Migration Outflow in Monotowns of Kemerovo Region
Studied by Methods of Mathematical Modelling: Integrated Approach

E S Chernova¹, V V Meshechkin¹, K E Glinchikov¹
¹Kemerovo State University, Kemerovo, Russia

E-mail: elvangie@mail.ru

Abstract. The article deals with the problem of population migration as a factor affecting the prospects for the development of monotowns in Kemerovo region (by the example of Novokuznetsk - a monotown with a stable social and economic situation). One of the negative trends being observed in the monotowns of Kuzbass and determining their development is the growth of natural population decline and negative migration balance. The authors approach the solution of the problem posed from the standpoint of the mathematical theory of optimal processes. At the first stage, integrated assessments of social and environmental attractiveness of a monotown for the population are constructed to analyze this problem. To find them, the process under investigation is decomposed and presented as a hierarchical model. In the second stage, the dynamics of change in the resulting integrated assessments - environmental attractiveness, housing conditions, the effectiveness of health care and education system operation - is studied by methods of statistical analysis alongside with the impact produced on them due to changes in municipal budget expenditures of the urban district under consideration in various areas of financing: "National issues", "National economy", "Education", "Culture, cinematography", "Public health", "Social policy", "Environmental protection". Based on the dependencies obtained, a model of optimal control is constructed that allows determining the effective distribution of budgetary funds in order to achieve the most favorable socio-ecological situation in a monotown. The proposed model can be used by municipal authorities in developing programs for the strategic development of monotowns.

1. Introduction
The problem of sustainable development of monotowns becomes more and more relevant as one of the main tasks of the authorities at all levels, as well as an object of research, which occupies an important place in the works of Russian scientists. This happens due to the scale of distribution of monotowns in Russia and the role they play in Russian economy: they account for about 40% of the country's gross domestic product [1].

Although the generally accepted definition of "monotown" as a concept does not exist, the criteria for classifying municipal entities of the Russian Federation as mono-profile (monotowns) are formulated in [2], and [3] provides a list of mono-profile municipal entities, according to which 24 out of 319 monotowns of the Russian Federation are located on the territory of Kuzbass. Thus, the problem of monotown development is especially urgent for Kemerovo region, where all cities except Kemerovo are mono-profile, and their development depends on one industry.
The created projects for the development of monotowns, as a rule, are based on the economic indicators (providing conditions for the stable development of monotowns by attracting investments and creating new jobs not connected with the activities of city-forming enterprises). At the same time, social problems are no less significant: keeping the able-bodied population, increasing the efficiency of health care and work of education system, improving housing conditions. The environmental situation in these cities is also not characterized by positive dynamics, since the city-forming enterprises, mainly, are the sources of emissions polluting the environment. However, one of the most serious problems of monotowns is the population decline, caused, firstly, by migration (mass exodus of the most qualified able-bodied population) and, secondly, by the reduction of the birth rate.

In international practice there is no single scientific approach to defining the concept of "monotown". Particularly, different terms can be used in literature simultaneously: one-industry town [4], single-industry town [5], mining town [6], resource town [6], company town [7].

The works devoted to mathematical research of problems in monotowns cover optimization models [8-9]; regression models and correlation analysis [10-13]; neural network models [14]; simulation models [15-16]; cluster analysis [17]; construction of integral indicators [18]; cognitive models [5].

The problems of population migration as an important social and demographic process that has a significant impact on the economy have been studied in the works of many authors [19, 20 etc.]. Since the beginning of the XX century, the methods of mathematical modelling have been used to study migration processes [21]. Among the migration models the most popular were regression models [22], Markov models [23], optimization models [9], neural network and imitation models [24].

At the same time in the works of Russian and foreign scientists the migration processes are given contradictory estimation that may occur due to the lack of an optimal model for calculating the economic expediency of investing in labour migrants arriving in the territory, as well as the model for assessing their human capital (cultural and social) [25]. One possible way of such an assessment can be based on the results obtained from combining the regression approach with modelling demographic indicators by using optimization problems and optimal control problems that allow analyzing available alternatives and choosing the best ones in terms of the given criterion.

2. Construction of Integrated Assessment of Social and Environmental Attractiveness of a Monotown

When modelling complex social and economic processes, various integral indicators or integrated assessments of the phenomena are often applied, and that can significantly reduce the number of factors introduced into the model and make it possible to comprehensively display the studied process where the components are sometimes difficult to measure. One of the approaches to the construction of integrated assessment is thoroughly described in [26], so it served exactly as a basis for this work. The primary data included the following items:

1) to calculate the effectiveness index of education system: the proportion of children aged 1-6 years who receive pre-school educational services and (or) service for their maintenance in municipal educational organizations, in the total number of children aged 1-6 years; the proportion of municipal general education organizations that meet modern training requirements in the total number of municipal general education organizations; the proportion of students who are systematically engaged in physical culture and sports, in the total number of students;

2) to calculate the effectiveness index of health care: the number of doctors, the number of nurses, the number of hospital beds, the capacity of outpatient and polyclinic organizations (all indicators are for 10 000 people);

3) to calculate the indicator of housing conditions – the specific weight of the total area of residential premises equipped with water supply and sewage systems; heating; hot water supply system; gas pipeline and electric cookers;

4) to calculate the index of environmental attractiveness: the number of objects with stationary sources of emissions; emissions of pollutants from stationary sources into the atmosphere; percentage
of captured and neutralized pollutants; the proportion of water samples from the water supply network that do not meet hygienic standards.

3. Construction of Optimal Control Model

In this article, Novokuznetsk is considered as an example for modelling, since it is the largest monotown of Kemerovo region with a stable social and economic situation.

To build a mathematical model for the optimal management of budget allocations, at the first stage, there are constructed the equations of autoregression, where the integrated assessments listed above are taken as dependent variables: the effectiveness of education system at a time moment \( t \) (denoted by \( x_1(t) \)), health care effectiveness \( (x_2(t)) \), housing conditions \( (x_3(t)) \), environmental attractiveness \( (x_4(t)) \).

The shares of the municipal budget expenditures are considered as factors at a time moment \( t \) by items: “National issues” (denoted by \( u_1(t) \)), “National economy” \( (u_2(t)) \), “Housing and utilities” \( (u_3(t)) \), “Education” \( (u_4(t)) \), “Culture and cinematography” \( (u_5(t)) \), “Health care” \( (u_6(t)) \), “Social policy” \( (u_7(t)) \), “Protection of the environment” \( (u_8(t)) \).

The constructed autoregressive relations are then used as the equations for the dynamics of the optimal control model. For Novokuznetsk they take the following form:

\[
\begin{align*}
x_1(t) & = x_1(t-1) + 0.2087 u_2(t) - 1.3561 u_7(t), \\
x_2(t) & = -0.5281 x_2(t-1) + 3.2092 u_1(t) + 0.5703 u_5(t) + \\
& + 2.4980 u_7(t) + 1.0898 u_8(t) - 17.4190 u_9(t), \\
x_3(t) & = 0.0829 x_3(t-1) + 0.9660 ln(u_1(t)) + 0.0055 ln(u_2(t)) + \\
& + 0.0062 ln(u_3(t)) + 0.0335 ln(u_4(t)) - 0.0141 ln(u_5(t)), \\
x_4(t) & = \exp(-1.9751 + 0.5659 x_4(t-1) + 2.3902 u_1(t) + 1.2996 u_2(t) + \\
& + 1.6179 u_3(t) + 1.2451 u_4(t) + 1.1553 u_5(t) + 1.5906 u_7(t) + 30.8518 u_8(t)), \\
\end{align*}
\]

where \( T \) is the final point in time (the end of the planning period).

The values of the constructed integrated assessments at the time of 2006 are regarded as the initial state of the system:

\[
\begin{align*}
x_1(0) & = 0.6809; x_2(0) = 0.7683; x_3(0) = 0.8021; x_4(0) = 0.8355. \\
\end{align*}
\]

Let us define the constraints on the controls. Since the control parameters represent the share of budgetary allocations to various spheres of financing, it is obvious that their amount should not exceed unity. Let us choose the corresponding minimum value from statistical data for the period 2006-2016 as the lower boundary for each of them. Similarly, let us set the upper limits. Thus:

\[
\begin{align*}
0,0174 & \leq u_1(t) \leq 0,0320, 0,1016 \leq u_2(t) \leq 0,1942, 0,1936 \leq u_3(t) \leq 0,2703, \\
0,2883 & \leq u_4(t) \leq 0,4292, 0,0115 \leq u_5(t) \leq 0,0235, 0,0251 \leq u_6(t) \leq 0,1111, \\
0,1154 & \leq u_7(t) \leq 0,1986, 0,0001 \leq u_8(t) \leq 0,0004, t = 1, 2, ..., T, \\
\sum_{i=1}^{8} u_i(t) & \leq 1. \\
\end{align*}
\]

The phase constraints of the model are determined on the basis of normalization of the constructed integrated assessments:

\[
0 \leq x_i(t) \leq 1, \ i = 1, ..., 4, \ t = 1, 2, ..., T. \\
\]

The quality criterion has an integral form and represents the maximization of a linear combination of phase variables – indicators of social and ecological functioning of the region – over the whole period of time under consideration:

\[
F(x(0), u(\cdot)) = \sum_{t=1}^{T} \sum_{i=1}^{4} x_i(t) \rightarrow \max_{u(\cdot) \in U}, \\
\]

where \( u(\cdot) = \{u(1), u(2), ..., u(T)\} \) \( (u(t) = (u_1(t), u_2(t), ..., u_8(t))) - \) admissible system control \( (1)-(9), U - \) the set of all admissible controls, defined by relations (6), (7).
4. Results
Model calculations were carried out for the period of time from 2006 to 2016 and compared with real data on budget allocations of Novokuznetsk urban district. The results are given in Table 1.

**Table 1.** Results of calculating the share of the budgets of Novokuznetsk urban district in various spheres of financing in comparison with actual data.

| Budget expenditure by item | National issues | National economy | Housing and utilities | Education | Protection of the environment |
|----------------------------|-----------------|------------------|----------------------|-----------|-------------------------------|
|                            | actual          | calc.            | actual               | calc.     | actual                        |
| 2006                       | 0.0239          | 0.0320           | 0.1302               | 0.1822    | 0.2607                        |
| 2007                       | 0.0320          | 0.0320           | 0.1446               | 0.1821    | 0.2424                        |
|                            |                 |                  |                      | 0.2580    | 0.2883                        |
|                            |                 |                  |                      |           | 0.2985                        |
|                            |                 |                  |                      |           | 0.2957                        |
| 2008                       | 0.0197          | 0.0320           | 0.1942               | 0.1942    | 0.2419                        |
|                            |                 |                  |                      | 0.2701    | 0.2908                        |
|                            |                 |                  |                      |           | 0.2888                        |
| 2009                       | 0.0203          | 0.0320           | 0.1350               | 0.1350    | 0.2703                        |
|                            |                 |                  |                      | 0.2703    | 0.2899                        |
|                            |                 |                  |                      |           | 0.3012                        |
| 2010                       | 0.0294          | 0.0313           | 0.1118               | 0.1173    | 0.2251                        |
|                            |                 |                  |                      | 0.2373    | 0.3208                        |
|                            |                 |                  |                      |           | 0.3330                        |
| 2011                       | 0.0246          | 0.0320           | 0.1128               | 0.1130    | 0.2224                        |
|                            |                 |                  |                      | 0.2320    | 0.3364                        |
|                            |                 |                  |                      |           | 0.3464                        |
| 2012                       | 0.0197          | 0.0320           | 0.1137               | 0.1108    | 0.2198                        |
|                            |                 |                  |                      | 0.2220    | 0.3520                        |
|                            |                 |                  |                      |           | 0.3593                        |
| 2013                       | 0.0218          | 0.0320           | 0.1286               | 0.1165    | 0.1938                        |
|                            |                 |                  |                      | 0.1984    | 0.4037                        |
|                            |                 |                  |                      |           | 0.4139                        |
| 2014                       | 0.0175          | 0.0320           | 0.1017               | 0.1137    | 0.2166                        |
|                            |                 |                  |                      | 0.2062    | 0.4292                        |
|                            |                 |                  |                      |           | 0.4292                        |
| 2015                       | 0.0197          | 0.0320           | 0.1090               | 0.1140    | 0.1996                        |
|                            |                 |                  |                      | 0.1978    | 0.4109                        |
|                            |                 |                  |                      |           | 0.4218                        |

5. Conclusion
The results show the need to reduce budget allocations for the sphere of culture and cinematography. Periodic fluctuations are observed in the sphere of national issues, while optimal control assumes smaller deviations from the maximum value during the considered period of time. In the sphere of national economy, the calculated values, on the whole, turned out to be close to the actual values. For the item “Housing and utilities” the trend has remained, however, the optimal expenses in the period from 2006 to 2012, exceed the actual ones. A similar situation is observed within “Education” for the period from 2009 to 2015. In the health care sector, on the contrary, the calculated values obtained in many cases were less than observed. In the sphere of social policy, the optimal values exceed those observed only in periods from 2007 to 2008 and from 2011 to 2013. The greatest fluctuations are ob-
served in the costs of environmental protection. Real data demonstrate a downward tendency, while calculated values indicate the need for periodic changes in this area.

The proposed model can be used by municipal authorities in creating programs for the strategic development of monotonews. It can be supplemented with the considera- tion of economic factors.

6. References

[1] Sukhanov G G, Sukhanova E V 2012 Estimation of the potential of a monotown as a basis for developing an integrated investment plan for its development Economics and Management 7 (81) pp 103-109

[2] Postanovlenie Pravitelstva RF ot 29.07.2014 N 709 Resolution of the Government of the RF from 29.07.2014 N 709 “On the criteria for classifying municipal entities of the Russian Federation as mono-profile (monotonews) and the categories of mono-profile municipal entities of the Russian Federation (monotowns), depending on the risks of deterioration of their social and economic status” LRS “Consultant Plus” http://www.consultant.ru/cons/cgi/online.cgi?req=doc&base=LAW&n=166538&fld=134&dst=100000001,0&rnd=0.1764876450692063#0626 838380662059, last accessed 2018/04/29

[3] The order of the Government of the RF from 29.07.2014 N 1398-p (ed. from 13.05.2016) “On the approval of the list of single-profile municipal entities of the Russian Federation (monotowns)” LRS “Consultant Plus” http://www.consultant.ru/cons/cgi/online.cgi?req=doc&base=LAW&n=197975&fld=134&dst=100000001,0&rnd=0.07152200407823228#0251031822393756, last accessed 2018/04/29

[4] Miron J R 2017 The organization of cities: Initiative, ordinary life, and the good life Springer, Cham

[5] Rogachev A F, Melikhova E V, Shokhnekh A V 2017 Information technology of cognitive modeling of industrial and investment self-development of the medium-sized and single-industry towns Revista Espacios vol 38 27 http://www.revistaespacios.com/a17v38n27/17382704.html

[6] Sullivan L, Ryser L, Halseth G 2014 Recognizing change, recognizing rural: The new rural economy and towards a new model of rural service The journal of rural and community development 9(4)219–245

[7] Morisset L K 2017 From town-building to society-making: company towns in Canada JSSAC 1 43–60

[8] Lemyaskin A A, Stoyanova I A 2012 Economic and mathematical model for assessing the complex of measures for city-forming coal mining enterprises in monotonews. Bulletin of Moscow State Mining University 2 pp 73–76

[9] Nekrasova E V 2012 Optimization of internal migration as a mechanism for solving the problems of monotonews in Sverdlovsk region Economy of Region 2(30) pp 315-320

[10] Manaeva I V, Rastvortseva S N 2016 Economic and mathematical model for forecasting the social and economic development of a monotown Economic Analysis: Theory and Practice 10 (457) pp 131-139

[11] Rama M, Scott K 1999 Labor earnings in one-company towns: theory and evidence from Kazakhstan The World Bank Economic Review vol 13 1 185–209

[12] Commander S, Nikoloski Z, Plekhanov A 2011 Employment concentration and re-source allocation: one-company towns in Russia EBRD, Working paper 130

[13] Antonova I S, Pchelintsev E A, Vavilov D D 2016 Company town socio-economic transformation: concentration and factors system SHS Web of Conferences 28, 01006 https://www.shs-conferences.org/articles/shsconf/pdf/2016/06/shsconf_rptss2016_01006. pdf (2016), last accessed 2018/04/29
[14] Kovyazin V F, Lepikhina O Yu, Zimin V P 2018 Development of a prognostic model of monotown land value with the account of economic factors in the activities of city-forming enterprises (on the example of Murmansk region) Bulletin of Moscow State Regional University. Series: Natural Sciences 1 pp 51-65
[15] Ramazanov R R 2015 Agent-oriented modeling of the movement of monotown workforce Artificial societies vol 10 1-4 7
[16] Rushdy S, Power G S 1986 Housing policies for a newly-created resource town: a new application of the BOOM H simulation model in Canada Canadian journal of regional science vol 09 2 157–181
[17] Shastitko A E, Fatikhova A F 2016 Monotown: the experience of quantitative analysis Baltic region 8 2 pp 7-29
[18] Manaeva I V, Rastvortseva S N 2016Methodological tools for assessing the competitiveness of a monotown Regional economy: theory and practice 5 (428) pp 23-39
[19] Lee E S 1966 A theory of migration Demography 1 47–57
[20] Shabashev V A, Shorokhov S I, Verkhozina M F, Chelombitko A N 2017 Economic, social and demographic factors of migration attractiveness of Russian regions Regional economy: theory and practice 15 2 (437) pp 391-404
[21] Korepina T A 2017 Comparative analysis of approaches to migration modeling Issues of territorial development 1 (36) pp 1-12
[22] Lowry I S 1966 Migration and metropolitan growth: two analytical models Chandler Publishing Company, San Francisco
[23] Hirst M A 1976 A markovian analysis of inter-regional migration in Uganda. Geograf-iska Annaler, series B, Human Geography 58(2) http://www.jstor.org/stable/ 490612
[24] Svarc, P.: Modeling migration using neural networks. Charles University in Prague (2005).
[25] Mikidenko N L, Monastyrskaia T I, Storozheva S P 2017 The experience of assessing the human capital of labor ethnic migration Journal of Siberian Federal University Humanities & Social Sciences 9 1382–1395
[26] Kagan E S 2015 Construction of complex fuzzy assessments of the university effectiveness and public formalization of the teacher’s activities News of Altai State University 1 1(85) pp 152-157