Petri Nets Application for Management of Biodegradable Components of Municipal Waste

ROBERT BAŤA[1], ILONA OBRŠÁLOVÁ[1], JOSEF VOLEK[2], TICIANO COSTA JORDÃO[1]
[1] Faculty of Economics and Administration, Institute of Public Administration and Law and
[2] Jan Perner Transport Faculty, Department of Informatics in Transport
University of Pardubice
Studentská 95, 532 10 Pardubice
CZECH REPUBLIC
robert.bata@upce.cz; ilona.obrsalova@upce.cz; josef.volek@upce.cz;
ticiano.costa-jordao@upce.cz http://www.upce.cz

Abstract: The contribution presents the possibility of modelling by means of Petri nets with the aim to find a solution, which would minimize the impact on environment and maximize utilization of this component of municipal waste. Various possibilities of separation, logistics and collection with technical alternatives of these material flows solutions have been focused. There was calculated one of possible situation for bio-waste fraction utilization and potential environmental impacts estimated. Petri nets using gave good results for regional decision making and offered quick tool for different scenarios creating.

Key- Words: Petri nets, municipal waste disposal, municipal waste material utilization, biodegradable waste, Umberto, LCA, material flow, modelling, composting**.**

1 Introduction

The effort to reduce the amount of biodegradable constituent of municipal waste has been recently being lead by not only legislation, conceptions and plans in waste management, economic tools of environmental policy but also by initiatives from below, on regional level.

The basic purpose of legal regulations concerning waste disposal is the protection of the environment from negative waste exposure and purposeful utilization of natural resources. Nowadays there is already a complex law Nr. 185/2001 Coll. about waste and subsequent amendments. This law has been already novelized several times and more changes are being discussed [1, 2, 3, 5].

By municipal waste such waste is meant which is created in the area of a municipality by activity of physical persons and is listed in the Catalogue of Wastes established by a decree of The Ministry for Environment, with the exception of waste produced by legal persons or physical persons permitted to entrepreneurship.

According to the Council Directive 99/31/EC, member states are obliged to ensure decreasing the amount of biologically degradable municipal waste (BDMW) flowing to landfills to 50% in 2009 and to 35% in 2016 from the amount produced in 1995. The plan of waste management of the Czech Republic aims to lower the maximum amount of biologically degradable municipal waste placed to landfills so that the proportion would be up to 75% of weight in 2010, 50% of weight in 2013 and distantly seen 35% of the total amount produced in 1995 by 2020 [17, 27].

The paper deals with a part of this problem and that is biodegradable waste created as a part of municipal waste. Sorting this waste and its recycling is little, compared to other states of the EU. The region chosen for this paper is the Pardubice Region, territorial statistical unit NUTS III with individual municipalities where the generating of

BDMW was watched.

The production of municipal waste (in kg) per capita in the Czech Republic is, compared internationally, relatively low, in 2005 it was 55% of the level in the EU 25. The proportion between landfilled and incinerated municipal waste is different from the EU average, landfilled waste is two thirds above the EU average while incinerated waste is below average.
The amount of produced municipal waste in the Pardubice region between 2003 and 2005 was growing slowly; the growth in 2006 was more significant up to 231,3kg per capita (by 9% higher compared to 2003). This amount was as well as in previous years below the average in the Czech Republic (296.0 kg per capita in 2006, 6% more than in 2003) [8, 13, 17].
There are not available long-term data for valuation. Tab.1 demonstrates changes in the municipal waste disposal in the Czech Republic.

Tab.1 Municipal waste disposal in the Czech Republic, 2002 - 2006

Manner of use	**Amount (t)**				
	2002	**2003**	**2004**	**2005**	**2006**
Landfilling	2 922 146	2 924 458	2 997 185	3 072 660	3 223
Treatment by soil process	11 652	18 117	4 074	2 080	479
Deep injection	12	-	872	-	53
Storage in surface	-	-	-	-	9
reservoirs	34	414	6	-	-
Depositing in spec.landfills	276 737	132 163	142 377	133 066	-
Biological treatment	3 692	8 835	6 577	8 211	9 877
Phys.-chem. treatment	314 888	222 928	214 388	1 741	7 113
Combustion	202	212	227	2 254	2 132
Final or permanent depos.					1 833

Source: [7, 8]

The amount of bio-waste from households fluctuates, according to analyses, between 30 and 60 kg per capita and year depending mostly on life style. Various estimations state [7, 8, 12, 25, 27] that 30-60% weight of municipal waste is formed by BDMW.
The proportion of separated constituents of municipal waste in the Czech Republic in recent years has grown to 10.8%, in the Pardubice region 12.2%. However, the time line is not informing enough about the trend on regional level [21, 28].
Quantification and evaluation of time lines on this level is very complicated due to the changes in methods of their declaration. This is true especially for analyses of material utilization of waste. The data for the calculation are collected from the Czech Statistical Office, EKO KOM a.s., Waste Management Information System (ISOH) and own research [7, 8, 13, 17, 18, 27].

The whole (project) capacity of municipal-waste landfills in the area of the Pardubice region is 5.3 mil. m^3, which, with respect to municipal waste production on the level of 160,000 t per year and to the method of storage (compaction coefficient 1.2), provides an outlook, considering even partial usage of capacities nowadays, at least until 2030. There were 99 composting plants with the capacity of 8 855 859 t/year in the Czech Republic [9]
Incinerating as an alternative for land filling is not popular disposal of municipal waste in the Czech Republic, there are three incinerating plants, in the particular region none.

1.1 Waste disposal techniques

Nowadays several options for dealing with municipal waste. As a solution on territorial entity decision level, we have chosen separation biowaste and its composting. This task can be solved by many ways, which differ in gathering and disposing logistics [4, 11, 14, 15].
Tackling specific distance of collecting containers from quarters is not a subject of law of waste, which has more general nature. Main reason for that is, that it is always necessary to impeach concrete conditions, its location, quarters accessibility, landscape pattern ect. That is why it is up to each town to solve this problem in its own territorial scope. We can also approach the problem from preventative viewpoint. One of possibilities is for example
Cleaner production/consumption.
Application for lowering municipal waste in village [21] was applied.

General means of dealing with biologically degradable waste , which are applied in EU member countries are:

- separate collection,
- heat processing,
- central composting,
- material recyclation.

In Czech Republic devices for composting waste, which process mainly other waste (especially processing wood and paper, but also fetched biologically degradable waste, such as garden waste and so on. Capacity of waste composting factilities is present time sufficient [13].

1.2 Methods for waste disposal modelling

Judging impact of waste composting on environment is a task for management of material and energy flows observed according to principles LCA, because only by quoting of all the material and energy flows from creation of compostable material in a biomass form via all the relevant steps of its processing to its coversion into final product, in this case compost. If any negligance of important, mainly material flows occurs, results may be severely disorted and that may lead to plain wrong conclusions.

This risk can be characterised by an example from information sources for LCA [19, 22], where only gas outputs during composting process are consulted. As an output, significant amount of CO_2 was measured, which is considered to be a greenhouse gas. Quite logical conclusion, that composting contributes to global warming, is in this place plain wrong, because previously mentioned idea does not take in account whole life cycle of the material, which is being processed in composting facility. In this case, significant material flow of CO_2 that is directly or implicitly absorbed from the atmosphere is ignored.

Involving these regularities via modelling means is quite difficult; models of CMP type are not suitable, because they are unable to sufficiently represent circulation of some components during these processes. Modelling means, that are not capable of involving dynamics of these processes, like UML, does not offer sufficiently representative results. Petri nets approve to be convenient tool for creating such models.

2 Problem formulation

Fulfilling strategic objectives in the area of BDMW disposal is a considerable problem and that is why this issue was chosen for the analysis of possible solution approaches.
The aim of the paper is evaluation of development of BDMW production in the region, analysis and presentation of one modelling possibility from the perspective of desired product output as well as evaluation of undesired impacts from the perspective of the LCA conception [24, 25].
The EKO KOM a.s. database [7], which describes the amount and structure of

municipal waste of municipalities in the selected region, was used for the solution. Data was processed with respect to the type and size of a settlement
(urban settlement, suburban town, village), and the average weight of bio waste for potential material utilization was estimated.
Utilization for composting or thermal utilization is assumed. The first option has been being used until now, the others only marginally.
The Pardubice region has 511 400 inhabitants, it covers 4 518 km^2, the population density is 113 per km^2. The Pardubice region has 451 municipalities, which were sorted by size and residential pattern. BDMW proportions in municipal waste were estimated from average values. Collection logistics was evaluated and entry data for modelling processed.

There is one composting plant in the region with the capacity of 9 000 t of waste per year where the waste is brought by trucks and other facilities (pellet pressing, bio gas station).
Various scenarios of solution based on the hierarchy of the most suitable methods (from waste handling to prevention strategy) were formulated. Apart from the basic solution strategy, composting in a high-capacity facility, it has been also counted on composting at the waste production premises (within possibilities own composting machines or communal composting). The paper will summarize the result of evaluation of one of these options.

3 Problem solution

As a suitable instrument for the modelling of material flows was chosen Petri nets [23], defined as follow:

A Petri net (PN) is a kind of directed graph.
An ordinary Petri net could be defined for example like 5-tupe N = (P,, T, I, O, M_0):
where:

$P = \{p_1, p_2, ..., p_n\}$is the finite set of places, represented graphically by circles.

$T = \{t_1, t_2, ..., t_n\}$is the finite set of transitions, represented graphically by rectangles.

I: (PXT)→N is a function that defines the weight of directed arcs from places to transitions.

O: (TXP)→N is a function that defines the weight of directed arcs from transitions to places
M_0 is the initial marking.

A marking is an array that assigns to each place a nonnegative integer of tokens. Tokens are graphically represented by black dots. A transition is enabled by the marking M, if $\forall p \in M : M(p) \geq I(p, ti)$. The firing transition generates a new marking *M´*. [23]

The important attributes of Petri nets are their dynamic attributes, detailing behaviour of the simulation. This implements so, that in the net are some places including tokens, which then travel on oriented arcs of the net according justified rules. The initial marking can include more places. The investigated problem is, if will be possible to achieve some marking trough a firing of a defined transition sequence. The defined firing transition sequence is such a sequence $\sigma = t_1 t_2 t_3 ... t_k$, which begins with initial marking m_0 and for which holds:

$$\begin{array}{ll} t_1^- \leq m_0, & m_1 = m_0 + \Delta t_1 \\ t_2^- \leq m_1, & m_2 = m_1 + \Delta t_2 \\ \cdot & \\ \cdot & \\ t_k^- \leq m_{k-1}, & m_k = m_{k-1} + \Delta t_k \end{array} \qquad (1.1)$$

where

$$\Delta t = t^+ - t^- \ a \ t^+ = \begin{Bmatrix} W(t,p) \ if \ \ p \in t\bullet \\ 0 \quad else \end{Bmatrix}, \quad (1.2)$$

$$t^- = \begin{Bmatrix} W(p,t) \ if \ \ p \in \bullet t \\ 0 \quad else \end{Bmatrix} \quad (1.3)$$

are the functions definable for each transition t in given Petri net. This functions could be represented like vectors $t^+, t^- a \, \Delta t$.

Definition:

The marking m_k of Petri net PN is attainable then exist a sequence of transition firing beginning with initial marking m_0, for which holds: $m_k = m_0 + \sum_{s=1}^{k} \Delta t_s$. The initial marking m_0 is regarded as attainable as well. The set of all attainable markings is specified like $R_{PN}(m_0)$ and holds $m_0 \in R_{PN}(m_0)$ [6, 10, 16].

The other important attributes of Petri nets are restriction, livens and conservatism

In case of modeling final sources or resources of the system, it is important to follow so-called limitation, or more precisely k-limitation of Petri net. If location p is k-limited for k∈N, it is called limited. If each location of Petri net N is limited, then N is called limited Petri net.

Definition

Petri net N defined by (P. T, F, W, K, M_0). Place p ∈P is called limited, if applies

$$\exists k \in N : \forall M \in [M0\rangle : M(p) \le k \quad (1.4)$$

Special case of Petri net limitation is so-called safe Petri net, for which applies:

$$\forall M \in [M0\rangle : M(p) \le 1 \quad (1.5)$$

So in any stage of Petri net, number of marks can not go over 1 in any place. That type of Petri net is called C/E Petri net. [6]

Decision about limitation or non-limitation of respective Petri net can be carried out by correspondent tree of reachable markings. If some of peaks contains mark ω, then the net is not limited. In the other case it is easy to elicit k value for k-limited net or decide whether the net is safe.

3.1 Petri net liveness

Liveness is one of the most important characteristics of Petri nets. This problem is also related to possible occurrence of deadlock, which can be defined as condition, when all processes waits for stimulation, whereas they themselves are sources of stimulation.

Definition

Let N be Petri net with set of transitions T and initial marking M_0.
1) Transition t ∈T is live on stage 0, if it is not executable for any mark from $|Mo\rangle$.
2) Transition t ∈T is live on stage 1, if exists such M∈ $|M0\rangle$, that transition t is M-executable.
3) Transition t ∈T is live on stage 2, if for each n ∈N exists calculating sequence of Petri net *N*, where transition t occurs at least n-times.
4) Transition t ∈T is live on stage 3, if exists calculating sequence of Petri net *N*, where transition t occurs infinite-times.
5) Transition t ∈T is live on stage 4, if for each M∈ $|M0\rangle$ exists such mark M´, that M´∈ $|M0\rangle$ and t is M´-executable.
Petri net is called live on stage h, where h ∈ {0, 1, 2, 3, 4}, if each transition t ∈T is live on stage h.

3.2 Illiberality of Petri nets

Illiberality of Petri net means than marks in the net during simulation are neither generated nor destroyed, so their number stays invariable. There are two possibilities – it can be either strict illiberality or illiberality with regard to weight vector.

Definition

Consider Petri net N = (P. T, F, W, K, M_0).

Strict illiberal Petri net must fulfill the

following condition:

$$\forall M \in [M0 \rangle : \sum_{p \in P} M(p) = \sum_{p \in P} Mo(p) \quad (1.6)$$

Strict illiberality is a very strong characteristics. That is why it is mentioned with regard to weight vector, thus net is illeberate in regard of set weights of individual locations in the net. [6]

Definition

If Petri net is defined as in first case and vector $\underline{v}$: P → N, for illiberal with regard to weight vector $\underline{v}$ > 0 ($\forall p \in P : v(p)$ >0) then applies:

$$\forall M \in [Mo \rangle : \sum_{p \in P} v(p).M(p) = \sum_{p \in P} v(p).Mo(p)$$

(1.7) [6]

That results from the fact, that the programme is based on high-level Petri nets, considers usage of coloured Petri nets, works with constant, but user defined edges set usually within parameters of particular transitions either by user or from module library, allows even construction of hierarchic nets and of all combinations mentioned. The environment is oriented on support of evidence and optimalization of material and energy flows related to environmental accounting [18], [19], [20], [21], which gave rise to need of significant modifications of the very conception of simulated nets function. Since the environment presumes executing calculations during fixed (for example accounting) interval, usage of live Petri nets is not considered, while, by the definition, Petri net is considered live, if all its transitions are on live level 4. [6, 10]. Usually we use procedure, when user sets in advance number of marks, that passes through some edge during fixed time interval and simulation then calculates requisite number of input marks and also layout and types of marks in all places after finishing transitions during fixed time interval. Another usage is not considered and therefore live Petri net can not be constructed.

Models in Umberto programme still shows some other anomalies in both graphical expression and overall conception of net functionality. Besides the fact, that it is impossible to model live

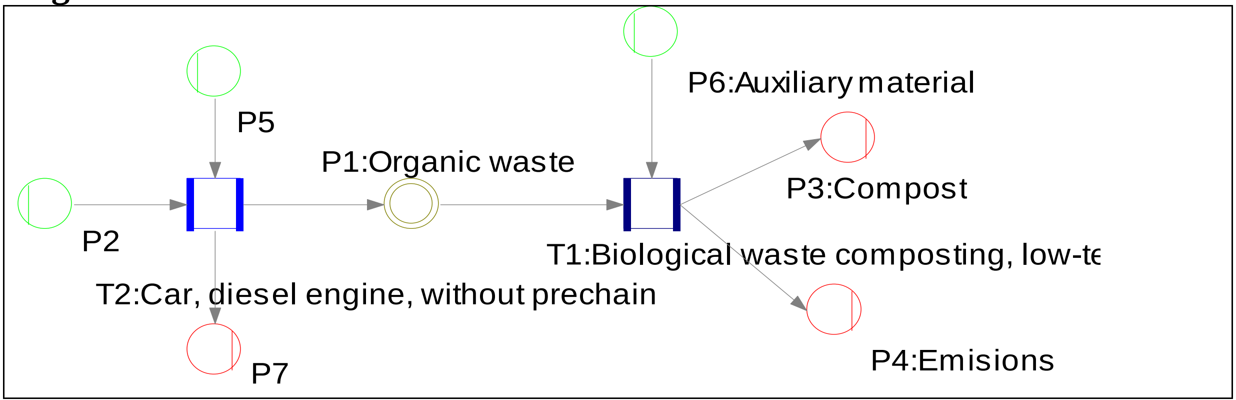
Petri net, programme also permits even negative values notation, model analysis form viewpoint of characteristics as illiberality, limitation and other has no meaning.

The firing transitions can represent the material flows. The processed material flow model using Petri nets is described in Fig. 1.

A model based on Petri nets implemented in the Umberto environment was carried out for modelling of material flow and quantification of negative impacts caused by handling BDMW. So conceived a model enabled us to calculate solution options in terms of the LCA approach. Sorted and pre-processed data was submitted for calculation with the help of the Umberto software [26], which apart from flow variables modelling allows modelling and monitoring of e.g. material and power flow in a region,

financial flow or information flow etc.
A Petri net elaborated by Umberto software have some specificity. This net is not live, but a high level, coloured. By a not-live Petri net it isn't necessary to analyse the characteristics, like conservatism, determinism etc. A situation with combined solution of composting at the source and transport to a composting plant within reasonable transport range was chosen for presentation.

Fig. 1 Model of material flow



In this case it was necessary to define inputs, places of transformation, material outputs; the starting situation in a simplified way is shown in a model in Fig. 1.

Figure 1 shows a model including both material transport for composting and the composting process itself. Place P2 shows the entry of organic material to composting, place P5 the entry of fuel for the transporting process and place P7 emissions produced by material transport for composting. Transition T2 presents the material transport process to the composting plant. Place P1 represents material brought to the composting plant where P6 shows auxiliary substances necessary for composting, place P3 produced compost and place P4 emissions created at composting. With respect to the character of used Petri net in the environment of the Umberto program, this net was not analyzed from the perspective of properties as the particular environment already determines these properties and these are identical for all created models.
With entered parameters of transport to the facility the most important non-desired outputs in material balance were calculated and described in Tab. 2.

Tab. 2 The calculated material outputs

Material	Output (kg)
AOX	0,06
BOD	123,64
COD	639,63
NMVOC (hydrocarbons)	0,17
NMVOC from diesel emission	68,49
NMVOC, unspec.	128,86
NOx	2373,02
PAH not B(a)P, unspec.	2,35
PCB	2,97
PCB	2,94
TOC)	10596,08
VOC, unspec.	213,77
amonia	26256,04
ammonium	91,07

Material	Output (kg)
ashes and slags	175,25
benzene	4,80
carbohydrates, unspec.	10,67
carbon dioxide, fossil	238080,11
carbon dioxide, renewable	1936360,55
carbon monooxide	865,40
carbon, organic	286,88
compost	3 790 550
dinitrogen monooxide	717,69
flue gas	3,74
gypsum (flue gas clean)	111,51
hydrogen chloride	4,80
hydrogen sulfide	4,64
landfil gas, difuse	42145,15 m3
landfil volume	451,23 m3
methane	77,27
methane, renewable	37749,70
methylene oxide	18,74
nitrate	41,84
nitrogen	450,42
nitrogen compounds as N	35,06
particles	194,61

Tab. 2 show a model output calculated for the maximal capacity of the composting plant which is 9000 t of material per year. It is clear what amount of substances will be created by processing 9000 t of material. 3 790 550 kg of compost and mentioned amount of other substances was created.

4 Conclusion

The use of Petri nets with the quoted software enables very fast variant calculations and the possibility to monitor whole variety of impacts according to the LCA concept. The domain of biodegradable-waste decreasing in municipal waste is a matter of integrated strategy of prevention, separation and collection as well as of the end technology for processing.

The effort to quantify the impacts on the environment is very important as it is revealed that recycling at any price is not always the optimal solution. Problems of LCA concept was also identified in the area of system boundaries.

Processes based on LCA allow the decision -making sphere on regional level to decide the alternative with respect not only to economic result bur also to other significant context which might not be evident in short run.

The particular problem has, of course, also economic (financial flows are favourable to model similarly like material flows) and social bearability dimensions which must be resolved concurrently.

This work was supported by the scientific research project of GACR 402/06/0084 Modelling and Optimalization of Decisions Processes in the Municipal and Regional Administration and scientific research project of Ministry of Environment, Czech Republic under Grant No SP/4i2/60/07 Indicators for valuation and modelling of interactions among environment, economics and social relations.

References:

[1] Act No. 185/2001 Coll., on waste http://www.env.cz/ris/vis-legcz-en.nsf/0/3AF3925653DDDC52C125735C0043814E/$file/20010185Sb_kv.pdf [cit. 2008-07-15].

[2] Act No. 477/2001 Coll.., on packaging http://www.env.cz/ris/vis-legcz-en.nsf/0/37A3BDF546537587C125735C0043813F/$file/Z%C3%A1kon_o_obalech_4772001angl.pdf [cit. 2008-07-15].

[3] Act No. 76/2002 Coll.., on integrated pollution prevention and control http://www.env.cz/ris/vis-legcz-en.nsf/0/1B1407ADB185A15DC125735C00438147/$file/20020076Sb.pdf [cit. 2008-07-15].

[4] Dumitrascu D.D., Pascu R. V., Dumitrascu C. L.: *Justifying Data about the Need and Feasibility of Waste Management Projects in Romania.* WSEAS TRANSACTIONS on ENVIRONMENT and DEVELOPMENT Issue 11, Volume 2, November 2006 pp.1411-1416 ISSN 1790-5079

[5] Changes proposal of the Act no.185/2001 Coll. [cit. 2008-07-25] http://www.env.cz/__C1256D3D006B1934.nsf/$pid/MZPKPFOH6B4L in czech

[6] Češka, M. *Petri nets, Introduction Theory and Instruments for Application of Petri Nets*. Brno: Akademické nakladatelství Cerm, 1994. 94s. ISBN 80-85867-35-4. in czech

[7] EKO KOM a.s. database, unpublished material, 2008

[8] Generation, Recovery and Disposal of Waste in the CR in 2006 [cit. 2008 -08-25] http://www.czso.cz/eng/edicniplan.nsf/aktual/ep-2

[9]http://ceho.vuv.cz/CeHO/CeHO/Bioodpad/BRO_Prehled_zarizeni/Bro_CR.htm [cit. 2008-07-15].

[10] Janoušek, V. *Objects Modelling by Petri Nets*. Brno: Vysoké učení technické. Fakulta elektrotechniky a informatiky. Ústav informatiky a výpočetní techniky, 1998. 121 s. in czech

[11] Kikuchi R., Sato H., Yamamoto T.& R. Gerardo: *Economic comparison of competitive waste treatments: case studies of municipal waste, sewage sludge and automobile shredder residue* 4th IASME/WSEAS International Conference on ENERGY, ENVIRONMENT, ECOSYSTEMS and SUSTAINABLE DEVELOPMENT (EEESD'08) Algarve, Portugal, June 11-13, 2008 pp. 285-290 ISSN: 1790-5095

[12] Kotoulová Z.,Váňa J.: Handbook of municipal waste disposal. MŽP, ČEÚ Praha 2001, ISBN80-7212-20 in czech

[13] Krajský úřad Pardubického kraje: Conception of waste management in Pardubice Region. Pardubice 2002. in czech

[14] Kralj D., Markič M.: Processes Innovation and Sustainable Development. *WSEAS TRANSACTIONS on ENVIRONMENT and DEVELOPMENT* Issue 2, Volume 4, February 2008 pp.99-108, ISSN: 1790-5079

[15] Kralj D., Markič M.: Sustainable Development Strategy and Product *Responsibility.WSEAS TRANSACTIONS on ENVIRONMENT and DEVELOPMENT*. 12 Issue 1, Volume 4, January 2008. pp. 12-23, ISSN: 1790-5079

[16] Marsan, M. A. et. al. *Modelling with Generalised Stochastic Petri Nets.* 1. vyd. John Wiley and Sons, 1994. ISBN: 0-471-93059-8.

[17] *Municipal waste generated in selected countries.* http://www.czso.cz/csu/2008edicniplan.nsf/engt/D4003CDB26/$File/20010819.pdf [cit. 2008 – 09 -20]

[18] Obršálová, I., Baťa, R. Environmental Accounting at the Corporate-Level. In *Environmental management accounting and cleaner production. Environmental Management Accounting Network, 9th Annual Conference.* Graz: Graz university of Technology, 2006. Poster Session. p. 66. ISBN 3-902465-36-0.

[19] Obršálová, I., Kožená, M., Baťa, R. *Research Report II - Environmental accounting on the micro-level.* Pardubice:

Univerzita Pardubice, 2006. 39 s. ISBN 80-7194850-0.

[20] Obršálová, I., Munzarová, S., Kožená, M., Baťa, R., Převrátil, B. Contribution to the Topic of Environmental Accounting in Czech Companies. In *Proceedings of Environmental Accounting Sustainable Development Indicators*. Ústí nal Labem: Universita Jana Evangelisty Purkyně, 2005. Str. 331. ISBN 80-7044-676-5.

[21] Obršálová I.,Kožená M.,Baťa R., Jordao Costa T.:*Environmental Management Accounting for Municipal Waste Reduction with Utilization of Clean Production(Consumption) Principles* SDI-EA Praha, 2007. ISSN pp.258-264 ISSN 978-80-87076-03-3

[22] Petre E., Bobasu E.:*A new adaptive control strategy for a class of anaerobic wastewater treatment bioprocesses.* 4th IASME/WSEAS International Conference on ENERGY, ENVIRONMENT, ECOSYSTEMS and SUSTAINABLE DEVELOPMENT (EEESD'08) Algarve, Portugal, June 11-13, 2008, pp. 303-309 ISSN: 1790-5095

[23] Riera, D., Narciso, M., Benqlilou, CH.: A Petri Nets-Based Scheduling Methodology for Multipurpose Batch Plants. *SIMULATION*, 2005, Vol. 81, No. 9, pp. 614 -623.

[24] Rimaityté I., Denafas G., Račys V.: Implementation of Life Cycle Assessment Tools for Evaluation of Municipal Waste Management Scenarios. *Environmental research, engineering and management*, 2006.No. 2 (36), pp.68-76

[25] Tichá M., Černík B.: LCA of mixed municipal waste landfill and incineration. *Environmentální aspekty podnikání*. CEMC Praha, 2003 (5), no.1, p.2 in czech

[26] UMBERTO ifu Institut für Umweltinformatik Hamburg GmbH, Hamburg Germany http://www.umberto.de/en/ [cit. 2008 - 07-20

[27] Waste management plan - Czech Rep. [cit. 2008 - 07-20] http://www.env.cz/AIS/web-pub.nsf/$pid/MZPJZFGV0QT2/$FILE/POH%20CR_kompletni%20dokument.pdf in czech

[28] Waste management plan - Pardubice region. [cit. 2008 -07-20], http://www.pardubickykraj.cz/article.asp?thema=3036 in czech