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Sorting Line Modelling as an Integral Part of Complex Tools for Decision-making in Waste Management

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This paper describes sorting line technology modelling as a potential key element of waste management at the municipal level, which, however, does not mean final treatment but only waste pre-treatment as an integral part of waste management chain. The outputs of the presented model are used as one of the key inputs to the NERUDA tool. The NERUDA tool provides support for strategic decision making in the field of waste management. The computational system of NERUDA has been created as an open tool and it is still being developed and expanded to suit current research tasks. The key part of NERUDA is a waste management related logistic problem. Hereafter, the NERUDA tool consists of a number of sub-modules and components that represent waste management technologies and procedures. Excessive separation not coupled with utilization of recyclables in the market can significantly disadvantage the overall economics of the chain. For the reason, a techno-economic model that can establish a representative waste treatment cost in order to obtain a valuable secondary raw material has been developed. Combination of techno-economic models allows to prepare unique, comprehensive and high-quality case studies.
Various technological arrangements of sorting line, attainable rates of material separation and potential for subsequent energy recovery are considered. It is also appropriate to consider related costs of sorted waste collection, which may be a very economically demanding issue in overall waste processing balance. Positive selling price of secondary raw materials on the market is an assumption in addition to processing prices estimation. The model can serve as a useful tool for costs estimating (investment, profits). Furthermore, the model can serve as a key tool for feasibility studies in the context of sorting systems and the secondary raw material production over the lifetime of facilities. The practical contribution of described model is presented through a case study in the conditions of the Czech waste management.

1. Introduction and motivation

Current trends in European waste management (WM) focus on technologies and methods that comply with preferred procedures of waste treatment hierarchy. Under Directive 2008/98/EC of the European Parliament and of the Council on waste, the Member States are encouraged to increase the preparing for re-use and the recycling of waste materials, such as paper, metal, plastic and glass from households at least, and possibly from other sources as far as these waste streams are similar to waste from households to a minimum of overall 50 % by weight by 2020. Further, in January 2018 the European Commission adopted a new set of ”Circular Economy Package” measures, including the Europe-wide EU Strategy for Plastics, options to address the interface between chemical, product and waste legislation and a Report on Critical Raw Materials and the circular economy. This paper focuses directly on municipal WM in the Czech Republic where relevant legislation is now being changed. It’s therefore necessary to modify existing networks of municipal waste management. We may expect more attention on obtaining of high-quality pure secondary materials from Municipal Waste (MW), and on waste separation (separated collection of waste by the producers). Recent changes have been reflected in the current Czech Waste Management Plan that has been in force on the country level since 2015. In the future, we expect an increase in the number of sorting lines and their upgrading in the context of large processing capacities or implementation of promising technological units.

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Sorting lines are a key element in municipal WM; they are a crucial step for further processing of MW fractions suitable for recovery (of material or energy) (Marieke et al., 2017). A similar method, that is the mechanical biological treatment (MBT), should also be mentioned here as it also focuses on the processing of MW for energy or material recovery. Compared to sorting lines, MBT method helps process and stabilize biologically degradable fractions that may potentially produce compost or biogas. However, MBT has had a somewhat ambivalent reception abroad and there is not much interest in it now in the Czech Republic (see the country or regional Waste Management Plans). Sorting line, as of now, seems like a promising technology for MW treatment in the Czech Republic. Therefore, a Techno-Economic (TE) model for economic and material assessment of investment projects and facilities of sorting lines was drafted.

The model is based on requirements of NERUDA tool (Šomplák et al., 2014), a computational system, so that a complex waste flow from producers to final treatment facilities may be assessed. NERUDA tool supplies the TE model input data, such as availability and parameters of MW. Subsequently, outputs from the TE model may be supplied to NERUDA tool to conduct further complex optimization analyses for transportation and flow balances. For sorting line, we may observe related parameters of the operations, such as requirements on the waste collection, transportation to the waste processing facility, competitors or composition of MW in time (Šomplák et al., 2017). The paper by Gregor et al. (2016), presents transport techno-economic models used for WM assessment by computational NERUDA tool.

2. Sorting line

Sorting line is a technology for separation of waste, either manual, semi-automatic or fully automated. Each type of technology has its own benefits and each technology differs in financial requirements necessary either for initial investments or for actual operations of the technology.

2.1 Sorting line: state of the art

The paper by Gundupalli et al. (2017), discusses typical arrangement of sorting lines and their particular automated features. Gundupalli's paper very well describes typical sorting features for MBT, which are especially NIR sensors, air separation, vibration sieves and others.

A large number of research papers focuses on separation and collection of MW both in terms of optimization (Groot et al., 2014) as well as in terms of collection efficiency. Other research tasks focus on a comparison of technical sorting and separate collection (Feil et al., 2017). The comparisons are always useful since it is hard to tell which type of treatment of recoverable MW is more helpful (Kropáč et al., 2016). Suitability of a particular technical solution depends on local requirements. This means that if quality of the final separated fractions is preferred, then the focus should be on separate collection, which improves positions on the global market. Technical sorting is able to process larger volumes of MW but the quality of material separation is rather poor, which affects sale prices of the secondary raw materials. In general, technical sorting facilities must be linked to facilities processing residues coming from the sorting.

According to state of the art it is very useful to prepared unique TE model which can describe the balance flow and economic view of sorting line facilities. The model should be implemented in a complex optimization tool, e.g. NERUDA tool. Calculation of complex costs for a waste treatment system is a very complex task, therefore, is necessary to prepare TE module of waste sorting operation which can analyse real operating data and can be used for feasibility studies solving.

2.2 Sorting line: considered technology

There are 137 sorting lines in the Czech Republic (as of 2015); these facilities sort paper, plastic and Tetrapack cartons. Other commodities, such as glass and metals, are sorted on a much smaller scale in the Czech Republic, or they are sorted directly in the material recovery facilities. Based on the requirements and plans of the Waste Management Plan valid for the Czech Republic, manual sorting line for paper and plastic that had been pre-separated is the core of the TE model. Technical operations, such as pre-separation and post-sorting, have been included. These concern especially rotary screen (pre-separation) and use of over-belt separators for an elimination of metal parts (post-separation). Basic arrangement of the considered technology is in Figure 1.

Separately collected waste (paper, plastic and Tetrapack containers) is piled in heaps in processing premises of the facility. Employee working at the entrance to the line is responsible for supplying the material on a belt conveyer located on the floor. A tilted conveyor takes the material upward and supplies it to the rotary screen separator. The rotary screen separates the unwanted fraction and leads it to a container, and the fraction left in the separator passes through a rotary screen and is lead on to a belt conveyor, followed by manual sorting. At the end of the conveyer, there is an over-belt magnetic separator which is able to separate metal parts. All sorted fractions together with the residues may be redirected to press equipment. Pressed packets are then transported by a forklift to the storage site.

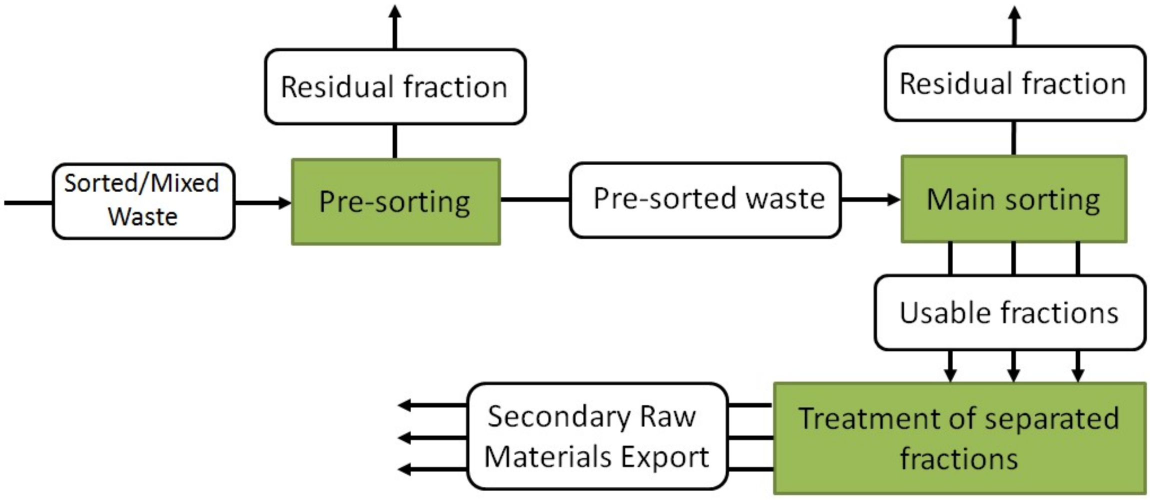

Figure 1: Simplified scheme of considered sorting line technology

3. TE Model of Sorting Line

The mathematical model has been developed in MS Excel. The model evaluates technical and economic parameters of the facility using input data. The aim of the TE model is to evaluate costs of MW sorting for recovery of secondary materials which are to be profitable on the market. The TE model may evaluate existing facilities as well as designs of future units. In order to do so, the model allows to consider all construction work, purchase of land, distribution of energy lines and other investments.
Input MW may have the form of residual MW, sorted MW or mixed MW (such as dry fraction) pre-sorted by producers. The TE model works with random amounts of fractions in the input MW flow. The TE model further allows to use various combinations of working time, that is, for example, how much time out of the total annual working time is spent on sorting of a specific commodity. This arrangement is common in facilities that sort paper or plastic and where Tetrapack containers are collected together with paper or plastic.

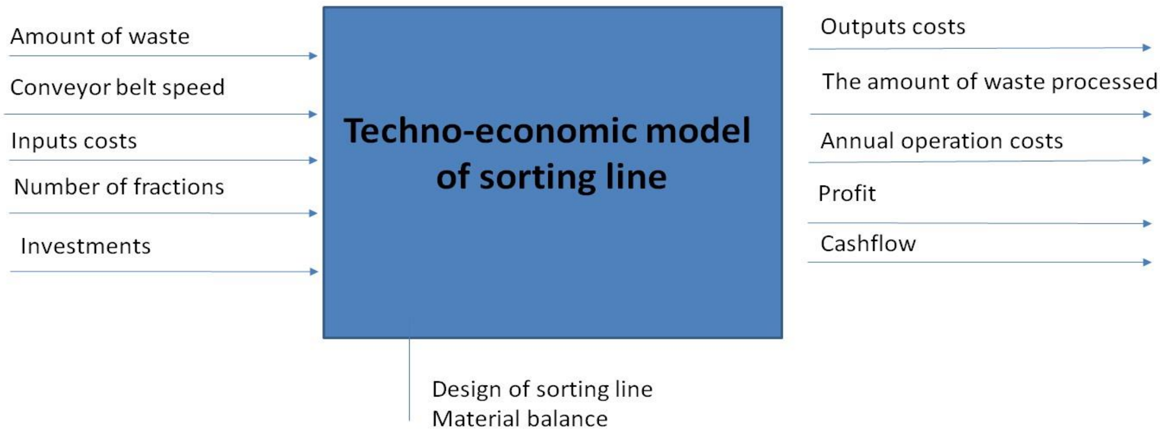

Figure 2: Sorting line TE model simplified scheme

The basic operational parameter is the required level of sorting, that is what kind of fractions and what kind of fraction quality (affected by waste collection system) are to be sorted from the input material flow based on the requirements imposed on the final secondary material. The user defines the morphological composition of a specific commodity and the maximum yield of the sorted fraction is thus determined using the working time and speed of the belt conveyer. User can randomly change the key parameters. The key parameters include coefficient of sorting quality (present to 98 %), morphological composition of the sorted commodity (in %),

purchase price of the fractions (see Table 1 and Table 2, and many other input data. Facility processing up to 6 input material flows (in the form of dumping pits and residues from the conveyer) may be modelled. The basic process flowsheet is presented in Figure 2.
The main outcome of the TE model is evaluation of operational and investment requirements which are crucial for efficient and economically sustainable operations of the relevant facility. Concurrent use of computational system NERUDA (Šomplák et al., 2014) allows conducting evaluation and optimization of the whole system of secondary materials production at a regional or country-wide level.

4. Case study

Sorting line is situated in a facility at the outskirts of a city (200 thousand inhabitants). The designed life time of the sorting line is 10 y for an annual working time of 4,000 h/y and 2-shift operations. The project is a greenfield investment and all the initial investments are included in the calculation of the project. Purchase of the land, reinforcement, and enclosure of the plot of land are calculated at EUR 728,346 (25.4 CZK is 1 EUR in March 2018). Construction work (relevant technical facilities, buildings, energy lines) are calculated at EUR 1,051,181. Investments necessary for the sorting line equipped with a press have been estimated at EUR 653,543. Annual reinvestments necessary for the whole facility have been calculated at EUR 31,496, wage costs at EUR 291,339 and variable costs (operating costs) at EUR 55,118. Overall costs for the launching of the sorting line have been estimated at EUR 2,389,764, annual mean operating costs including inflation reach EUR 374,016. Results of the case study don't include subsidies, financial aid or other state or commercial support. Purchase prices of particular sorted fractions were defined using annual prices in 2015 from server Letsrecycle, prices used in the case study are displayed in Table 1 and Table 2. The model further includes annual inflation for the following areas: reinvestment and operations (1 percent), wages (3 percent), utilities (1 percent) and inflation on profit from the selling of paper and plastics (2 percent). TE model of the sorting line was developed for three scenarios with identical working times:

- Scenario No 1: the line sorts out paper for 100 % of the working time.
- Scenario No 2: the line sorts out plastic for 100 % of the working time.
- Scenario No 3: the so-called 40/60 regime where the line sorts out plastic for 40 % of the working time and paper for 60 % of the working time.

For these scenarios, the speed of the conveyor in the main sorting cabin was set to 0.1 m/s and we may presume that processing of 2.5 kt/y of plastics and 8.6 kt/y of paper (Scenario No 3). For evaluation of the scenarios, the following morphological composition of particular commodities with typical bulk density and weight share of given fractions was selected; the purchase price for the relevant fractions was defined, too. Residues from plastic are set at 30 percent, residues from the paper amount to 5 %. The percentage share of residues was defined using data from real sorting line technologies. Data describing plastics is given in Table 1 and waste paper including tetrapack containers (collected with the paper), is described in Table 2.

Table 1: Sorting plastic fractions with particular properties

Plastic fractions	Volume weight (kg/m^3)	Weight share (wgt %)	Sorting weight (t/y)	Purchase price (EUR/t)
PET clear	44	13	322	130
PET green	44	10	247	111
PET blue	44	10	247	111
PET mixtures	44	14	346	60
HDPE	80	20	495	169
Plastic film	40	3	74	59
Mixture of plastics	60	0	0	47
Tetrapack cartons in plastic	110	0	0	68
Not suitable/Residues	55	30	793	0

Total economic evaluation of life time of the sorting line is displayed in Figure 3. Scenario No 3 is expected to provide EUR 74,803 of annual mean profits throughout the life time of the sorting line. Scenario No 2 generates no profit and is loss-making. Scenario No 1 generates EUR 214,519 annually on average. This level of estimated profit is based on assumption that large amounts of paper are supplied to the sorting line. Results show a total annual average economic balance of the sorting line and allow the model to provide deeper analysis for the development of large quantities of scenarios where the share of processed commodities and other operational parameters may be easily changed.

Table 2: Sorting paper fractions with specified properties

Paper fractions	Volume weight (*kg/m³*)	Weight share (*wgt %*)	Sorting weight (*t/y*)	Purchase price (*EUR/t*)
Magazines	200	13	1,100	104
Newspapers	200	11	931	104
Cardboard	120	30	2,539	68
Mixture of papers	220	15	1,269	40
Tetrapack cartons in paper	110	6	508	68
Not suitable/Residues	240	25	2,289	0

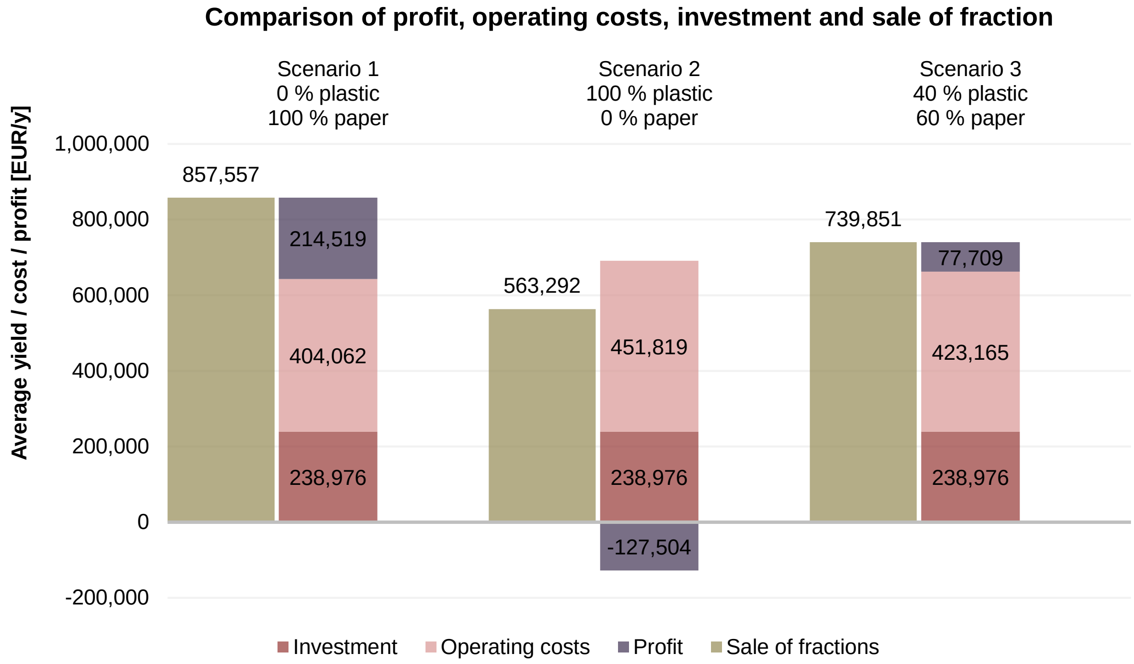

Figure 3: Sorting line calculation according to three scenarios

5. Conclusions

This paper introduced the newly developed TE model of sorting line. Using a case study, it was proven that the TE model is an excellent tool for evaluation of a relevant type of facility, and the model may be easily modified to evaluate semi-automated or fully automated facilities.
Using the results of the case study (Figure 3), it is clear that the sorting line is one of the efficient methods for waste processing that is also economically sustainable as long as there are sufficient amounts of waste for sorting and demand for the sorted fractions. Manual sorting lines can handle large amounts of waste. Regular supplies of the sortable commodity within the economically reasonable collection area is the limit parameter here. Transfer stations may be used for collection of the waste so that efficiency of waste supply into the facility is economically viable. Sorting lines in the Czech Republic process sortable waste from a relevant micro region. This means that the waste is collected in the waste collection sites and transported directly to material and energy recovery centres where it is sorted to a certain degree, depending on the concrete facility.
In case of sorting lines and lines for final sorting, the initial investments necessary for the technology are crucial. Small capacity systems with dominantly manual sorting are expected to require investments of up to 4 MEUR. Fully-automated systems with large capacities of 200 kt/a and more require investments of at least 12 MEUR and more. This means that the fully automated sorting lines are comparable to WTE facilities, in terms of investments. Major problems which the automated sorting lines have to face are quality of the sorting and cleanliness of the final fractions.
The model presented in the paper is prepared for further analyses and future implementation into NERUDA tool (Šomplák et al., 2014) or for use in combination with transportation TE models (Gregor et al., 2016). It is possible to say, that the authors prepared one new excellent part of NERUDA tool which will be tested. The model allows

to calculate complex costs for a waste treatment system consisting of the waste collection, sorting line operation and transportation for final processing (Waste-to-Energy plant or recycling facility). For the official integration to NERUDA tool it is necessary to prepare various types of scenarios for cost establishing, e.g. capacity, commodities, and other operational parameters.
The models and tools presented in this paper will be further analysed in more detail for a purpose of technical sorting and separate collection overall assessment.

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