Algorithm of the Software Modules Interaction for Managing the Collection and Transportation of Municipal Solid Waste

A A Popov¹, A O Kuzmina²

¹Department of Informatics, Plekhanov Russian University of Economics, Stremyanny lane, 36, Moscow, 117997, Russia
²Department CRM, GMCS, 7, Pokryshkina street, Moscow, 119602

E-mail: popov.aa@rea.ru, a1710p@mail.ru

Abstract. The article is devoted to research of automation of collecting and transporting municipal solid waste. The aim of the article is development of methodology for substantiating the selection and evaluation of the economic efficiency of the software for managing the collection and transportation of the municipal solid waste. The mathematical models, which are used to predict the type and amount of waste, are considered. A multiplicity of parameters, characterizing municipal solid waste collecting and transporting, was determined. The resulting multiplicity of parameters allows tracking the implementation of the municipal solid waste collecting and transporting cycle. The end of the cycle occurs at the balance between the amount of municipal solid waste, generated by multitenant apartment management organizations and the amount of municipal solid waste, unloaded from garbage trucks to sorting organizations. The composition and functionality of the software modules set for automation of collecting and transporting municipal solid waste was substantiated. Software modules set uses mathematical models to determine the routes for the garbage trucks movement, which corresponds to the minimum costs. The order of the software modules interaction and the conditions, under which the implementation of the software modules set will be cost-effective, are considered.

1. Introduction
Municipal solid waste management is one of the most complicated problems because of lack of reliable data about keeping, collecting, transporting, separating, recycling and burial. The composition of waste becomes more complicated (plastic and electronic consumer goods became widespread). This trend makes waste management more complicated. Waste management strategy, its composition and amount depend on cultural, climatic and socio-economic parameters of the region. The main problems of the municipal solid waste management include integration of the municipal solid waste management in developing and industrialized cities, increasing and standardizing of collection and analysis of the data on amount and types of waste, which tend to get complicated [1, 2, 3].

European Union introduced a five-tiered waste management hierarchy (prevention, preparation for reuse, reuse, recirculation, utilization). Improved version of this hierarchy is hierarchy “Three R”: reduce waste, including its prevention, reuse, recycle. The aim of this waste management is zero amount of waste for burial.
2. Mathematical models for waste management and the possibility of using digital technologies in the management of solid household waste

Consider the mathematical models, which can be used in work of the software modules of the management information system for collecting and transporting municipal solid waste.

In [4] models for predicting the amount of waste, based on the neural network and multiple linear regression, are given. In [5] predicting amount of waste, using multidimensional Grey model, is considered. The most important factor (population density), which has the greatest impact on the amount of municipal solid waste, is determined. In [6] demographic indicators are used as input variables to predict the number of types of municipal solid waste using regression analysis and time series analysis. In [7] for planning the municipal solid waste management system is used mixed integer linear programming with fuzzy random limits. In [8] integer linear programming and mixed integer linear programming for modeling municipal solid waste management scenarios are used. In [9] for waste management is used method of linear programming with fuzzy stochastic interval. In [10] is used fuzzy parametric programming for selecting type of waste and selecting facilities for waste processing and utilization (distribution of the municipal solid waste, taking into account the fuzzy values characterizing the amount of waste and operational capabilities of waste management facilities, is made). In [11, 12] is used multi-agent view model of the municipal solid waste management system. In [13] is considered using the genetic algorithm to reduce costs in collecting and transporting waste, considering technical, economic and environmental constraints. In [14] are considered semi-static and dynamic model for routing garbage trucks along the shortest way, which is complemented by the ability of using Internet of Things (IoT) devices. For municipal solid waste management digital technologies began to be used (cloud technologies, IoT technology, neural networks and artificial intelligence, blockchain technology).

Consider the possibility of using digital technologies in the management of solid household waste. In [12, 15] the task of waste management using IoT devices, installed in garbage containers, is considered. Using data, received from sensors, transportation costs are minimized. In [16] the use of Arduino boards with microcontroller and module GSM and infrared sensors for municipal solid waste level detection in the garbage containers is considered. Implemented intellectual component for municipal solid waste management (collecting and transporting municipal solid waste is done only when it is necessary). In [17] is considered using cloud technologies and IoT devices, using wireless protocol ZigBee, installed in garbage containers for municipal solid waste level detection in the garbage containers and issuing signals to garbage truck drivers to fill garbage containers. In [18] the possibility of use the mobile software application to organize the collection of some types of municipal solid waste is considered. In [19] is suggested to use microcomputers Raspberry Pi and ultrasonic sensors for measuring the level of waste in garbage containers. Data, characterizing waste level in garbage containers, are used for forecasting the municipal solid waste level in containers, also for dynamic formation of routes for the garbage trucks. In [20] is considered the use of Big Bucket IoT Cloud environment, in which intelligent garbage containers are equipped with IoT devices and software with open source. In [21] the blockchain, IoT, Unified Modeling Language (UML) and Temporal Logic of Actions (TLA+) for modeling and automating waste management system, is considered. In [22] is considered the use of IoT devices, interacting with MQTT protocol to determine level of filling of garbage containers. Data about waste level reaching the threshold value is used to determine the optimal route for collecting municipal solid waste from the filled containers using Haversine formulas and the traveling salesman algorithm. After this information about the route for collecting municipal solid waste is given to garbage trucks drivers via Telegram messaging application. In [23] is considered intelligent monitoring system of municipal solid waste using IoT technology and cloud platform ThingSpeak. Data about level of garbage containers filling is sent as notifications (tweets) to the appropriate management organizations.
3. Parameters, characterizing collecting and transporting municipal solid waste

As the source of waste are considered multitenant apartments (MTA) management organizations. Information about MTA is contained in the array \[ \text{ORG} = \{\text{org}(io); \ io=1, 2, \ldots, IO\} \], where \( IO \) – number of organizations, generating waste. Each \( io \)-th organization for the fixed time interval generates waste of \( iw \)-th type (element \( w(io, iw) \) of matrix \( W \), \( iw=0 \) – mixed municipal solid waste, \( iw\neq0 \) – separately collected waste of \( iw \)-th type): \( W = \{w(io, iw); \ io=1, 2, \ldots, IO; iw = 1, 2, \ldots, IW\} \), where \( IW \)- number of types of waste. Total amount of waste, generated by all MTA management organizations, equals

\[
WG = \sum_{io=1}^{IO} \sum_{iw=0}^{IW} w(io, iw)
\]

For forecasting amount and types of waste, generated by MTA management organizations, can be used mathematical models [4, 5, 6]. For collecting waste are used “smart” containers, intended for both mixed and separated collecting of waste. Commonly used \( KT \) types of "smart" containers ("smart" vacuum containers, “smart” underground containers, common “smart” land containers), which are equipped with sensors that record the level of waste in the container. For \( iw \)-th type of municipal solid waste are used \( K(iw) \) garbage containers, where \( K(iw) = j(1, iw) + j(2, iw) + \ldots + j(KT, iw) \) and \( J(k, iw) \) - number of \( k \)-th type of containers for separated collecting \( iw \)-th type of municipal solid waste. Waste of \( iw \)-th type, received from \( io \)-th organization, placed in one or more \( k \)-th type of containers for \( iw \)-th type of municipal solid waste. Thus:

\[
w(io, iw) = kn(io, iw, 1) + kn(io, iw, 2) + \ldots + kn(io, iw, KT)
\]

\[
k^{n}(io, iw, k) = k^{r}(io, iw, k, 1) + k^{r}(io, iw, k, 2) + \ldots + k^{r}(io, iw, k, J(k, iw)).
\]

where \( kn(io, iw, k) \), \( k^{r}(io, iw, k, j) \) – accordingly amount of \( iw \)-th type of waste, which \( io \)-th organization places in \( k \)-th type of containers, and amount of \( iw \)-th type of waste, which \( io \)-th organization places in \( j \)-th container of \( k \)-th type. Total amount of waste, loaded into containers:

\[
WS = \sum_{io=1}^{IO} \sum_{iw=1}^{IW} \sum_{k=1}^{KT} \sum_{j=1}^{J(k,iw)} k^{r}(io, iw, k, j)
\]

Generated waste loading cycle in containers ends while \( WS = WG \).

For collecting and transporting municipal solid waste are used \( MR \) garbage trucks. Wherein for transporting \( iw \)-th type of waste is used \( M(iw) \) garbage trucks. Amount of \( iw \)-th type of municipal solid waste, loaded into \( m \)-th garbage trucks from containers, equals \( WR(iw, m) \). In \( m \)-th garbage truck for \( iw \)-th type of municipal solid waste loading can be done from one or several different types of containers:

\[
WR(iw, m) = mr(iw, m, 1) + mr(iw, m, 2) + \ldots + mr(iw, m, KT)
\]

\[
mr(iw, m, k) = r(iw, m, k, 1) + r(iw, m, k, 2) + \ldots + r(iw, m, k, J(k, iw)).
\]

where \( mr(iw, m, k) \), \( r(iw, m, k, j) \) – amount of \( iw \)-th type of municipal solid waste, loaded into \( m \)-th garbage truck from \( i \)-th type of garbage containers, and amount of \( iw \)-th type of municipal solid waste, loaded into \( m \)-th garbage truck, from \( j \)-th container of \( k \)-th type.

Total amount of transported municipal solid waste:

\[
WP = \sum_{iw=1}^{IW} \sum_{m=1}^{M(iw)} \sum_{k=1}^{KT} \sum_{j=1}^{J(k,iw)} r(iw, m, k, j)
\]

Waste loading cycle in containers ends while \( WP = WS \).

Containers and garbage trucks are characterized by the following parameters:

- \( KP(iw, k, j) \), \( KL(iw, k, j) \) – location of \( j \)-th container of \( k \)-th type for collecting \( iw \)-th type of municipal solid waste, also level of filling \( j \)-th container of \( k \)-th type for collecting \( iw \)-th type of municipal solid waste.
\[
\text{Parameters}, \text{ characterizing garbage containers, are included in multiplicity } \mathbf{KF}:
\]
\[
\mathbf{KF} = \{kn(iw, io, k), KP(iw, j, k), KL(iw, k, j); w = 1, 2, ..., IW; k = 1, 2, ..., KT; j = 1, 2, ..., J(k, iw)\}
\]

Parameters, characterizing work of garbage trucks on collecting and transporting municipal solid waste, are included in multiplicity \( \mathbf{ST} \):
\[
\mathbf{ST} = \{WR(iw, m); iw = 1, 2, ..., IW; m = 1, 2, ..., M(iw)\}.
\]

Restrictions on work of garbage trucks are included in multiplicity \( \mathbf{DR} \):
\[
\mathbf{DR} = \{MP(iw, m), MF(iw, m), MM(iw, m); iw = 1, 2, ..., IW; m = 1, 2, ..., M(iw)\}.
\]

Unloading waste from garbage trucks is done by PP organizations, carrying out waste sorting. Sorted waste can be sent for reuse, for recycle, for utilization on polygon or for burning. Amount of \( iw \)-th type of municipal solid waste, unloaded on \( pp \)-th organization:
\[
WW(pp) = ZW(pp, 0) + ZW(pp, 1) + ZW(pp, 2) + ... + ZW(pp, IW),
\]
where
\[
ZW(pp, iw) = s(pp, iw, 1) + s(pp, iw, 2) + ... + s(pp, iw, M(iw)),
\]
\[
\text{amount of } iw \text{-th type of municipal solid waste, unloaded from garbage trucks to } pp \text{-th sorting organization, and amount of } iw \text{-th type of municipal solid waste, also amount of } iw \text{-th type of municipal solid waste, unloaded to } pp \text{-th sorting organization from } m \text{-th garbage truck.}
\]

Amount of all types of municipal solid waste, unloaded from garbage trucks to sorting organizations:
\[
WT = \sum_{pp=1}^{PP} \sum_{iw=1}^{IW} \sum_{m=1}^{M(iw)} s(pp, iw, m).
\]

Waste collecting and transporting cycle ends while \( WT = WP \).

After ending of the next waste collecting and transporting cycle, which continues for \( \Delta t \) time interval, value \( WT \) in the element \( cw(u) \) of multiplicity \( \mathbf{CW} = \{cw(u); u = 1, 2, ..., U\} \) is recorded. After that, if necessary there is a transition to the next waste collecting and transporting cycle. Each sorting organization is characterized by location \( SP(pp) \), where \( pp = 1, 2, ..., PP \). Also sorting organization has restrictions on maximum amount of \( iw \)-th type of municipal solid waste, which can be received in at the current time: \( WW(pp, iw) \leq WW_{\text{max}}(pp, iw) \). Municipal solid waste unloading on sorting organization can be done from one or several garbage trucks taking into account these restrictions.

Parameters, characterizing work of sorting organizations, included in multiplicity \( \mathbf{SR} \):
\[
\mathbf{SR} = \{SP(pp), WW_{\text{max}}(pp, iw); pp = 1, 2, ..., PP; iw = 1, 2, ..., IW\}.
\]

For municipal solid waste management and its transporting can be used mathematical models [7, 8, 9, 10, 11]. Each garbage truck moves on the assigned route for collecting municipal solid waste from containers and transporting waste to the sorting organizations. For each \( m \)-th garbage truck, intended for transporting \( iw \)-th type of municipal solid waste, taking into account the above parameters is built \( Z(iw, m) \) route options \( RR(iw, m, z) \), subject to different sequence of bypassing containers and sorting organizations. Wherein number of routes \( Z(iw, m) \) for each garbage truck can be different:
\[
RR(iw, m, z) = FR(KP(iw, j, k), KL(iw, k, j), MP(iw, m),
MF(iw, m), MM(iw, m), SP(pp), WW_{\text{max}}(pp, iw, z)),
\]
where \( z = 1, 2, ..., Z(iw, m) \);
\( FR \) – function for building the garbage trucks routes, collecting and transporting municipal solid waste to sorting organizations;
\( z, Z(iw, m) \) – garbage truck route number and number of routes, built for \( m \)-th garbage truck, collecting and transporting \( iw \)-th type of municipal solid waste.

Garbage trucks routes are the elements of multiplicity \( \mathbf{RT} \):
\[
\mathbf{RT} = \{RR(iw, m, z)\}.
\]

Each garbage truck route correspond costs for collecting and transporting municipal solid waste to sorting organizations: \( PY(iw): \{RR(iw, m, z)\} \rightarrow \{PS(iw, m, z)\} \), where \( PY(iw) \) – function, transforming garbage trucks routes, transporting \( iw \)-th type of waste, in costs for collecting and transporting municipal solid waste.
4. Statement of the problem

Given:

Array ORG. Matrix W. Multiplicities KF, ST, DR, RT, SR. Functions PY(iw), iw = 1, 2, ..., IW. Required to determine:

Set of the software modules PM = \{pm(1), pm(2), ..., pm(P)\}, allows to determine combination of the garbage trucks routes R*, which corresponds to minimum municipal solid waste collecting and transporting costs MNP: PM: (ORG, W, KF, ST, DR, RT, SR, PY(iw)) → MNPs, R* = \{RTR(iw, m, z(iw, m))\}, MNPs = PY1(R*) + PY2(R*) + ... + PY(iw)(R*), z*(iw, m) – number of the route for multiplicity R*, selected from the number Z(iw, M(iw)) of routes m-th garbage truck for collecting and transporting iw-th type of municipal solid waste.

5. Software modules, included in the information system for collecting and transporting municipal solid waste, and their interaction

To manage collecting and transporting waste are necessary the following software modules:

- Software module GEN for input array ORG and matrix W and for determination WG value.
- Software module WCONT for the loading amount of generated waste in different types of garbage containers and for determination WS value.
- Software module GTRCONT for determination WPs value.
- Software module DRIVERGTR for taking into account and clarify restrictions on loading and movement of garbage trucks.
- Software module PEST for taking into account and clarify restrictions on municipal solid waste unloading from garbage trucks to waste sorting organizations.
- Software module WORKGAR for determination set of routes for each garbage truck.
- Software module ROUTOPT for determination routes of garbage trucks R*, which corresponds to MNPs.
- Software module WORKGAR for bringing routes to garbage trucks drivers.
- Software module GTRSORT for determination WS – amount of municipal solid waste, unloaded from garbage trucks to waste sorting organizations.
- Software module CYCLE for information system preparation to the new collecting and transporting waste cycle.

Software modules interaction, included in set PM, occurs according to the algorithm, given in the figure 1. Thus, using set of the software modules PM allows achieving balance of amount of generated waste, loaded into garbage containers, waste, transported by garbage trucks, and waste, placed for sorting. Wherein minimum costs MNP for collecting and transporting waste are achieved. In case of the end of the process of the collecting and transporting waste, the archive of the amount of waste as the multiplicity CW remains.

Using the set of software to achieve minimum costs MNP for collecting and transporting municipal solid waste allows reduce the overall costs of organizations in the housing and communal services by the amount \(\Delta X_{MSW} = X_{WG} - X\), where X – costs for collecting and transporting municipal solid waste without using the set of software modules, a \(X_{WG}\) – costs for collecting and transporting municipal solid waste using the set of software modules. The economic effect (positive value \(\Delta X_{MSW}\)) is achieved as the result of determination of optimal garbage trucks routes R*, and, accordingly, MNP is achieved saving fuel costs for garbage trucks (value \(\Delta X_{fuel}\)) and working with it (value \(\Delta X_{WorkGarb}\)). Besides, costs for salaries of employees, involved in organization of the collecting and transporting municipal solid waste (value \(\Delta X_{emp}\)), decrease. Wherein, while implementing the set of software modules appear additional costs for its service (value \(\Delta X_{WG}\)). Also in case of using “smart” garbage containers, might increase costs for service of garbage containers and salaries of employees, serving garbage containers (value \(\Delta X_{cont}\)). The article assumes that number of garbage trucks and number of garbage containers while implementing the set of software modules, does not change.

Thus \(\Delta X_{MSW} > 0\), if \(|\Delta X_{fuel} + \Delta X_{emp} + \Delta X_{WorkGarb} - \Delta X_{WG} - \Delta X_{cont}| > 0\).
Figure 1. Order of the software modules interaction of the collecting and transporting municipal solid waste information system.

6. Conclusion
As the result of research, conducted in this article, are received the following results:
• Parameters, characterizing collecting and transporting municipal solid waste, were analyzed.
• The set of the software modules, included in collecting and transporting municipal solid waste information system, is obtained. The algorithm for the interaction of software modules is developed.
• Conditions, at which implementation of set of the software modules will be economic effective for MTA management organizations, are formulated.

7. References
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