

# Modelling of municipal solid waste utilisation market of a resort city

Andrey Kopyrin<sup>1,\*</sup>

<sup>1</sup>Sochi state university, Sovetskaya st., 26a, 354000, Sochi, Russia

**Abstract.** The issue is devoted to the method of multi-approach simulation model construction and verification. The model presents the collection, removal and disposal of municipal solid waste of a resort city (on the example of Sochi-city). It allows analysing complex urban system, taking into account a large number of factors and elements of uncertainty, predict the future state of the system, and identify relationships and anomalies. The city management and private companies can use the resulting tool in the preparation of administrative decisions in this socially significant market. The article contains the relevance of the research topic, the definition of the research goal. The choice of multi-approach simulation as a method is substantiated; a cognitive model and flow diagram of the interaction system between the population and the formation of garbage flows are presented. The discrete-event state-chart of the agent-based garbage collection model is also considered, and the model verification procedures performed are demonstrated.

## 1 Introduction

The development of the tourism sector of the economy is one of the priorities set by the Krasnodar Territory and Russia leadership. However, the economic development of the region is accompanied by an increase in anthropogenic pressure on the territory and causes environmental problems. One of these problems is the removal and disposal of municipal solid waste (MSW).

The technologies used for the collection, storage and disposal of solid waste are obsolete and inadequate for the natural and climatic conditions of the territory and recreational requirements of the resort of Sochi-city. Wastes are practically not used as secondary material resources, because of which valuable components suitable for recycling after appropriate setting are irreversibly lost. Adopted in preparation for the Olympic Games, the Zero Waste program was never implemented.

It should also be noted that the utilisation of MSW is a socially significant market, and the lack of modern technologies, on the one hand, and strict sanitary standards, on the other, critically increase the cost of services. The disposal of solid waste in Sochi is the most expensive in the region [1].

In order to optimize the management system for the utilization of municipal solid waste, it is now necessary to apply advanced methods and tools based on the achievements of

---

\* Corresponding author: kopyrin\_a@mail.ru

Russian and foreign scientists. One of such methods is the construction of a computer simulation model and subsequent scenario analysis with the aim of identifying the advantages and disadvantages of various concepts of the development of the studied area [2].

The object of research is the system of formation, removal and disposal of solid waste in the city of Sochi. The subject of research is the interaction of the population of the city, the organization of garbage disposal and tourist flows. The purpose of the work is to build an integrated computer model with which it will be possible:

- to research on the development trends of a particular market;
- to conduct scenario analysis and simulation modelling to determine the possible consequences of management decisions.

Information base of the research is open statistical data of the Federal State Statistics Service, the Administration of the City of Sochi and the Ministry of the Fuel and Energy Complex and the Housing and Communal Services of the Krasnodar Territory.

## 2 Materials and Methods

### 2.1 Review of existing models

Many papers have been devoted to the modelling of solid waste utilization, but these studies are mainly focused on one side of the problem. One part of the issue examines the logistics of garbage disposal by various transports [3, 4], the other one - the ecological problem of accumulation of garbage [5, 6, 7, 8], the third one - the economic side of the process [9, 10, 11].

The author tried to develop a single synthetic model combining the social, economic and environmental aspects of the research subject. The technological basis of the work is multi-approach modelling, combining system dynamics, discrete-event and agent modelling [12].

### 2.2 Description of the study object

In the Sochi-city, there are more than 300 treatment and recreation facilities, hotels and tourist bases of various comfort levels with a total capacity of about 200 thousand places. The leading role in the sectoral structure of the region is occupied by the resort and tourist complexes, the value and proportion of which increase with time. The industrial and non-industrial sectors of the region are focused on tourism and its maintenance. In a material production sphere, construction, food processing and agriculture are the leading ones. Tourist flows to Sochi reach 4500-4800 thousand people per year. The main part of it falls in the period from April to October. The maximum influx of tourists comes in the summer.

The cleaning system of the territory of Sochi is regulated by the “territorial waste management scheme, including municipal solid waste in the Krasnodar Territory” [13], in accordance with which construction of a waste sorting complex (WSC) was planned, with a capacity of 200 thousand tons per year with a composting plant. The second phase involved the construction of a plant for the composting of organic waste and a workshop for the processing of plastics.

Of all the facilities at the WSC in 2018, only a waste sorting station was commissioned, with a capacity of 200 thousand tons per year (500-600 tons per day). The launch of the second phase was cancelled.

Currently, for the territory of the city of Sochi, from Krasnaya Polyana to the village of Detlyazhka of the Lazarevsky District, the following MSW management system is

organized: collection of MSW, transporting it to WSC, manual sorting, pressing and packaging of solid residues into briquettes, transportation of packaged briquettes and organic waste by road to the landfill in the Belorechensk, Krasnodar Territory. The distance from Sochi (Central District) to the MSW Belorechensk landfill is 250 km (through the Shahumian Pass), or 325 km through the Goryachiy Klyuch, both sides - 650 km.

For the Lazarevskiy district from the Detlazhka to the Magri: collection of solid waste, transfer to transport garbage trucks and transportation MSW at MSW Belorechensk landfill [6, 14]. The distance from Lazarevskaya to the landfill in the Belorechensk region through the town of Goryachiy Klyuch is 500 km round-trip. Such long distances for transporting MSW to a landfill site require a significant number of garbage trucks, which will increase the load on the roads and air pollution, and emissions of harmful substances from motor vehicles.

With this scheme for the treatment of MSW in Sochi, the entire organic part of the MSW enters the landfill, and the landfill decomposes debris in the ground, which negatively affects the components of the environment.

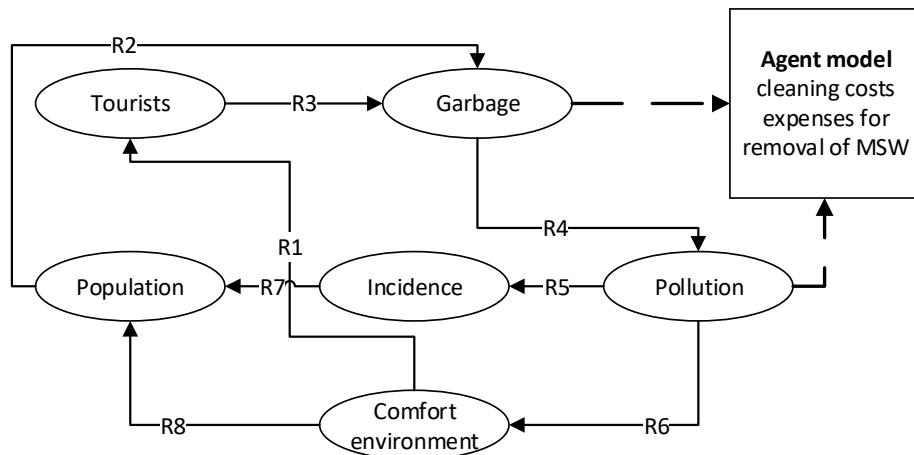
MSW is sorted with a low percentage of the collection of recycled materials (7% of waste fractions) and transportation of almost the entire volume of Sochi garbage to the landfill is unprofitable and the development and implementation of a modern system for the treatment of city MSW is required.

The current WSC capacity is calculated at 200 thousand tons per year, and the average volume of solid waste generation will soon reach 330-400 thousand tons per year [12]. In Summer, the volume of solid waste generation exceeds the average by 30%

### 2.3 Cognitive model

The main factors affecting the flow of municipal solid waste are the resident population and the number of tourists. Increasing the amount of waste affects environmental pollution, which in turn reduces the comfort of living on the territory and increases the incidence. Increasing the number of cases reduces the average lifespan and, consequently, the population. Reducing the comfort of the environment adversely affects the tourists flow and the population (increasing emigration from the city)

After formalizing the model takes the form shown in Fig. 1.



**Fig. 1.** Cognitive model of general relations.

Description of cognitive model indicators is presented in Table 1, and relations - in Table 2.

**Table 1.** Cognitive model indicators.

Indicator	Description	Unit of measurement
Population	The number of people permanently residing in the city	person
Tourists	Average monthly number of tourists	person
Garbage	The amount of accumulated MSW in the city	tons
Pollution	Pollution level	-
Incidence	Average monthly number of the diseased	person per month
Comfort environment	Level of comfort of the environment	-

**Table 2.** Cognitive model relations.

Relation	Description	Type
R1	Comfort environment- Tourists	Direct
R2	Population - Garbage	Direct
R3	Tourists - Garbage	Direct
R4	Garbage - Pollution	Direct
R5	Pollution - Incidence	Direct
R6	Pollution - Comfort environment	Reverse
R7	Incidence - Population	Reverse
R8	Comfort environment - Population	Direct

## 3 Results

### 3.1 Simulation model

Based on the cognitive model, a flow chart was built in the Anylogic system.

All variables in a flowchart are divided into 3 types:

- level variables (or states) interconnected by threads;
- rates controlling flow;
- auxiliary variables.

The mathematical apparatus of the model is a system of differential equations. Level variables usually describe the state of the system. The state of level L at time  $t+dt$  is as

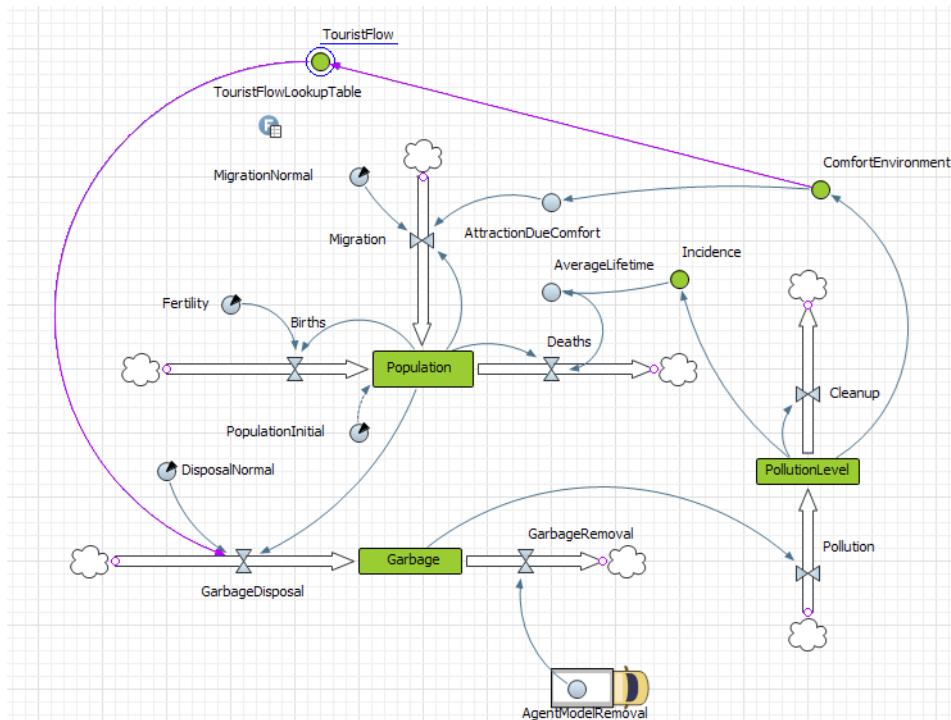
$$L(t+dt) = L(t) + \sum R(t) dt \quad (1)$$

where  $L(t)$  is the level value at the moment of time  $t$ , and  $R$  is the rate values associated with it.

It should be noted that input flows are counted with a “+” sign, and output flows with a “-” sign.

Rates show how quickly the level changes per unit of time, equal to the simulation step. The rate can depend on levels and constants and does not depend on its previous values.

In Fig. 2 is shown flowchart of the model. It contains 3 levels and 17 variables. Key factors of a cognitive model are highlighted in color. The flowchart also contains the relationship with the agent model through the *AgentModelRemoval* variable Description of the levels and variables is presented in Table 3

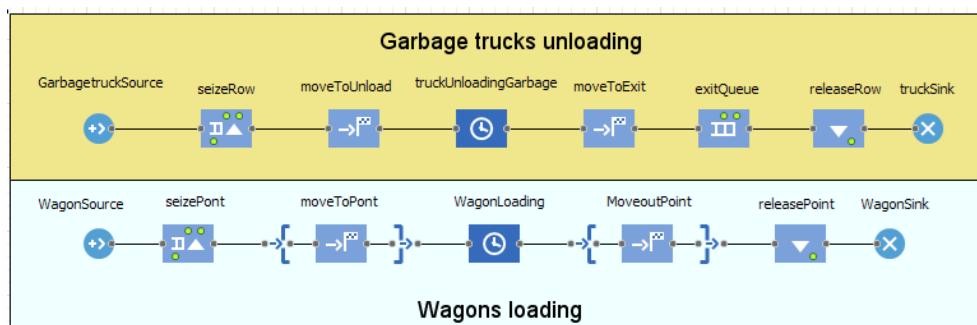


**Fig. 2.** Model's flowchart.

The agent part of the model includes 3 classes of objects:

- a waste sorting complex;
- a garbage truck, collecting waste from container sites and transporting it to a WSC;
- a wagon transporting sorted and pressed waste to a landfill in Belorechensk.

The complex is generated in the singular; the discrete event diagram is shown in Fig.3. Garbage trucks and transports are generated as needed, depending on the volume of waste, but not more than the maximum number of special vehicles available.



**Fig. 3.** Statechart of the waste sorting complex model.

**Table 3.** Description of flowchart variables.

<b>Relation</b>	<b>Description</b>	<b>Type</b>
Population	P	$P(t+dt)=P(t)+B(t)*dt-D(t)*dt+M(t)*dt$
Garbage	G	$G(t+dt)=F(t)+GD(t)*dt-GR(t)*dt$
PollutionLevel	PL	$PL(t+dt)=PL(t)+Po(t)*dt-CU(t)*dt$
Births	B	$B=P*F, (F - Fertility - 0.0152)$
Deaths	D	$D=P/AL$
Migration	M	$M=P*MN*AC, (MN - MigrationNormal - 0.0231)$
GarbageDisposal	GD	$GD=(P+TF*0.3101)*DN, (DN - DisposalNormal - 0.251)$
GarbageRemoval	GR	GR=AMR (link to AgentModelRemoval)
Pollution	Po	$Po=(G/243000)/(1-(G/234000)^2)^{0.5}$
CleanUp	CU	$CU=PL/15$
ComfortEnvironment	CE	$CE=1-PL$
Incidence	In	$IN=PL$
AverageLifetime	AL	$AL=69.5-In*1.5359$
AttractionDueComfort	AC	$AC=0.414*CE+0.814$
TouristsFlow	TF	$TF=TFLT*CE, (TFLT - TouristsFlowLookupTable - statistical table function)$

### 3.2 Model verification

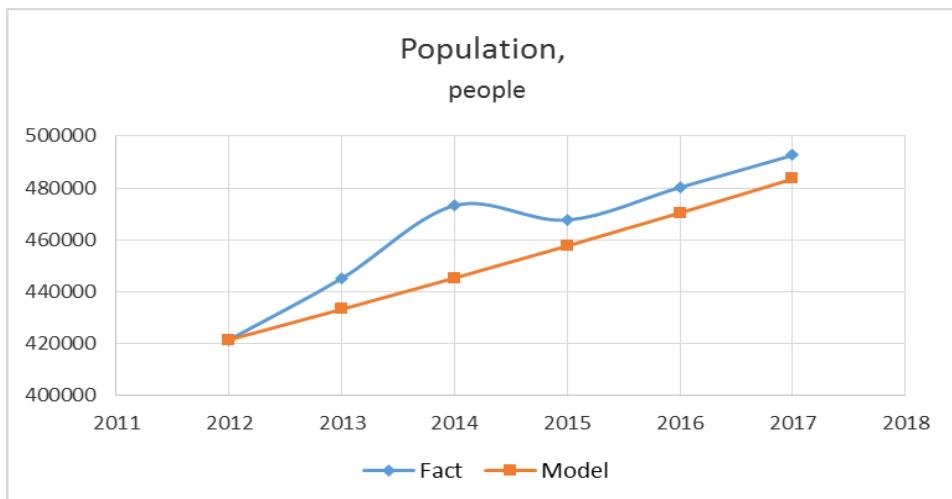
To increase the level of confidence in the simulation results formal verification procedures were carried out.

The verification (validation) of the model is carried out in order to improve the model and test its validity, i.e. how well the resulting model describes the behavior of the simulated system. When verifying the model, the structure and parameters (e.g., initial conditions and constants) can be refined, i.e. the model is calibrated.

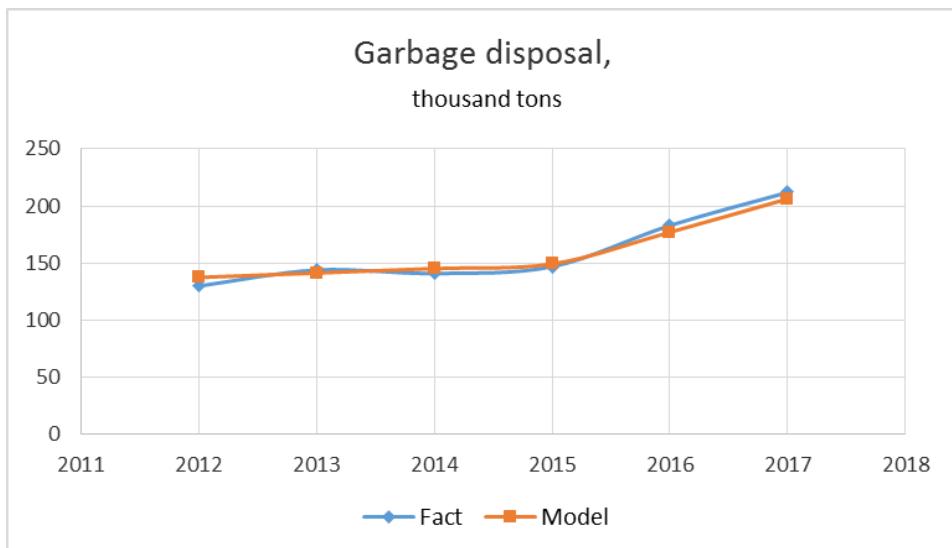
In the course of carrying out formal verification procedures, logical interconnections were checked to confirm the validity of the logical structure of the simulation model. Verification was made with the actual statistical data available.

For example, we give the ratio of retrospective actual data and results obtained by the model according to 2 parameters: population and garbage disposal. All the initial data correspond to the development of the system in the period from 2012 to 2017. The modelling step is 1 year; the modelling horizon is 2017.

The results of the forecast are shown in Fig. 4, 5



**Fig. 4.** Results of modelling on the indicator "Population".



**Fig. 5.** The results of modelling on the indicator "Garbage disposal".

Apparently in the presented figures modelling reproduces actual statistics. At first experiment the average deviation error is 2.45%, and in the second – 3.26%.

## 4 Conclusion

Based on the research conducted, the following conclusions can be formulated.

1. The multi-approach model of the Sochi MSW utilization system was developed, which allows for the study of trends in the development of the market, as well as a scenario analysis of the consequences of various management decisions.
2. Using this tool for medium- and long-term planning will provide the decision maker with more information in the face of uncertainty, thus avoiding many mistakes in the management.

3. The accuracy of the model is based on statistical data that is publicly available. Unfortunately, these data are not complete and do not include many indicators, the values of which in the model were obtained by the method of expert estimates.

Further, it is supposed to refine and adjust the model using newer statistical data; to organize computational experiments that reveal the economic trends of the impact of complex programs and scenarios for the development of the MSW market, both from the point of view of the municipality and of private companies

## References

1. V.I. Smetanin, S.P. Krasovskaya, E.V. Shchekudov, L.A. Vorob'ev, Dinamika obrazovaniya i nakopleniya othodov proizvodstva i potrebleniya v kurortnyh gorodah (na primere goroda Sochi) **1**, 7-13 (2012)
2. E.D. Antmann, N. Celik, X. Shi, Y. Dai, Simulation-based optimization of solid waste management and recycling programs, *62nd IIE Ann. Conf. & Ex.*, 759-768 (2012)
3. M.N. Aptalaev, M.E. Zhalko, D.S. Balabanov, K.A. Kalinina, Rus. J of res., cons. & rec. **4** (2017) Doi: 10.15862/12RRO417
4. K.I. Manaev, A.N Mel'nikov, V. of the Or. St. Un. **10(171)**, 130-134 (2014)
5. R. Cremiato, M.L. Mastellone, C. Tagliaferri, L. Zaccariello, P. Lettieri, Ren. En. **124**, 180-188 (2018)
6. N.I. Gutova, A.A. Shostak, Problemy utilizacii othodov g. Sochi, K-rekr. kompl. v sist.reg. razv. **1**, 97-100 (2017)
7. Y. Podchashinskiy, I. Kotsiuba, T. Yelnikova, E-Eu. J. of E. T. **1(10)**, 4-10 (2017)
8. M. Chopda, A. M. Malek, IRJET **5(4)**, 4836-4842 (2018)
9. M.Yu. Belousov, The HSE Ec. J. **14(3)**, 379-394 (2010)
10. E.A. Arustamov, Rus. J of res., cons. & rec., **2** (2018) Doi: 10.15862/05NZOR218
11. I.A. Proskurnikova, GIAB **3(1)**, 335-337 (2013)
12. A. Kopyrin, MATEC Web of Conf. **170**, 01030 (2018) doi:10.1051/matecconf/201817001030
13. *Resolution of the head of the administration (governor) of Krasnodar Territory, dated Sep. 26, 2016 № 747* (2016)
14. A. Solomin, Elementy razrabotki ekologicheski bezopasnoj gorodskoj sistemy pererabotki tverdyh bytovyh othodov na primere goroda Sochi **2**, 13-16 (2015)