Development of a complex system models in mixed municipal waste bales

Lovorka Gotal Dmitrovic

Assistant Professor, University North, Varazdin, Croatia, EU
E-mail: lgotaldmitrovic@unin.hr

Abstract. The development of the organic matter decomposition model in mixed municipal waste is presented in the paper. The decomposition takes place in two main processes: aerobic and anaerobic. The whole system, according to system theory, belongs to complex ecosystems. Model development begins with conceptualisation. Because the process belongs to hybrid systems (continuous and discrete states are changing) for conceptualization, the model for discrete simulation (the Activity Cycle Diagram (ACD)), but also for systems dynamics (Flow Chart) was used. To evaluate the simulation model, the Rank Sum Test (or Mann-Whitney U-test) was used. The research conducted for the purposes of this paper is reflected in an interdisciplinary field covering information science and ecology and environmental protection (eco-informatics), which enables the systematic study and proposing of measures for environmental protection, by transferring environmental testing to the simulation model. The developed model is adaptive and portable, in terms of the application of such systems at other locations, that is, with different values of input pollution concentrations. Methods of modelling and conceptualizing such situations contribute significantly to environmental protection and human health.

1. Introduction
In Varazdin City (in the north of Croatia), mixed municipal waste was collected, crushed, crossed, and baled (wrapped with 3 layers of different types of linear low-density polyethylene (LLDPE)). A huge number of complex processes take place in the part bio-waste.

Due to the complexity of the overall system, models have been developed in this work to show the decomposition of organic matter, with the emphasis on dissolved organic carbon (DOC). Initial moisture in bio-waste is increased by water generated by decomposition processes (as well as by precipitation water that penetrates damaged bales after the termination of water tightness from the foil).

First, aerobic decomposition begins. The moisture is increased, as well as the microbial population. Oxygen (O₂) is consumed. Biological oxygen consumption (BOC) is increased. Volatile short-chain organic acids and water-soluble metals compounds are present. At this stage, carbon dioxide (CO₂), water (H₂O) and nitrates (NO₃⁻) are produced. The pH value content is gradually reduced and conditions for anaerobic degradation are created. As oxygen is consumed, anaerobic conditions start prevalent. In the anaerobic phase, carbon dioxide (CO₂) and methane (CH₄) are formed from organic acids (previously formed), with the pH increasing.

2. Conceptual models
The development and application of conceptual models are very important in the development of computer models because they provide an explicit view of the operation of the complex system and thus facilitate understanding. Each of the simulation modelling methods has characteristic conceptual models
and symbols. One of the most important conceptual models in discrete simulation is the Activity Cycle Diagram (ACD). [1] Conceptual representations of systems dynamics models is a flow chart. [1] The models of both phases (aerobic and anaerobic) were first developed as conceptual models using the Activity Cycle Diagrams (Figure 1).

![Activity Cycle Diagram](image1)

**Figure 1.** Activity Cycle Diagram.

The entity for which the activity cycle diagram is made is "CARBON". In this activity cycle diagram, the active states (squares) and the passive states (ellipses) alternate. Ishikawa diagram (Figure 2) is a causal diagram that shows the causes of a specific event. That diagram uses it to discover the root cause of a problem and to uncover the bottleneck to processes. [2]

![Ishikawa Diagram](image2)

**Figure 2.** Ishikawa Diagram.
Diagram analysis shows:
- The level of detail is almost balanced.
- The causes do not recur.
- Substances and devices have the greatest impact.
- Substances are the causes that are most diverse and action can be taken.

The flowchart provides a more detailed view of the relationship between levels, speeds, and delays. In systems dynamics models, entities and events are aggregated into levels that are actually system state variables and flows. At levels, material accumulation occurs while material and information flows are determined by transition rates [3]. The flowchart is a "skeleton" of a computer model, whose icons include mathematical dependencies (chapter 4. System dynamics models).

3. Data collection and processing
Samples were collected before waste treatment began, i.e., immediately after the truck was emptied. After laboratory measurements, dissolved organic carbon (DOC) concentrations were extracted for the purposes of this study. Results were collected over 4 years. Descriptive statistics of the obtained values are presented in Table 1.

Table 1. Descriptive statistics.

| parameter                        | value  |
|----------------------------------|--------|
| average (arithmetic mean) (mg/kg)| 728.6  |
| standard deviation               | 1128.742 |
| minimum (mg/kg)                  | 8      |
| maximum (mg/kg)                  | 2799   |
| range (mg/kg)                    | 2791   |

Using Stat: Fit application, it was obtained a theoretical probability distribution that best fits the real data - The Weibull distribution with parameter: minimum (min) = 8, shape parameter \( \alpha \)=0.36415 and scale parameter \( \beta \)=233.314 (Figure 3).

![Figure 3. Weibull distribution for DOC on input.](image)

The Weibull distribution (or the Frechet Distribution and the Weibull-Gnedenko distribution) is a continuous distribution bounded on the lower side. According to Johnson [4] the standard form is:
The Weibull distribution is used to model: the strength of materials, to represent wear out lifetimes in reliability, wind speed, rainfall intensity, health related issues, germination, duration of industrial stoppages, migratory systems, and thunderstorm data [4, 5].

According to (1) and parameter, input distribution of DOC is:

$$f(x) = \frac{a}{\beta} \left( \frac{x - \min \beta}{\beta} \right)^{a-1} \exp \left( -\left( \frac{x - \min \beta}{\beta} \right)^a \right)$$  \hspace{1cm} (1)

For calculating the goodness of fit tests was used the Kolmogorov Smirnov Test, and the Anderson Darling Test. Tests results are in Table 2.

| parameter                        | value  |
|----------------------------------|--------|
| average (arithmetic mean) (mg/kg)| 728.6  |
| standard deviation               | 1128.742 |
| minimum (mg/kg)                  | 8      |
| maximum (mg/kg)                  | 2799   |
| range (mg/kg)                    | 2791   |

The Kolmogorov Smirnov Test is a test of the goodness of fit of the fitted cumulative distribution to the input data, point by point, and the Anderson Darling Test, by point pairs, weighted to make the tails of the distribution more sensitive.

### 4. System dynamics models

In the system dynamics model, levels are displayed with rectangles. Material flows are represented by a valve symbol. With valve, throughput is governed by information flows. Auxiliary variables are displayed with a circle. A special type of auxiliary variables is constant? The cloud is a symbol for the in/out. The dynamics model of the dissolved organic carbon (DOC) decomposition system is shown in the flowchart in Figure 4, for the aerobic process and in Figure 5, for anaerobic process.
5. Results
The results obtained by the model are shown in Figure 6. The organic matter concentration graph shows the "breaking point" when the aerobic process ends and the anaerobic process begins. Then the oxygen ($O_2$) concentration approaches 0 and methane ($CH_4$) begins to develop.

The graph for the organic matter concentration (in Figure 6.) shows the "breaking point", i.e. the moment, when the aerobic process finished and the anaerobic process begins. At that moment, the oxygen concentration is almost 0.

The dynamics model of the organic matter (like dissolved organic carbon (DOC)) decomposition system is shown in the two subsystems. The first subsystem shows the model of the aerobic process (Figure 4.) where the oxygen concentration is bigger than zero (but falls towards zero). Organic matter decomposes on carbon dioxide ($CO_2$) and water ($H_2O$).

Initial concentration of organic matter (like dissolved organic carbon) is maximum real value - 2800 mg/kg (Table 1.). After 30 months, oxygen concentration is near to 0 mg/kg, and the anaerobic process (Figure 5.) beginning (ne paše mi nekak, ne znam, ne bi bilo bolje begins? - počinje).
Organic matter (in the shape of volatile short chain organic acid) decomposes on methane and carbon dioxide. The model developed is a worst-case scenario, i.e. concentration which was used to predicate is the maximum concentration.

The evaluation of the simulation model examines whether the simulation model adequately represents the actual system. The actual output values are compared with the model output [6]. Since these are distributions that do not belong to the family of Gaussian curves or are asymmetric, non-parametric methods are used for testing (sometimes referred to as “distribution-free statistics”) [7]. Because these are two independent samples, the Rank Sum Test was used.

The Rank Sum Test is also called the Mann-Whitney U-test. This test is somewhat similar to the homogeneous array test, but it uses more information (i.e. it uses ranks, not just a division into two categories) and can, therefore, be considered better and more powerful. The Rank Sum test is used to test whether two samples belong to a population with the same median.

The data are ranked, and the sum of the rankings is calculated. Then \( z \) is calculated:

\[
z = \frac{|2T_i - N_i(N + 1)| - 2}{\sqrt{\frac{N_1N_2(N+1)}{3}}}
\]  

where \( T_i \) is any of the sums of ranks, and \( N_i \) is the number of values in the group from which we took \( z \). The sensitivity level is 0.05. Statistica 12 application by StatSoft, Inc. was used for rank sum tests.

After the rank sum tests have been performed. The values obtained are shown in Table 3. The same table shows the minimum, maximum and mean values for the actual mass concentrations and for the mass concentrations obtained by the model.

| parameter                  | real value | model value |
|----------------------------|------------|-------------|
| average (arithmetic mean) (mg/kg) | 1390.13    | 1481.25     |
| minimum (mg/kg)            | 775.5      | 700         |
| maximum (mg/kg)            | 2799       | 2900        |
| range (mg/kg)              | 2791       | 2750        |
| Mann-Whitney U test        | H_0        | -0.05251    |
| z-score                    |            | 0.96012     |
| p-value                    |            | 31          |
| U-value                    |            |             |

The statistical test shows that there is no statistically significant difference for \( p < 0.5 \).

6. Conclusion

Environmental protection as an interdisciplinary scientific discipline is evolving rapidly, using information and communication technologies (ICT). Simulation modeling provides tools and approaches for managing environmental indicators, and converting them into information and knowledge.

The focus of the paper is the model of decomposition of the organic matter in baled, mixed municipal waste. The main features of this system that each complex ecosystem has: complexity (complex flow of information and matter), reality (existing in the physical world), openness, but with clearly defined boundaries (exchange of matter, energy and information across system boundaries), dynamic in time (time-varying system or its subsystem), hybridity (mixed continuous states of systems with discrete), the system is not under human control but by nature control (autonomous system).

A complex adaptive ecosystem of organic matter decomposition has been formed in baled mixed municipal waste. The process is divided into two stages:
• Aerobic process and
• Anaerobic process.
Each component (subsystem) consists of a series of physical, chemical and/or biological processes. The formation of a complex adaptive ecosystem of organic matter decomposition is the fundamental and expected outcome of this research, beginning with its conceptual level.
The model was validated, i.e. the simulation model was evaluated using the Man Whitney U test (The Rank Sum Test). It demonstrates that the simulation model adequately represents the actual system.

7. References
[1] Gotal Dmitrovic L 2019 Appliance of Simulation Modelling in Wastewater Treatment, International Journal of Environmental Science and Development (IJESD), Vol. 10, No. 12
[2] Gotal Dmitrovic L; Dusak V and Anic Vucinic A 2015 The Development of Conceptual, Mathematical and System Dynamics Model for Food Industry Wastewater Purifying System, Journal of Information and Organizational Sciences (JIOS), Vol. 39, No. 2
[3] Blazinic B; Gotal Dmitrovic L and Stojic M (2020) Development of a Models of Interpersonal Competencies as a Complex System, Journal of Information and Organizational Sciences (JIOS), Vol. 44, No. 2
[4] Johnson N L; Kotz S; Balakrishnan N (1994) Continuous Univariate Distributions, Vol. 1, John Wiley&Sons, p628
[5] Shooman M L (1990) Probabilistic Reliability: An Engineering Approach, Robert E. Krieger, p190
[6] Gotal Dmitrovic L; Lesina M; Stojic M (2019) Transformation of National Economies in Boundless World, 37th International Scientific Conference on Economic and Social Development (ESD Conference) – Socio Economic Problems of Sustainable Development - Book of Proceedings, Edit.: M. Ibrahimov, A. Aleksic, D. Dukic, February, 14-15, 2019, Baku, Azerbaijan, p1117-1127
[7] Petz B; Kolesarić V; Ivanec D (2012) Petzova statistika, Naklada Slap, Zagreb