is going to follow directions through the applicable instruments for reaching the desired objectives. This thesis should be valid for both of organizations – private and public sector as well. This fact appears to be needed to have a strategy and its corresponding methods for management.

One of the methods that allow incorporate the strategic direction into the life of the organization is the method of Balanced Scorecard (BSC). This is currently a very popular method which diffuses into organizations of the private sector and to institutions of the public sphere. BSC method can be used at municipal level, where it has the potential to promote the development of the municipality when it is used in its proper and consistent application. Its basic characteristic is the use of even non-financial characteristics to support governance and promoting development. The further rated aspect is the involvement of system dynamics into this method. Benefits of system dynamics is the overcoming of the simplified causality.

Practical use of dynamic BSC method that is applicable at the municipal level will be presented in this article on the example of Vsetín municipality. Vsetín is the county seat with around 28,000 inhabitants, which simultaneously performs delegated state administration role for 32 surrounding villages (about 68,000 inhabitants). The city began to develop a strategy and methodology to apply the BSC in 2004, as one of the first municipalities in the country. The strategic map of Vsetín and a set of scales were published by Půček and Ochrana [7]. Other towns in the Czech Republic which apply this method are Děčín and Uherské Hradiště.

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[1] University of Pardubice, Faculty of Economics and Administration, Institute of Economic Sciences, Studentská 95, 532 10 Pardubice, martin.sobotka@upce.cz
[2] Charles University in Prague, Faculty of Social Sciences, Smetanovo nábř. 6, 110 00 Prague1, milan.pucek@seznam.cz
[3] University of Pardubice, Faculty of Economics and Administration, Institute of Economic Sciences, Studentská 95, 532 10 Pardubice, lucie.sobotkova@upce.cz
[4] University of Pardubice, Faculty of Economics and Administration, Institute of Economic Sciences, Studentská 95, 532 10 Pardubice, radka.knezackova@upce.cz

2   Theoretical outlines

2.1   Approach of system dynamics

 The discipline of system dynamics was created in the late fifties the 20th century by J.W. Forrenster from Sloan School of Management at the Massachusetts Institute of Technology. It was called "industrial dynamics" at the time. And this method dealt with the construction of a mathematical model of a dynamic system. This discipline has been widened since its inception.

System dynamics is a methodology used to understand how systems change over time. The way in which the elements or variables composing a system vary over time is referred to as the behavior of the system. System dynamics can also be used to analyze how structural changes in one part of a system might affect the behavior of the system as a whole. Perturbing a system allows one to test how the system will respond under varying sets of conditions (see e.g. Martin [6]).

According to Sterman [9] the system dynamics is a method to enhance learning in complex systems. But learning about complex dynamic systems requires more than technical tools to create mathematical models. System dynamics is fundamentally interdisciplinary.

The access of the system dynamics allows us to create models. The models can be used to solve a lot of problems, not only simple, but very complex and extensive problems too. To better understand the system structures we introduce a notation for representing system structures (cf. e.g. Kirkwood [5]). System dynamics uses graphical notations to display the mutual interrelations among the examined elements. We use feedbacks.

As noted by Sterman [9] feedback is one of the core concepts of system dynamics. We can define feedback like a closed sequence of causes and effects, that is, a closed path of action and information (cf. e.g. Kirkwood [5]).

We use several diagramming tools to capture the structure of systems, including causal loop diagrams and stock and flow diagrams. Causal loop diagrams are an important tool for representing the feedback structure of systems.

The casual loop diagram shows the links among elements of the system. It uses arrows (called causal links). These causal links are complemented by signs "+" to express a positive dependence (reinforcing manner) and "-" to express a negative dependence (balancing manner). These signs have the following meanings (cf. e.g. Kirkwood [5], Sterman [9]):

- a causal link from one element A to another element B is positive if either A adds to B or a change in A produces a change in B in the same direction,
- a causal link from one element A to another element B is negative if either A subtracts from B or a change in A produces a change in B in the opposite direction.

Mathematical expression for positive dependence:

$$\frac{\partial Y}{\partial X} > 0, \qquad\qquad (1)$$

In the case of accumulations:

$$Y_t = \int_{t_0}^{t}(X + \cdots)ds + Y_{t_0}. \qquad\qquad (2)$$

Mathematical expression for negative dependence:

$$\frac{\partial Y}{\partial X} < 0, \qquad\qquad (3)$$

In the case of accumulations:

$$Y_t = \int_{t_0}^{-t}(-X + \cdots)ds + Y_{t_0}. \qquad\qquad (4)$$

The stock and flow diagram is the second way for expressing the system and links among elements of the system. This method helps to overcome some limitations of the causal loop diagram. One of the most important limitations of causal diagrams is their inability to capture just the stock and flow structure of systems.

Stocks characterize the state of the system and generate the information upon which decisions and actions are based. Stocks create delays by accumulation the differences between the inflow to a process and its outflow. Stocks are the source of disequilibrium dynamics in systems. Stocks integrate their flows. The net flow into the stock is the rate of change of the stock.

For expression we can use the following integral equation:

$$Stock(t) = \int_{t_0}^{t}[Inflow(s) - Outflow(s)]ds + Stock(t_0). \tag{5}$$

Inflow represents the value of the inflow at any times between the initial time t_0 and the current time t.

This dependence can be also written by differential equation:

$$\frac{d(Stock)}{dt} = Inflow(t) - Outflow(t). \tag{6}$$

The flows will be functions of the stock and other state variables and parameters.

2.2 Methods and goals of the article

Modeling is based on a combination of positive and normative methodologies. When creating a dynamic model, it is next to impossible to disregard one aspect or the other. Positive methodology has been used particularly in the problem analysis and description. It was also used for the study of theoretical sources and the analysis of the BSC method application experience at the municipal level. The result of a positive methodology is represented by the recognition of the actual state and situation. Normative approach is related mainly to the basic revision of assembled models which were compared to the newly created municipal strategy and utilized scales. The result is a certain degree of optimization of the model as a whole.

The mix of positive and normative methodology has been used in many scientific research methods. The analysis method related to the study of literature and other information sources was used in the first row. The analysis method was used particularly for the creation of partial models (subsystems) where it was necessary to decompose the problem into individual elements. Besides that, the synthesis method was used as well, which is typical for dynamics models. Linking sub-models into a single unit enables us to examine mutual causalities and the behavior of the model as a whole.

Goals of the article: The analysis provided in this paper is focused on examining the potential of system dynamics in the form of the dynamic BSC method, related to the municipal development. In this context, authors aimed to (1) show using the system dynamics in the strategic management of town Vsetín, (2) present two models, including the simulation related to the municipal development.

3 Application of system dynamics

System dynamics can be used for modeling various processes within the various disciplines (cf. Vojtko a Mildeová [11]). Approach of system dynamics will be used for municipality strategic planning in the article. Town which was chosen for it is Vsetín municipality. There was applied Balanced Scorecard in practice.

3.1 The Balanced scorecard and dynamics

Management of the development of any organization requires inclusion in the various aspects of the decisions that have different impacts on the organization. Financial indicators are often generally preferred in the management of institutions. However, their use is often associated with many deficiencies. Namely the authors of Kaplan and Norton [4] highlighted the need to perceive and to apply also non-financial factors into decision-making processes. The authors created currently very popular method of Balanced Scorecard (BSC) for this purpose. BSC is a concept that uses traditional financial measures. These, however, reveal a history of development. For it for the determination of the future strategy, therefore, are not very suitable (cf. Kaplan and Norton, [3]. For this reason the BSC method completes the financial measures by the new measures which evaluate the new dimension of non-financial nature.

The BSC method is criticized because of static approach (cf. for example Bianchi and Montemaggiore [2], Sloper et al. [8]. The relationships among the four perspectives do not express their mutual internal dynamic relationship. This method is not considered directly with the possible delay between the cause and the resulting effect. It is stressed, in particular in the case of the linear approach to the BSC method to the evaluation of the string causes and the resulting effects, although of the authors themselves, Kaplan and Norton [4] recommend that the BSC method can be captured in a systems dynamics model that provides a comprehensive, quantified model of a business´s value creation process.

## 3.2 The Balanced Scorecard on the municipality level

The BSC method can be applied in any organization. Therefore, it may not always be the private sector organization. Public sector institutions can apply ideas the BSC method in the same manner. Only their content will be modified in certain cases.

Using the Balanced Scorecard method in its dynamic form is shown on the town Vsetín in the Czech Republic.

For creation of this model there were applied models which have been drawn up under the professional management team Šusta – Půček. The BSC Model had been subsequently generalized by the authors of this article, and edited for the need of the simulation. Using synthesis is typical for dynamic modeling. The model is divided into several sub-models but it is simulated as a whole. So it is possible to examine causalities among elements of the system and simultaneously behavior of the whole system can be study. When creating case studies, the authors had access to all the necessary data and information from the point of view of executive management and strategic documents and data from a variety of databases which are available through the Internet. It can be mentioned the data from different base, in particular, the Czech Statistical Office, the ARIS System which concludes information of economies of municipalities in the Czech Republic, the system TIMUR is used, and the Dataplan database of Healthy Cities of the Czech Republic is used as well. By reason of data´s availability and consistency of the model on applied method of BSC in the town Vsetín simulations were carried out for period 2009 – 2019 in the Vensim PLE Plus 5.
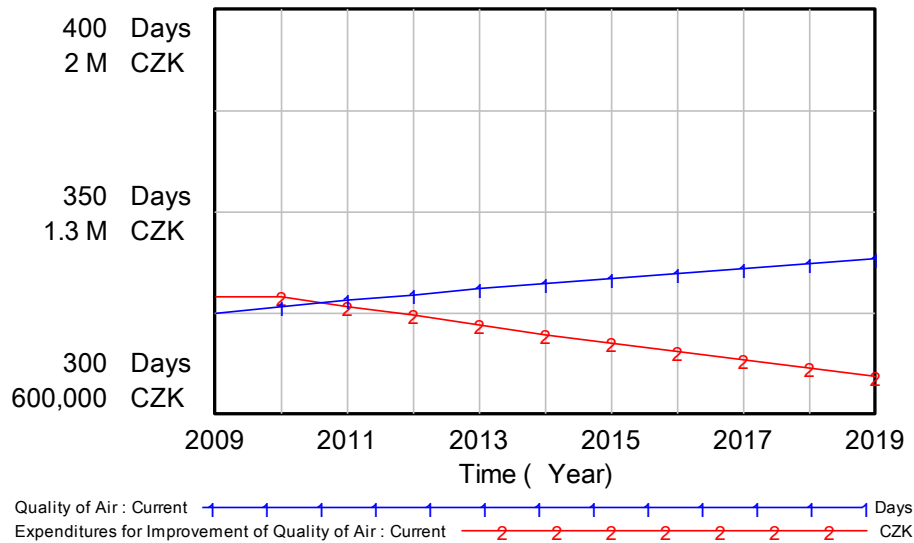
Dynamic model of town Vsetín which were treated by authors based on materials of the town and others dates, includes the following models and simulations: the model of population of the town, the model of quality of life (the attractiveness of the area, quality of life), the model of sporting opportunities, the model of town culture, the transport models, the models of environment, the models for education sector, the labor market model, the model of housing sector, the model of budget of the town.

In view of the scope of this article we included only some models. Using of the system dynamics in balanced scorecard will be explained on these models. The first model which was chosen is the model of parking places in the town (see figure No. 1). For this model there is typical inclusion of basic limits like limitation of place. Creation of new places for parking reduces open space. Also there is evident the model is connection to the strategic plan. The plan determines the number of necessary parking places in the town. This sub-model is incorporated into the overall model for development of the town. It is through budget. Parking places need finances for service. But they bring income from parking fee. Linking the number of parking places on the budgeted expenditures is by relative changes in parking places in the time. Size relative annual changes in the number of parking places is find through the using the time delay. Another important element of the system dynamics is the ability to work with time delay.
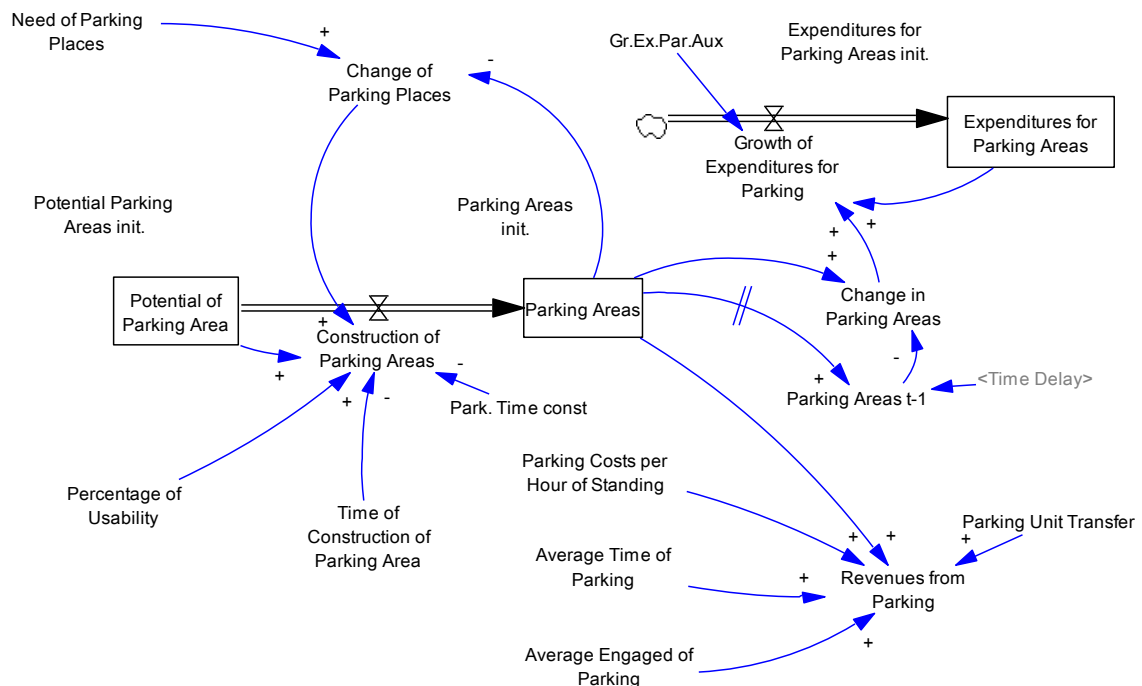
Source: Authors according to internal documents of the Town of Vsetín
Figure 1 Model of parking places in Town of Vsetín

Through simulation of model BSC was achieved the following scenarios of expected development. In expenditures for Parking Areas can be expected grow of parking places. Gradually it will be achieved the

expected state of parking spaces as is set in strategic development. Also similar development is expected in the case of budget management .

Source: Authors

Figure 2 The simulation of development for the model of parking areas in the town Vsetín

The model of air quality is the other illustrative model. This model describes the values from qualitative aspect and for the reason this model was added to this article. In order to simulate quality of air, it had to be expressed through quantitative indicators. The town Vsetín chose as an indicator the number of days in one year with good air. It is the same in the article. The connection between the assessment of quality of air and municipal budget expenditures is through annual examined the relative improvement of quality.

Source: Authors according to internal documents of the Town of Vsetín

Figure 3 Model of air quality of the Town of Vsetín

Quality of air should improve according to simulations. In this time Vsetin isn´t exposed to industrial emissions. For the reason expenditures for improvement of air can gradually drop.

Source: Authors

Figure 4 The simulation of model of air quality of the Town of Vsetín

These models are sub-models of comprehensive model of development of town. They are based on balanced scorecard. The outputs of them influence the quality of life in the town and they have impact on the attractiveness of the town. We can see the limits in the fact that these sub-models are mainly dependent on development of the town. So the model cannot make provision for actual development of quality in town. On the other side strategy of municipality is a stabilizing element and it is not subject to frequent changes.

4   Conclusion

The aim of the article was describing of system dynamics in municipality management. The dynamic model for development of the town Vsetín is a model example for this article. The second goal was to present two already processed city models (see Figure 1–4). This model is based on principles of balanced scorecard. The advantage of this approach is the fact that it points out on using non-monetary indicators. They can be represented by various factors of development and their character can be purely qualitative. But here is a question: is it possible use the factors for modeling and can we simulate their supposed development? Using balanced scorecard and the system dynamics in the article demonstrates their suitability for the strategic management in municipalities. Both methods leave the static view of development, but they allow see connections and interactions of elements. Additionally this approach allows examining qualitative factors and we can evaluate their impacts.

References

[1]   ARIS. [on-line]. Available from: http://wwwinfo.mfcr.cz/aris.
[2]   Bianchi, C., Montemaggiore, G. B.: Enhancing Strategy Design and Planning in Water Company. *System Dynamics Review* **24** (2008), 175 - 213.,
[3]   Kaplan, R. S., Norton, D. P.: *Balanced Scorecard*. Management Press, Prague, 2001.
[4]   Kaplan, S. R., Norton, D. P.: Linking the Balanced Scorecard to Strategy. *California Management Review* **39** (1996), 53 – 79.
[5]   Kirkwood, C. W.: *System Dynamics Methods: A Quick Introduction*. College of Business, Arizona State University, 1998.
[6]   Martin, L. A.: *The First Step. Massachusetts*. Institute of Technology, Cambridge, 1997.
[7]   Pǔček, P., and Ochrana, F.: *Smart Administration, Cohesion Policy*. The Ministry for Regional Development, Prague, 2009.
[8]   Sloper, P., Linard, K. T., Paterson, D.: Towards a Dynamic Feedback Framework for Public Sector Performance Management. In *The 17th International System Dynamics Conference*. Wellington, New Zaeland, 1999.
[9]   Sterman. J. D.: *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill, London, 2000.
[10] TIMUR [on-line] Available from: http://www.timur.cz.
[11] Vojtko, V., and Mildeová, S.: *Dynamika trhu*. Profess Consulting, Prague, 2007.