Conference and Seminar:
Medan, Indonesia,
April 2019

A Novel Mathematical Model for Robust Green Urban Waste Collection

Gerhard-Wilhelm Weber

Faculty of Engineering Management, Chair of Marketing and Economic Engineering, Poznan University of Technology, Poland;
Institute of Applied Mathematics, METU, Ankara, Turkey

Erfan Babaee Tirkolaee

Department of Industrial Engineering, Mazandaran University of Science and Technology, Babol, Iran

EURO THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

POLITECHNIKA POZNAŃSKA

Pacific Optimization Research Activity Group

EURO

IFORS International Federation of Operational Research Societies

Outline

- Introduction
- Literature review
- Problem description/Mathematical model
- Robust optimization approach
- Augmented ε-constraint method
- Illustrative example
- Model validation
- Sensitivity analysis
- References

Introduction

- ***Uncontrolled urban expansion*** and ***the massive increase in urban populations*** have led to a vast amount of consumption and different types of waste generation over the past years.

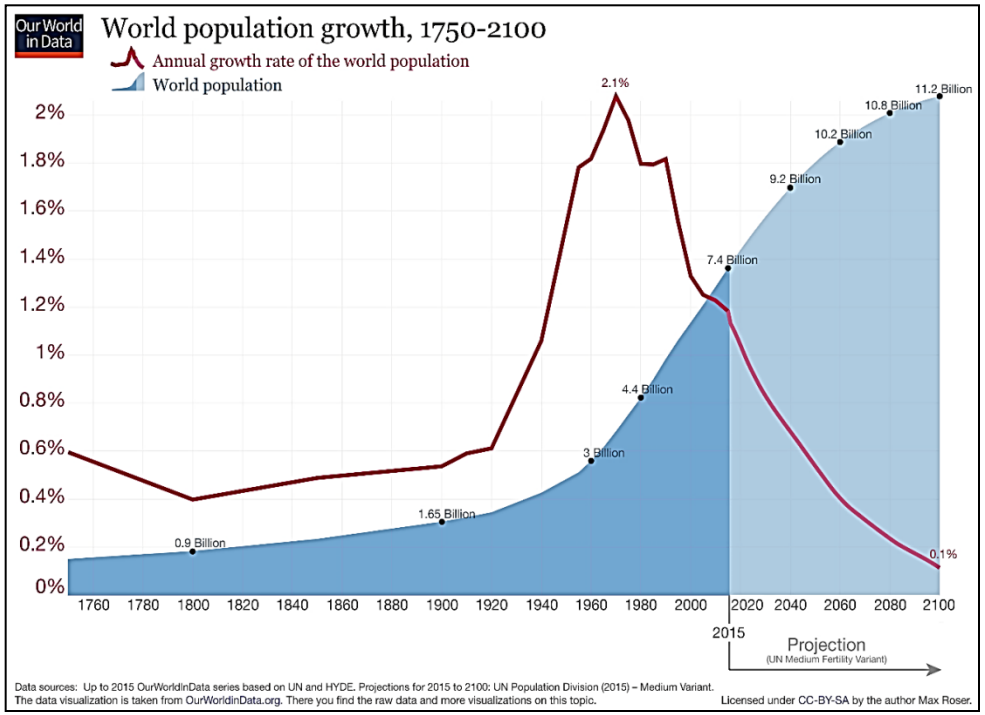
Introduction

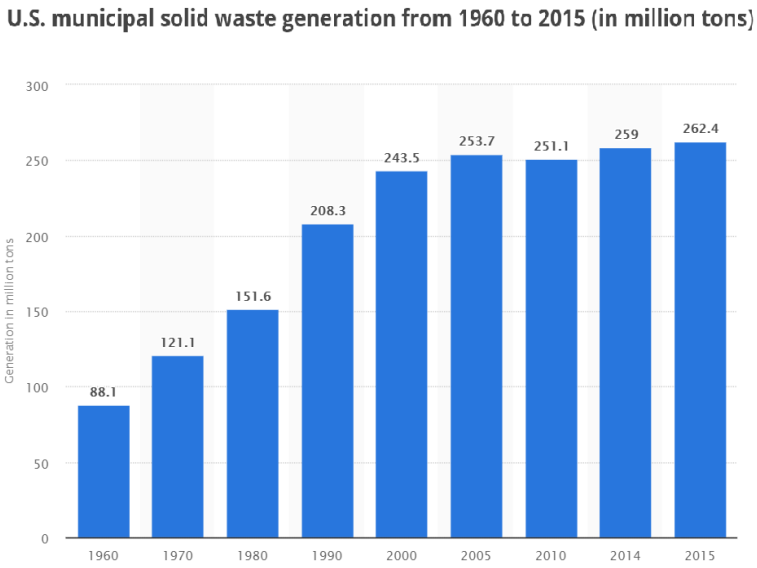
- In 2012, various cities in the world generated **1.3 billion** tons of solid waste, equivalent to **1.2 kg per person per day**.

https://www.statista.com

Introduction

- It is expected that annual waste generation rate will reach **2.2 billion tons** by **2025**, accordingly.





https://www.statista.com

Introduction

❖ Economical aspect:

- This amount of waste generation definitely leads to an increase in the necessary funds for *collection*, *transportation* and *disposal* operations, which contains **75%-80%** of **Urban Solid Waste Management** (**USWM**) costs (Tirkolaee et al., 2018).

Introduction

❖ Environmental and health aspect:

- These operational processes must be done within the ***shortest possible time*** to prevent the spread of potential contamination and infections.
- On the other hand, there is now a global force on **GHG reduction**, which should be considered in USWM too.

Introduction

❖ Uncertainty:

- The exact amount of generated waste is always **unknown** in each urban area due to its uncertain nature.
- In fact, each area may have a lower and an upper bound for the amount of waste according to its **minimum** and **maximum** values in a given time period.

Introduction

❖ Questions:

1. How can we investigate the economical and environmental aspects of the problem?

- Identifying the main parameters, variables and assumptions.
- Formulate the problem using OR concepts and techniques.

2. How can we optimize the amount of required budget and the amount of contamination?

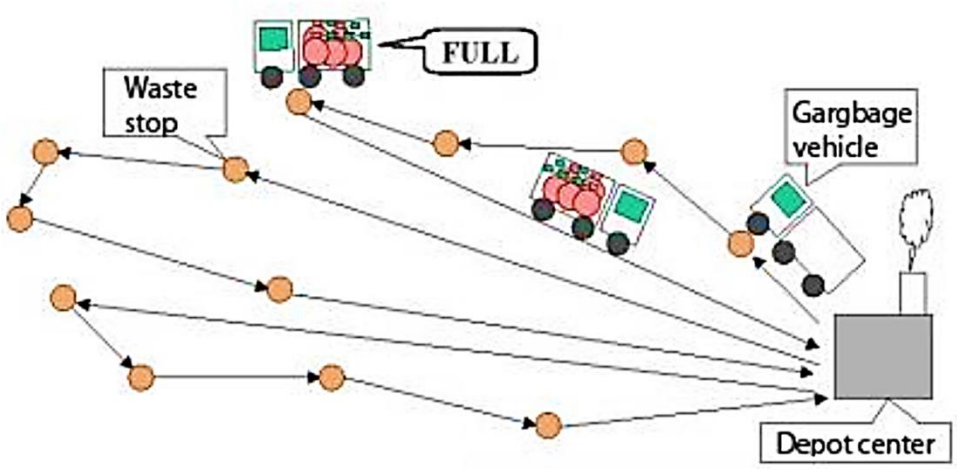
- Developing a bi-objective mathematical model considering all the defined assumptions.
- Implementing an efficient solution technique to deal with the bi-objectiveness of the problem; i.e., Augmented ε-constraint method.

3. How can we evaluate the effects of uncertainty?

- Applying Robust Optimization (RO) approach.
- Performing sensitivity analyses.

Introduction

- A *robust bi-objective model* is proposed for the **Multi-Trip Vehicle Routing Problem with *Time Windows*** (**MTVRPTW**) to concurrently minimize the ***total cost*** *and the* ***total GHG emission***.



Literature Review

References		Main features												Objective functions		Model/Methodology
Authors	Year	Hazardous waste	Electronic waste	Household waste	Proiority of service	Arc routing problem	Vehicle routing problem	Planning period	Disposal sites	Multiple trips	Deterministic approach	Non-deterministic approach	Case study	Total Cost	Greenness	
Tung and Pinnoi	2000			*	*		*				*		*	*		MILP/ Heuristic algorithm
Shih and Chang	2001	*					*	*			*		*	*		MIP/DP method
Angelelli and Speranza	2002			*			*	*	*		*			*		LP/TS algorithm
Poot et al.	2002			*			*				*			*		LP/ Heuristic algorithm
Aringhieri et al.	2004			*			*				*			*		MILP/ Heuristic algorithm
Kim et al.	2006			*	*		*			*	*		*	*		MILP/ Heuristic algorithm
Nuortio et al.	2006			*				*			*		*	*		Conceptual model/ GVNT metaheuristic
Karadimas et al.	2007			*			*				*		*	*		GIS/ACS algorithm
Alumur and Kara	2007	*					*				*		*	*	*	MILP/CPLEX
Kytöjoki et al.	2007			*			*				*		*	*		LP/VNS algorithm
Li et al.	2008			*			*	*	*	*	*		*	*		LP/ Heuristic algorithm
Bautista et al.	2008			*		*	*				*		*	*		LP/ ACS algorithm
Arribas et al.	2010			*			*	*			*		*	*		ILP+GIS/ LS algorithm
Buhrkal et al.	2012			*	*		*				*		*	*		MILP/ALNS algorithm
Kuo et al.	2012			*			*					*		*		LP/ HPSOGA algorithm

Literature Review

References		Main features												Objective functions		Model/Methodology
Authors	Year	Hazardous waste	Electronic waste	Household waste	Proiority of service	Arc routing problem	Vehicle routing problem	Planning period	Disposal sites	Multiple trips	Deterministic approach	Non-deterministic approach	Case study	Total Cost	Greenness	
Wy et al.	2013			*	*		*				*			*		LNS algorithm+ Heuristics
Huang and Lin	2015			*			*	*		*	*			*		MILP/ACO algorithm
Henke et al.	2015			*			*				*			*		MILP/VNS algorithm
Kinobe et al.	2015			*							*		*	*	*	GIS+ArcGIS
Inghels et al.	2016			*	*		*	*			*		*	*	*	LP/Simulation
Akhtar et al.	2017			*			*				*			*	*	LP/BSA
Erfani et al.	2017			*			*				*		*	*		LP+GIS/ESRI ArcGIS
Dotoli and Epicoco	2017	*		*	*		*				*			*		LP/ GLPK optimizer
López-Sánchez et al.	2018			*			*	*					*	*	*	GRASP_VND algorithm
Hannan et al.	2018			*			*	*			*			*		LP/PSO
Armington and Chen	2018			*			*				*			*		LP/ IBM CPLEX algorithm
Tirkolaee et al.	2018c			*		*		*		*		*		*		Robust LP/ GAMS+ SA algorithm
Nowakowski et al.	2018		*		*		*				*		*	*		LP/ SA, TS, Greedy, and BCO algorithms
Ramos et al.	2018			*			*				*		*	*		MILP/ GAMS
Rabbani et al.	2018	*					*				*			*	*	MILP/NSGA-II and MOPSO
Current study	2019	*		*	*		*		*	*		*		*	*	MILP/ Augmented ε-constraint

POLITECHNIKA POZNAŃSKA

Pacific Optimization Research Activity Group

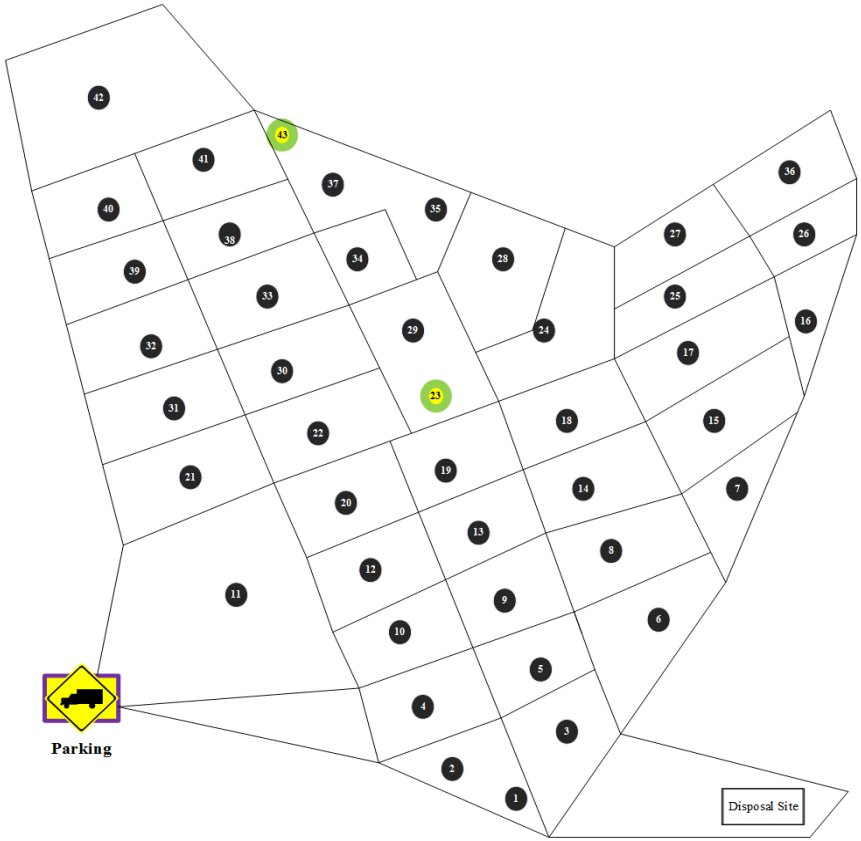
EURO

IFORS International Federation of Operational Research Societies

Problem Description

- Consider an urban graph network which represents the demand nodes, parking and disposal sites:

Black circles: Household waste,
Green circles: Hazardous Waste like hospital waste.



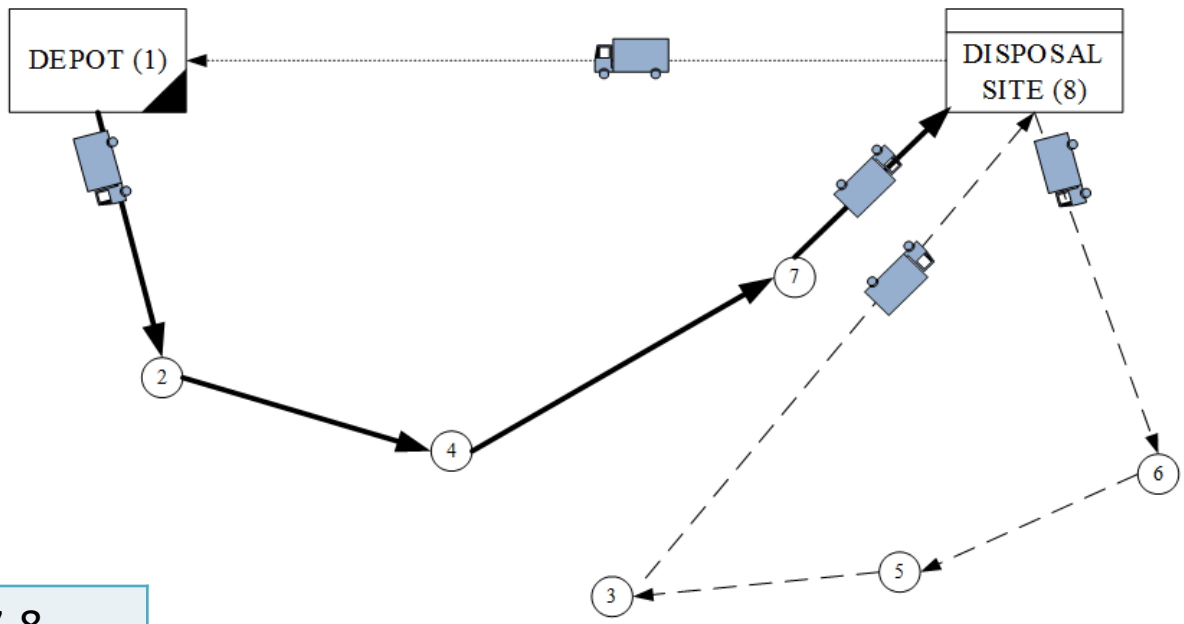
Assumptions

❖ The main assumptions of the problem are as follows:

- Each demand node is **only** serviced by one vehicle.
- There is **one** depot and **one** disposal site.
- Vehicles are **heterogeneous** and have a **maximum allowable time of service**.
- Vehicles may have **multiple trips**.
- **Traversing cost of a route** is the same for all vehicles.
- Each demand node has a **hard** and **soft time window of service**, which means that violating a *soft time window* will have a penalty, and violating a *hard time window* is not possible.

Multiple trips in USWM

- Consider **8 nodes** including *1 depot*, *1 disposal site* and **6 demand nodes**:



First trip	1-2-4-7-8
Second trip	8-6-5-3-8

Objectives

❖ The main objectives of the problem are represented as follows:

Minimizing total traversing cost,
total usage cost of vehicles and
total penalty cost of time windows violation

+

Minimizing total GHG emissions of vehicles

→

Economically and Environmentally Sustainable Waste Collection System

Mathematical Model

$$\text{minimize } Z = \theta\left(\sum_{i\in NT}\sum_{j\in NT}\sum_{k\in K}\sum_{r\in R} c_{ij}\, x_{ijk}^{r}\right) + \sum_{k\in K}\sum_{i\in NC}(Pe\, Ye_{ki} + Pl\, Yl_{ki}) + \sum_{k\in K} cv_k\, u_k$$

- 1st objective function is to minimize the total cost including *traversing costs*, *the penalty costs for violating permissible time windows* and *the usage costs of vehicles*.

$$\text{minimize } G = \sum_{i\in NT}\sum_{j\in NT}\sum_{k\in K}\sum_{r\in R} ghg_{ijk}\, x_{ijk}^{r}$$

- 2nd objective function indicating the total amount of emissions.

subject to

$$\sum_{j\in NT} x_{ijk}^{r} = \sum_{j\in NT} x_{jik}^{r} \qquad \forall i \in NT, \forall k \in K, \forall r \in R,$$

- The flow balance of each vehicle.

Mathematical Model

$$\sum_{k \in K} \sum_{r \in R} y_{jk}^{r} = 1 \qquad \forall j \in NC,$$

- Each demand node is only serviced by one vehicle:

$$\sum_{j \in NC} d_j \, y_{jk}^{r} \leq W_k \qquad \forall k \in K, \forall r \in R,$$

- Each vehicle has a capacity constraint.

$$y_{jk}^{r} \leq x_{ijk}^{r} \qquad \forall i, j \in NT, \forall k \in K, \forall r \in R,$$

- The demand node is served by the vehicle which has already been arrived at there.

$$\sum_{(i,j) \in NE} \sum_{r \in R} x_{ijk}^{r} \leq M \, u_k \qquad \forall k \in K,$$

- Vehicles can be used when their costs are paid.

Mathematical Model

$$LT_k^r = ul \sum_{j \in NC} d_j \, y_{jk}^r \qquad \forall k \in K, \forall r \in R,$$

$$UT_k^r = uu \sum_{j \in NC} d_j \, y_{jk}^r \qquad \forall k \in K, \forall r \in R,$$

- The total loading and unloading time for each vehicle per trip.

$$\sum_{r \in R} LT_k^r + \sum_{r \in R} UT_k^r + \sum_{(i,j) \in NE} \sum_{r \in R} t_{ij} \, x_{ijk}^r \leq T_{max} \qquad \forall k \in K,$$

- The usage time limitation of each vehicle.

$$\sum_{i \in S} \sum_{\substack{j \in S \\ i \neq j}} \sum_{k \in K} x_{ijk}^r \leq |S| - 1 \qquad \forall S \subseteq NC; |S| \geq 2, \forall r \in R,$$

- Sub-tour elimination constraint of each vehicle.

Mathematical Model

$$\sum_{j \in NC} x_{1jk}^{1} \geq \sum_{j \in NC} x_{njk}^{2} \qquad \forall k \in K,$$

$$\sum_{j \in NC} x_{njk}^{r} \geq \sum_{j \in NC} x_{njk}^{r+1} \qquad \forall r \in \{2,3,\dots,|R|-1\}, \forall k \in K,$$

- The order number of vehicle trips is from *r* to *r*+1 in succession.

$$tt_j = \sum_{i \in NT} \sum_{k \in K} \sum_{r \in R} (tt_i + t_{ij})\, x_{ijk}^{r} \qquad \forall j \in NC,$$

$$tt_i = 0 \qquad \forall i = 1,$$

$$e_i \leq tt_i \leq l_i \qquad \forall i \in NC,$$

- The arrival time of vehicles at each demand node and the **hard time window** is defined for each demand node.

Mathematical Model

$$Ye_{ki} \geq ee_i - tt_i \qquad \forall k \in K, \forall i \in NC,$$

$$Yl_{ki} \geq tt_i - ll_i \qquad \forall k \in K, \forall i \in NC,$$

- ***Soft time window:*** Calculation of earliness and lateness in serving each demand node.

$$\sum_{j \in NC} x^1{}_{1jk} = u_k \qquad \forall k \in K,$$

$$\sum_{i \in NC} x^1{}_{i\,n\,k} = u_k \qquad \forall k \in K,$$

- Vehicles' first trip starts from the depot and ends at the disposal site.

Mathematical Model

$$\sum_{i \in NC} x^{r}{}_{ink} \leq M(1-u_k)+1 \qquad \forall r \geq 2, \forall k \in K,$$

$$\sum_{j \in NC} x^{r}{}_{njk} \leq M(1-u_k)+1 \qquad \forall r \geq 2, \forall k \in K,$$

- Other trips of vehicles (except for first trip) will begin from the disposal site and end at the disposal site.

$$x^{r}{}_{n\,1\,k} \geq x^{r-1}{}_{n\,1\,k} \qquad \forall r \geq 2, \forall k \in K,$$

$$\sum_{r \in R} x^{r}{}_{n\,1\,k} = u_k \qquad \forall k \in K,$$

- Vehicles' last trip end at the depot again to complete their tours:

$$x^{r}_{ijk}, y^{r}_{jk}, u_k \in \{0,1\},\ Ye_{ki}, Yl_{ki}, tt_i, LT^{r}_{k}, UT^{r}_{k} \geq 0 \qquad \forall (i,j) \in NE, \forall k \in K, \forall r \in R.$$

- Types of variables.

Robust Optimization

- **Bertsimas and Sim (2003, 2004) suggested an optimization approach based on multi-dimensional uncertain sets.**
- **They claimed that it is very rare that at all the uncertain parameters of a constraint take different values far from their nominal and at their limit values simultaneously:**

  - ✓ For a parameter of $z_{ij} = \dfrac{a_{ij} - \bar{a}_{ij}}{\hat{a}_{ij}} \in [-1,+1]; \sum_j |z_{ij}| \le \Gamma_i \quad \forall i, \Gamma_i \in [0, |J_i|].$
  - ✓ J_i is the set of uncertain parameters in the *i*-th row of the coefficient matrix of constraints.
  - ✓ The constraints' coefficients are uncertain, taking values in an interval with the center of $\bar{a}_{ij}$ and the radius of $\hat{a}_{ij}$; i.e., $a_{ij} \in [\bar{a}_{ij} - \hat{a}_{ij}, \bar{a}_{ij} + \hat{a}_{ij}]$.

Robust Optimization

- Γ_i represents the conservatism level and is known as the **budget on uncertainty**.

- Γ_i is determined by a decision-maker and its value is dependent on the risk-aversion and the importance of the constraint for the decision-maker:

$\Gamma_i = 0,$ → The robust model turns into a deterministic model

$\Gamma_i = |J_i|$ → The robust model will be equal to the model proposed by Soyster (1973); uncertain coefficients take their worst possible values

Robust Optimization

Bertsimas and Sim approach

- The proposed optimization model by Bertsimas and Sim (2004):

$$\begin{aligned}
&\text{minimize } Z = \sum_j c_j x_j \\
&\text{subject to} \\
&\sum_j a_{ij} x_j \le b_i \qquad \forall i, \\
&l_j \le x_j \le u_j \qquad \forall j.
\end{aligned}
\quad \longrightarrow \quad
\begin{aligned}
&\text{minimize } Z = \sum_j c_j x_j \\
&\text{subject to} \\
&\sum_j \tilde{a}_{ij} x_j + z_i \Gamma_i + \sum_{j \in J_i} r_{ij} \le b_i \qquad \forall i, \\
&z_i + p_{ij} \ge \hat{a}_{ij} E_j \qquad \forall i, j, \\
&-E_j \le x_j \le E_j \qquad \forall j, \\
&l_j \le x_j \le u_j \qquad \forall j, \\
&p_{ij}, z_i, E_j \ge 0 \qquad \forall i, j.
\end{aligned}$$

- Here, r_{ij}, z_i and E_j are the ***auxiliary dual variables*** that are used to prevent from <u>non-linearization</u> of the problem.

Robust Optimization Model

- Since the amount of waste; i.e., demand parameter (d_j) leads to the uncertainty, the capacity constraint should be developed based on Bertsimas' and Sim's formulation:

$$\sum_{j \in NC} d_j \, y_{jk}^r \leq W_k \qquad \forall k \in K, \forall r \in R, \quad \longrightarrow$$

$$\sum_{j \in NC} \bar{d}_j \, y_{jk}^r + z_{kr}\Gamma_{kr} + \sum_{(i,j) \in J_{kr}} rr_{jk}^r \leq W_k \qquad \forall k \in K, \forall r \in R,$$

$$z_{kr} + rr_{jk}^r \geq \hat{d}_j \, E_{jk}^r \qquad \forall k \in K, \forall r \in R, \forall j \in NC,$$

$$E_{jk}^r \leq y_{jk}^r \leq E_{jk}^r \qquad \forall k \in K, \forall r \in R, \forall j \in NC,$$

$$E_{jk}^r, E_{jk}^r, z_{kr} \geq 0 \qquad \forall k \in K, \forall r \in R, \forall j \in NC.$$

$d_j \in [\bar{d}_j - \hat{d}_j, \bar{d}_j + \hat{d}_j], \hat{d}_j = \rho . \bar{d}_j \qquad \forall j \in NC$; ρ is uncertainty level.

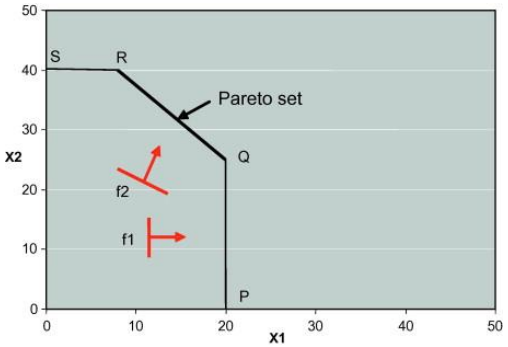
- Note that the other parts of the proposed model will remain unchanged.

Augmented ε-constraint method

- *Augmented ε-constraint technique* was proposed by **Mavrotas (2009)** to generate efficient Pareto solutions in multi-objective mathematical programming:

- Lexicographic approach is used to determine the range of objective functions' values (as its benefit compared to the traditional ε-constraint technique).

- Then, the augmented ε-constraint only generates **efficient** Pareto fronts and prevents from inefficient ones.



Augmented ε-constraint Method

❖ Formulation of the augmented ε-constraint:

$$\text{maximize/ minimize}\left(f_1(\bar{x}) + \varepsilon . di_1 \sum_{i=2}^{p} (s_{ik} / ra_i)\right)$$

subject to

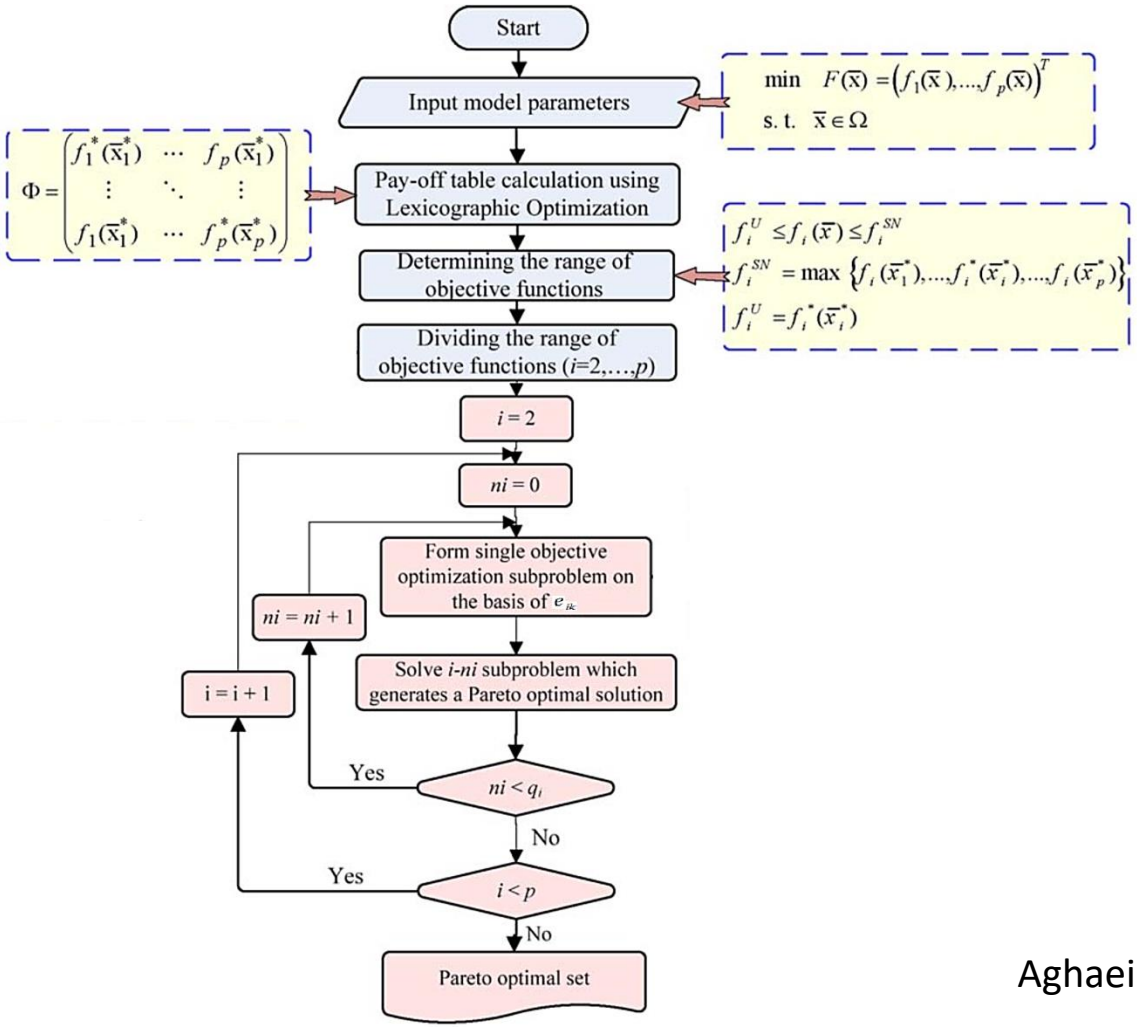
$$f_i(\bar{x}) - di_i s_{ik} = e_{ik} \qquad s_{ik} \in R^+, i = 2,3,\ldots,p, k = 0,1,\ldots,q_i,$$

$$e_{ik} = f_i^{\min}(di_2 + 1)/2 - f_i^{\max}(di_2 - 1)/2 + di_i r_i k / q_i \qquad i = 2,3,\ldots,p, k = 0,1,\ldots,q_i.$$

Mavrotas and Florios (2013)

p	The sub-objective function
di_i	Direction of *i*-th objective (i.e., -1 for minimization type and +1 for maximization type)
e_{ik}	Changing parameter to obtain efficient solutions
s_{ik}	Slack variable
ε	Very small value between 0.001 and 0.000001

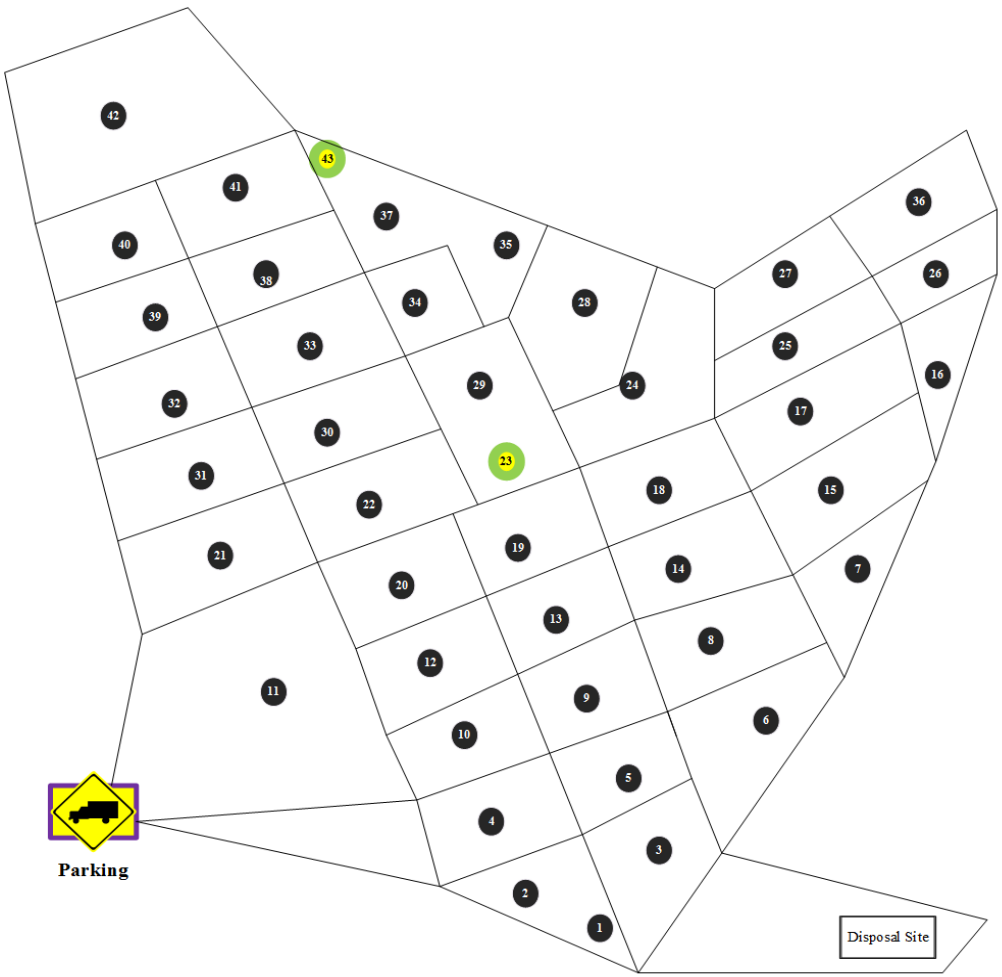
Augmented ε-constraint method



Aghaei et al. (2011)

Illustrative example

- Consider a town with an area of 330 square kilometers including a vehicle parking as the depot, a disposal site and 43 demand nodes,
- The values of the parameters are determined randomly using uniform distribution,
- The uncertainty level (ρ) and conservatism level (Γ_{kr}) are set to be 0.2 and 5, respectively.



Model Validation

- To validate the proposed robust bi-objective MILP model, CPLEX solver of GAMS 24.1 is employed. The execution steps of the augmented ε-constraint method to provide efficient Pareto solutions are as follows:

Lexicographic payoff table

Single-objective minimization	1st objective value	2nd objective value
1st objective	98346.690	117.824
2nd objective	117532.664	79.203

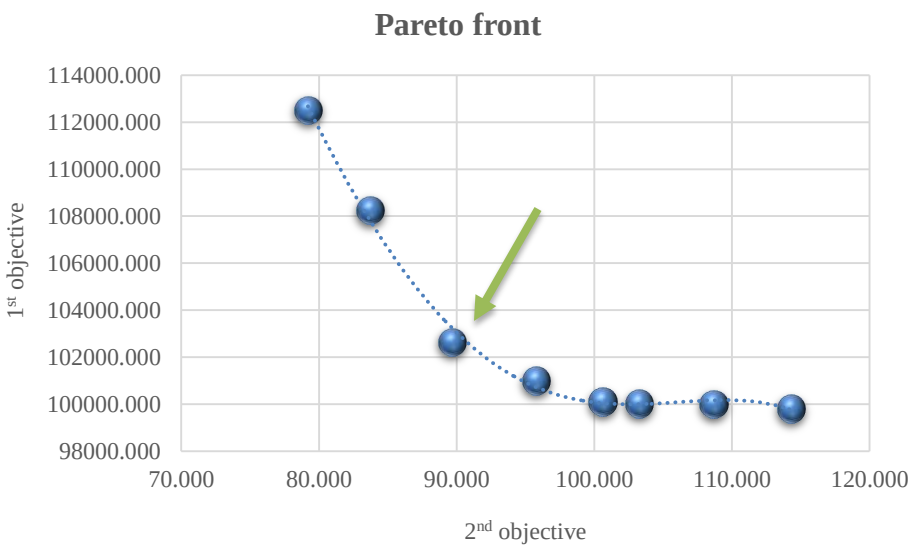
- In the next step, the subsidiary objective function (2nd objective function) is divided into 8 equal intervals (grid points):

Grid points							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
79.203	84.720	90.238	95.755	101.272	106.789	112.307	117.824

Model Validation

- We can generate all the efficient Pareto solutions using different grid points:

Pareto solution	Obj 1	Obj 2
1	112532.664	**79.203**
2	108251.113	**83.720**
3	102659.600	**89.664**
4	101006.099	**95.775**
5	100114.163	**100.584**
6	100030.486	**103.257**
7	100015.359	**108.668**
8	99816.297	**114.260**



- Now, decision-maker can choose his/her most preferred solution among these 8 efficient Pareto solutions. It is represented by a **green** arrow.

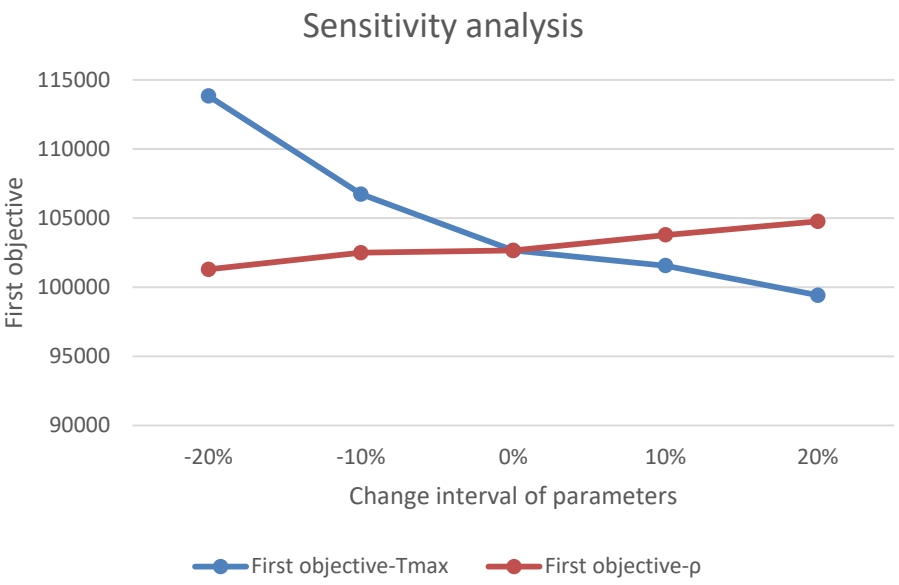
Sensitivity analysis

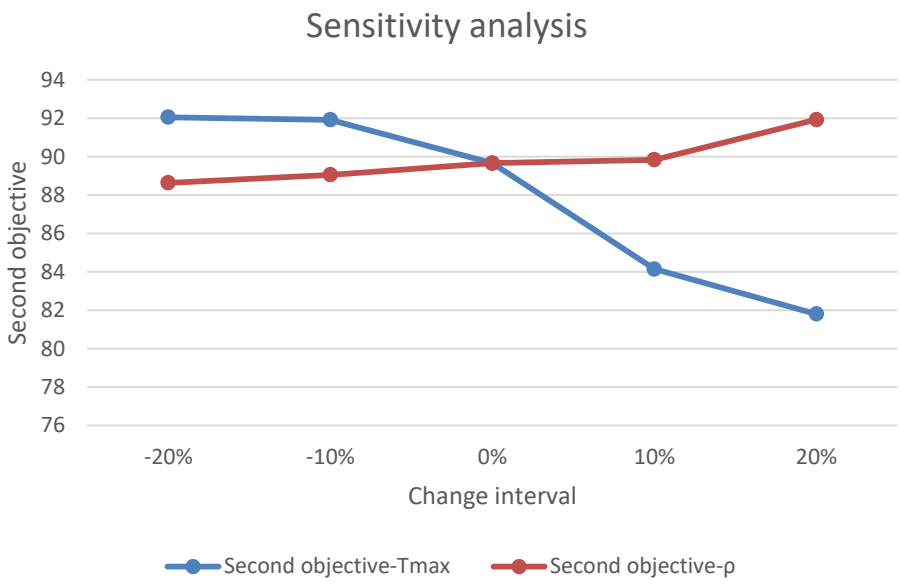
- Here, we analyze different conditions in the problem to simulate and study the instability of the real-world. To this end, sensitivity analyses are done on the maximum available time of vehicles (T_{max}) and uncertainty level (ρ).
- Note that the results are obtained by the grid point corresponding to the best Pareto solution.

Objective functions	Change interval of T_{max}				
	-20%	-10%	0%	10%	20%
First objective	113828.095	106739.293	102659.6	101563.211	99424.41568
Second objective	92.058	91.924	89.664	84.151	81.812

Objective functions	Change interval of ρ				
	-20%	-10%	0%	10%	20%
First objective	101298.382	102497.500	102659.600	103781.876	104772.883
Second objective	88.638	89.055	89.664	89.844	91.932

Sensitivity analysis





- The above figures can be investigated in order to be employed as effective managerial tools.
- As it is obvious, the behaviors of the objectives are corresponding to each other against the changes of the parameters.

Conclusion

- Optimal routing and vehicle allocating are two of the most important decisions of organizations such as municipalities for urban waste collection.
- Establishing an optimal waste collection system leads to an economically and environmentally sustainable waste management.
- Uncertainty in the waste amount plays an important role to estimate the required resources for waste collection.
- Robust optimization approach could provide feasible solutions under different uncertain conditions.

Conclusion

- Augmented ε-constraint technique could efficiently generate Pareto solutions and represent the trade-off between the economical and environmental aspects of the problem.
- Objective functions have a significant sensitivity to the maximum available time of vehicles and uncertainty level.
- The 1st and 2nd objectives increase by an increase of the uncertainty level, and decrease by a decrease of the maximum available time of vehicles.

Future Research Directions

- For future studies, the following items are suggested based on the main limitations of the research:

  - **Heuristic and metaheuristic** methods may be implemented to solve the problem in larger sizes efficiently such as those proposed by Babaee Tirkolaee et al. (2019), Goli et al. (2019).

  - Other uncertainty techniques such as **fuzzy theory** (Çalık et al., 2018), **grey systems** (Roy et al., 2017) and **stochastic optimal control** (Temoçin and Weber, 2014) may be compared to the current robust optimization approach.

  - Other objective functions including distribution reliability maximization or customers' satisfaction maximization can be studied, too.

Attachment

❖ Notations:

Sets and indices	
NC	Set of nodes with demand (demand node)
NT	Set of total nodes
K	Set of vehicles
R	Set of vehicle trips
S	Any optional subset of the demand node set
i, j	Demand node index
k	Vehicle index
r	Trip index

Parameters	
c_{ij}	Traversing cost of edge (i, j)
Pe	Early service cost per demand node
Pl	Late service cost per demand node
(e_i, l_i)	Hard time window of demand node *i*
(ee_i, ll_i)	Soft time window of demand node *i*
W_k	Capacity of vehicle *k*
d_j	Demand of node *j*
T_{max}	Maximum available time for each vehicle
M	Optional large number
$\boldsymbol{ghg_{ijk}}$	Amount of GHG emission by vehicle *k* when traversing edge (i, j)
ul	Unit of loading time for vehicles at demand nodes
uu	Unit of discharging time for vehicles at the disposal site
t_{ij}	Time for traversing edge (i, j)
θ	Converter coefficient of distance to cost ($/km)

Mathematical Model

❖ Notations:

Non-decision variables	
tt_i	Arrival time at demand node i
LT_k^r	Total loading time of vehicle k in trip r
UT_k^r	Total unloading time of vehicle k in trip r
Ye_{ki}	Amount of early service of the demand node i by vehicle k
Yl_{ki}	Amount of late service of the of the demand node i by vehicle k

Decision variables
$x_{ijk}^r = \begin{cases} 1 & \text{If vehicle } k \text{ moves from node } i \text{ to node } j \text{ in trip } r \text{ without serving node } j, \\ 0 & \text{Otherwise.} \end{cases}$
$y_{jk}^r = \begin{cases} 1 & \text{If vehicle } k \text{ serve node } j \text{ in trip } r, \\ 0 & \text{Otherwise.} \end{cases}$
$u_k = \begin{cases} 1 & \text{If vehicle } k \text{ is used,} \\ 0 & \text{Otherwise.} \end{cases}$

References

- Akhtar, M., Hannan, M.A., Begum, R. A., Basri, H., and Scavino, E. (2017). Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization. Waste Management, 61, 117-128.
- Arribas, C.A., Blazquez, C.A., and Lamas, A. (2010). Urban solid waste collection system using mathematical modelling and tools of geographic information systems. Waste Management and Research, 28(4), 355-363.
- Aringhieri, R., Bruglieri, M., Malucelli, F. and Nonato, M. (2004). An Asymmetric Vehicle Routing Problem Arising in the Collection and Disposal of Special Waste. Electronic Notes in Discrete Mathematics, 17, 41–47.
- Babaee Tirkolaee, E., Abbasian, P., Soltani, M., and Ghaffarian, S.A. (2019). Developing an applied algorithm for multi-trip vehicle routing problem with time windows in urban waste collection: A case study. Waste Management and Research, 37(1_suppl), 4-13.
- Bertsimas, D., and Sim, M. (2003). “Robust discrete optimization and network flows”. Mathematical programming, 98(1-3), 49-71.
- Bertsimas, D., and Sim, M. (2004). The price of robustness. Operations research, 52(1), 35-53.
- Çalık, A., Pehlivan, N.Y., Paksoy, T., and Weber, G.W. (2018). A Novel Interactive Fuzzy Programming Approach for Optimization of Allied Closed-Loop Supply Chains. International Journal of Computational Intelligence Systems, 11(1), 672-691.
- Gapminder, United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, DVD Edition; historical data.
- Huang, S.H., and Lin, P.C. (2015). Vehicle routing–scheduling for municipal waste collection system under the “Keep Trash off the Ground” policy. Omega, 55, 24-37.
- Inghels, D., Dullaert, W., and Vigo, D. (2016). A service network design model for multimodal municipal solid waste transport. European Journal of Operational Research, 254(1), 68-79.

References

- Kim, B-Y., Kim, S. and Sahoo, S. (2006). Waste Collection Vehicle Routing Problem with Time Windows. Computers and Operations Research, 33, 3624-3642.
- Kinobe, J.R., Bosona, T., Gebresenbet, G., Niwagaba, C.B., and Vinnerås, B. (2015). Optimization of waste collection and disposal in Kampala city. Habitat International, 49, 126-137.
- Li, J.Q., Borenstein, D., and Mirchandani, P.B. (2008). Truck scheduling for solid waste collection in the City of Porto Alegre, Brazil. Omega, 36(6), 1133-1149.
- López-Sánchez, A.D., Hernández-Díaz, A.G., Gortázar, F., and Hinojosa, M.A. (2018). A multiobjective GRASP–VND algorithm to solve the waste collection problem. International Transactions in Operational Research, 25(2), 545-567.
- Mavrotas, G. (2009). Effective implementation of the ε-constraint method in multi-objective mathematical programming problems. Applied mathematics and computation, 213(2), 455-465.
- Mavrotas, G., and Florios, K. (2013). An improved version of the augmented ε-constraint method (AUGMECON2) for finding the exact pareto set in multi-objective integer programming problems. Applied Mathematics and Computation, 219(18), 9652-9669.
- Soyster, A.L. (1973). Convex programming with set-inclusive constraints and applications to inexact linear programming. Operations research, 21(5), 1154-1157.
- Tirkolaee, E.B., Mahdavi, I., and Esfahani, M.M.S. (2018). A robust periodic capacitated arc routing problem for urban waste collection considering drivers and crew's working time. Waste Management.
- Wy, J., Kim, B.I., and Kim, S. (2013). The rollon–rolloff waste collection vehicle routing problem with time windows. European Journal of Operational Research, 224(3), 466-476.

Conference and Seminar:
Medan, Indonesia,
April 2019

Thank you very much for your attention!

gerhard.weber@put.poznan.pl

e.babaee@ustmb.ac.ir

NOW!Jakarta's Guidelines for Better Living: Waste Management

A JAKARTA SMARGASBORD | 10 October 2018

As sustainability movement is rising these days. Poeple in the household start thinking to have more green life by maintaining more conscious consumption and waste management. NOW!JAKARTA featured information about Waste4Change, a social enterprise dedicated to making Indonesia and cleaner and healthier place.

Jakarta produces 7,000 tons of waste every day. A person can use up to 700 plastic bags per Year. Where do these stuff go? NOW!JAKARTA

How Much Waste Do You Produce In A Year?

- Each person can produce waste up to 0,7 kg per day
- Jakarta produces 7,000 tons of waste every day

EURO
THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

GREEN BUSINESS IN
WASTE MANAGEMENT SECTOR

POLITECHNIKA POZNAŃSKA

Pacific Optimization Research Activity Group

EURO

IFORS
International Federation of Operational Research Societies