IEooc_Methods3_Exercise2: The lifetime of materials in the technosphere

Goal: *Develop and solve a basic model of the recycling loop, define and calculate the lifetime of a material in the technosphere and the average number of life cycles.*

NOTE: *This exercise builds on IEooc_Methods2_Exercise3 and on the reading material IEooc_Methods3_Reading1, please check those first!*

Problem setting

The metal industries often claim that metals can be recycled indefinitely often, without loss of quality. Unfortunately, this claim is not true. The reasons are that a) our waste management industries cannot perfectly separate the different metal fractions from the waste streams, so that there is contamination with other metals in most cases, and b) there are losses at all stages of the recycling loop. When a unit of metal, like steel, passes through different product life cycles, it needs to flow through the recycling loop several times. Each time it passes through that loop, some more impurities accumulated and some more metal gets lost in obsolete stocks, dissipative losses, shredder and other waste management residues, and slag during remelting. [http://www.blog.industrialecology.uni-freiburg.de/index.php/2017/10/29/the-lifetime-of-materials-in-the-technosphere/]

In this exercise we will define two central indicators to measure the performance of a metal cycle: the lifetime of a material in the technosphere and the average number of life cycles. We will quantify them using a simplified lifetime model for three cases: aluminium beverage cans, construction steel, and a hypothetical closed loop system for automotive steel.

System definition

For this exercise we will apply the system definition of MaTrace Global (Pauliuk et al., 2017) with the following three simplifications: a) the lifetime is fix (no lifetime distribution, all products have the average useful lifetime), b) no re-use is excluded and c) fabrication scrap (aka prompt scrap aka new scrap) is not considered. With these simplifications a simple solution for the technical metal lifetime can be obtained using pencil and paper. For the full system the model can be solved using the publicly available MaTrace Global software (https://github.com/stefanpauliuk/MaTrace_Global).

The system definition is shown in Figure 1, it is based on the MaTrace model by Nakamura et al. (2014) and the concept of absorbing Markov chains (Eckelman and Daigo, 2008). The figure shows a system for closed loop recycling, with an exogenous input F_{0_5} to the use phase (1), the waste management industries (2), remelting (3), and manufacturing (4). The system describes the stocks and flows of one metal only, other metals and the product(s) itself are not considered. The model is dynamic, meaning that the flows are quantified for each model year. The in-use stock (1) links the present to the future: The future outflow F_{1_2} depends on the historic consumption. All processes but the use phases are modelled as instantaneous.

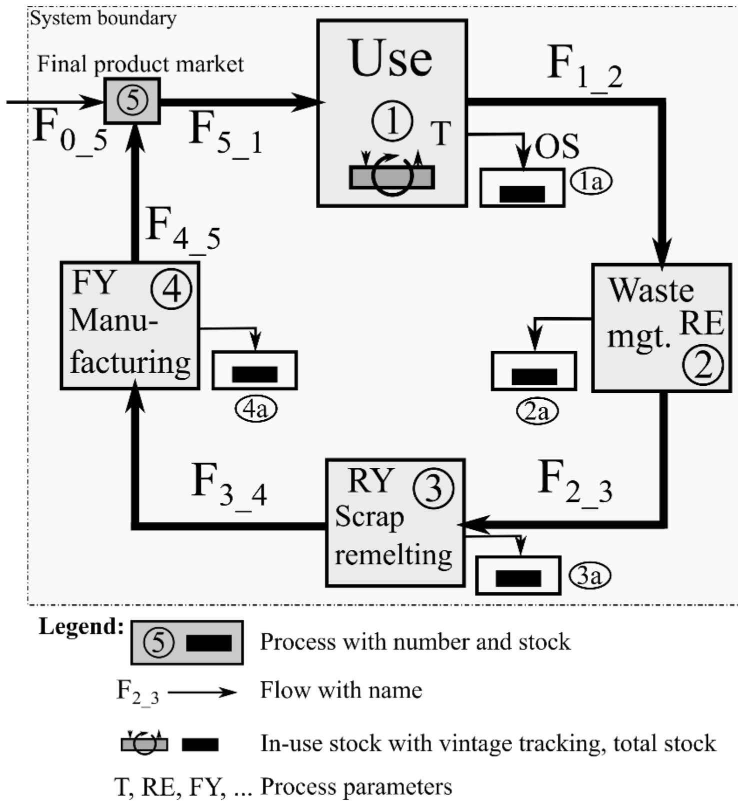

Figure 1. System definition for this exercise.

A number of process parameters are defined and values are gathered from the literature (Table 1). The parameter values reflect the real situation, with two exceptions: 1) No data could be found for the average cycling time of a beverage can, so 4 months was used, which includes the time lags of all steps in the cycle. 2) The assumed closed-loop recycling of automotive steel is hypothetical, as contamination with tramp elements is too high with current recycling technologies.

Table 1. Model parameters for the three cases. The parameter values reflect the real situation, with two exceptions: 1) No data could be found for the average cycling time of a beverage can, so 4 months was used, which includes the time lags of all steps in the cycle. 2) The assumed closed-loop recycling of automotive steel is hypothetical, as contamination with tramp elements is too high with current recycling technologies.

	Definition	**Aluminium (beverage can)**	**Steel (building)**	**Steel (passenger car)**
Lifetime T (yr)	Length of a single material life cycle	0.33	75	15
Obsolete stock formation OS (%)	$F_{1\_1a}/(F_{1\_1a}+F_{1\_2})$	0.04	0.1	0.09
Recovery rate of scrap RE (%)	F_{2_3}/F_{1_2}	0.95	0.86	0.85
Remelting yield RY (%)	F_{3_4}/F_{2_3}	0.97	0.97	0.94
Fabrication yield loss FY (%)	F_{4_4a}/F_{3_4}	0	0	0

Tasks and questions:

Assume that in model year 0 an amount of M_0 = 1 kg of metal was consumed in form of one of the three products (Flow F_{0_5}). There is no exogenous input to the system in any of the subsequent model years.

1) **Develop a (general) dynamic MFA model to quantify the amount of metal in the use phase (*S1*) at a given time t in the future! Assume that the lifetime is a fixed number of whole years (5, 18, …).**

2) **Determine the average lifetime of the metal in the technosphere for each of the three cases listed in Table 1!**

3) **Determine the average number of life cycles *N* of the metal in the technosphere for each of the three cases listed in Table 1!**

4) **Interpret your findings!**

Questions 2 and 3 were introduced to the industrial ecology community by Daigo et al. (2005).

References:

Daigo, I., Matsuno, Y., Ishihara, K.N., Adachi, Y., 2005. Application of Markov chain model to analyzing the average number of times of use and the average residence time of Fe element in society. Tetsu to Hagane (Journal Iron Steel Inst. Japan) 91, 159–166.

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Pauliuk, S., 2017. Critical Appraisal of the Circular Economy Standard BS 8001:2017 and a Dashboard of Quantitative System Indicators for its Implementation in Organizations. Resour. Conserv. Recycl. Forthcoming.

Pauliuk, S., Kondo, Y., Nakamura, S., Nakajima, K., 2017. Regional distribution and losses of end-of-life steel throughout multiple product life cycles—Insights from the global multiregional MaTrace model. Resour. Conserv. Recycl. 116, 84–93.