1st International Conference on Experiments/Process/System Modelling/Simulation/Optimization
1st IC-EpsMsO
Athens, 6-9 July, 2005

SYSTEM MODELING AND OPTIMIZATION OF AN END-OF-LIFE CAR RECYCLING FACILITY

Evangelos P. Koltsakis, Hariton M. Polatoglou

Physics Dept, Aristotle University of Thessaloniki, Thessaloniki, Greece, 54124.
e-mail: vangelis@auth.gr, hariton@auth.gr

Keywords: System modeling, optimization, ELV, car recycling.

Abstract. *In the present work we model procedures of an end-of-life vehicle (ELV) recycling plant. Material transformations and energy consumption are accounted. Variations and total changes in energy and materials quality are calculated. Critical control points (CCP) are detected and taken under special consideration.*

1. INTRODUCTION

The increase of the automobile industry over the last years by developing a mass consumer market and the shortening of products life circle[[1]] has created a lot of concern[[2]] for the management of the waste[[3]] of withdrawn automobiles because of the possible environmental physical and chemical hazardous substances[[4]] contained and of the environmental and energy costs[[5]] and benefits of materials recycling. As quality in waste management procedures has to be assured, a detailed study of each crucial parameter is essential. Energy[[6]] consumption and transformation is another crucial parameter. System modeling[7] is a useful tool for the optimization of the procedure.

2. FACTS

Nearly all of the 27 million cars around the world that reach the end of their useful life are recovered for recycling each year. Automotive recyclers now can recover nearly 80% of the total materials by weight from a vehicle. The remaining 20% of vehicle materials that cannot be recycled is called auto shredder residue (ASR). ASR includes plastics, rubber, wood, paper, fabric, glass, sand, dirt, and ferrous and nonferrous metal pieces. Five million tons of ASR are disposed of in landfills each year.

Consumers purchasing used or reconditioned parts save 50 percent or more compared to the cost of purchasing new parts.

More than 25 million tons of materials are recycled from vehicles each year. Nearly 90% of automotive aluminum is recovered and recycled. Although this aluminum represents less than 10% of the average motor vehicle by weight, it accounts for roughly half of the vehicle's value as scrap.

When manufacturers use scrap iron and steel instead of virgin ore, they reduce air and water pollution by more than half during the manufacturing process.

2.1 Car recycling description

Cars are recycled in four steps:

i. dismantling,
ii. crushing,
iii. shredding, and
iv. resource recovery.

In the dismantling stage, processors recover the fluids and take apart the usable parts and components. These include batteries, wheels and tires, steering columns, fenders, radios, engines, starters, transmissions, alternators, select plastic parts and components, glass, foams, catalytic converters, and other components, based on aftermarket demand. The processor then crushes the vehicle and loads it onto the vehicle shredder. The shredder grinds the vehicle into fist-sized pieces, which are then separated into ferrous and non-ferrous (aluminum) metals, as well as ASR (Fig. 1). After separation, the recovered metals are remelted at the mills, and the ASR is land filled.

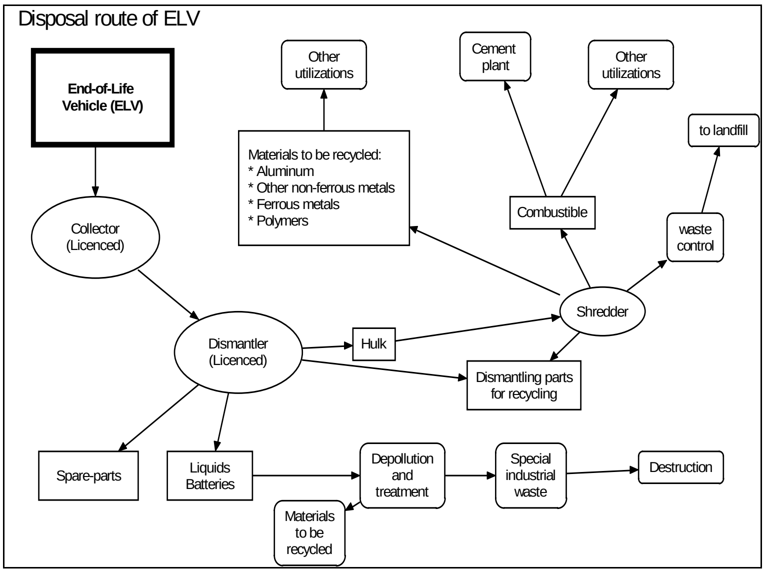

Fig. 1. The disposal route for end-of-life vehicles in an operational ELV site.

3. OUR WORK

In the present work we model procedures of an end of life car recycling plant. Also, we observe, describe and record the workings in an existing car recycling plant as they are actually achieved through official legislated procedures[8] that recently have been started. Observational data are used to adjust the model parameters and are also used to determine the effectiveness of the model. Material transformations and energy consumption / transformation are accounted. This leads to the determination of the model parameters and the assessment of the suitability of the model. CCPs are detected and taken under special consideration.

The recorded data analysis is significant for the improvement of stages of the procedures and for the improvement of the whole plan in the recycling plant, for the minimization of consumed energy and for the improvement of the recovery of the re-usable materials.

The aim of the work is the waste reduction through maximization of recycling degree, the stabilization of the hazardous materials and the improvement of the procedures by developing more thermodynamically efficient processes balanced with the environmental requirements.

4. MODELING

We develop a model for the study of the procedures of the processing of ELVs from the viewpoint of quality. There is a number of specific potential benefits from using simulation for recycling analyses, including:

- Increased throughput (production per unit of time)
- Decreased times in system of parts
- Increased utilizations of machines or workers
- Increased on-time deliveries of incoming and out coming materials
- Reduced capital requirements (land, buildings, machines, etc.) or operating expenses
- Insurance that a proposed system design will, in fact, operate as expected
- Information gathered to build the simulation model will promote a greater understanding of the system, which often produces other benefits.
- A simulation model for a proposed system often causes system designers to think about certain significant issues long before they normally would.
- Optimized control of CCPs.

4.1 The aim of the model planning

The model aims at the study of:

- the amount of energy which is consumed during the processing
- the energy transformations that are taking place during the processing
- the energetic content of the final products

- the possibility of minimizing the consumed energy during the processing
- the maximization to the useful energy of the final products
- the application of more environmental-friendly technologies
- the reusability of the final products
- the control of the possibly toxic materials
- the critical control points during the whole procedure

4.2 Quality consideration

Critical control points (Table 1) are of a great significance in the model, as recycling methods already applied have a big margin for improvement, in various sectors, like as: handpicking and / or automated picking, energy amount consumed, energy amount reusable, toxic metals in materials etc.

1	Energy waste (amount and quality)
2	Material waste
3	Toxic materials driven to landfill or to recycling
4	Staff health and safety

Table 1. Critical control points taken under consideration

The minimization of the energy consumed in the processing and the maximization of the recovered energy from recycling are today subjects of special interest in the context of industrial ecology, and for this reason they are one of the CCPs of our model.

The management of the disposable materials requires more analytical separation, with the search for new separation techniques for the salvage of re-usable materials and the detection and stabilization and the control of some possibly existing toxic materials, which at present they are dumped to the landfills or are incinerated.

Staff health and safety matters also are of great concern as another CCP in our model, because of the possibly dangerous materials mentioned above and of the possibly risky working conditions.

4.3 Description of the model

In this section we shall introduce the definitions of the model quantities. For the purpose of having a tractable model simplifications will be introduced. First of all we confine the material fractions into four, denoted by f_i, i.e ferrous, non-ferrous, plastic and glass. If m_{car} denotes the mass of the car then the mass of each fraction is given by $m_i = m_{car}f_i$.

As the data collected from the facility indicate, most of the energy in processing ELVs goes to the shredding and separating step. To estimate this energy we must consider the energy per mass unit that is consumed in each step. If e_i is the average energy per mass unit consumed for each fraction, then the total energy consumed per hulk mass unit is given by:

$$E = \sum_i f_i e_i m_{car} \tag{1}$$

But electric energy consumed as well as electric energy way of charging depends on the rhythm hulk is driven to shredder and on off-line time (as breakdown times are not significant). An other parameter for energy consumption would be the further materials separation, a step that demands a longer production line with more machinery involved and more time spent as well.

4.4 Process Modeling

Here we describe the modeling for the time evolution of the process to include the idle periods of the plant, the feeding speed, the number of incoming cars per day and the time constants for the different processes. This can help us find the optimum conditions for the operation of the plant (example in Fig. 2).

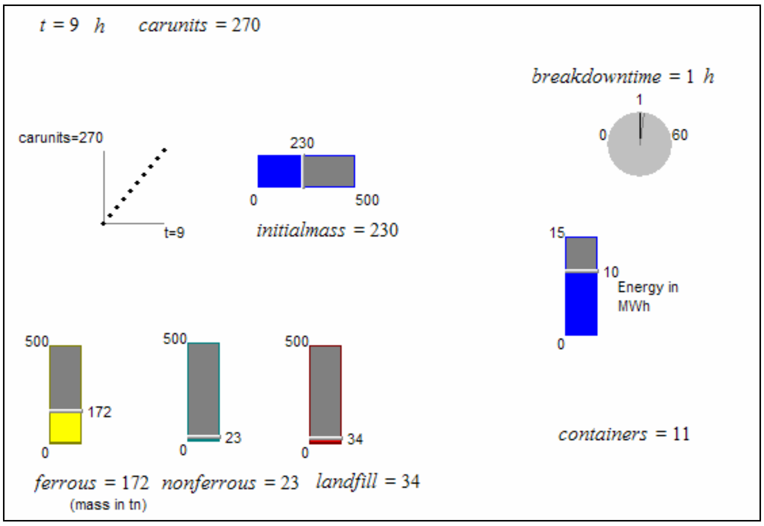

Fig. 2. Modeling application graph.

More specifically, the model aims at the documentation, study and analysis of:

- the quantities of the incoming materials and the separated output materials
- the procedures and methods that are employed in relation to:
    - the degree of the material separation
    - the energy that is consumed or recovered
    - the recovery of useful materials
    - the possibility of applying more efficient methods
    - the time that the materials remain in the plant
    - the environment
    - the stuff health and safety

In addition the model would allow the study of different scenarios and determine their outcome.

5. A SIMULATION CASE STUDY OF AN ELV RECYCLING PLANT.

In this section we describe the results of a simulation study of an ELV recycling plant.

5.1 Description of the System

The recycling facility receives, disassemblies and dismantles ELVs, separates materials and leads the finally produced materials to recycling or to landfill (Fig. 3).

The facility operates 5 days a week, and shredder goes on for eight hours a least, every time that the hulk mass is enough or there is no more free restoring space. There are no seriously long breakdown periods and bottlenecks are for the present conditions predicted and avoided.

At the present time, plastic and glass are not separated for recycling but driven to landfill. Non-ferrous materials (brass, copper and aluminum) are not individually separated. In coming materials (ELV) are gathered rather in random frequency. Out coming products are loaded on 20 tn containers.

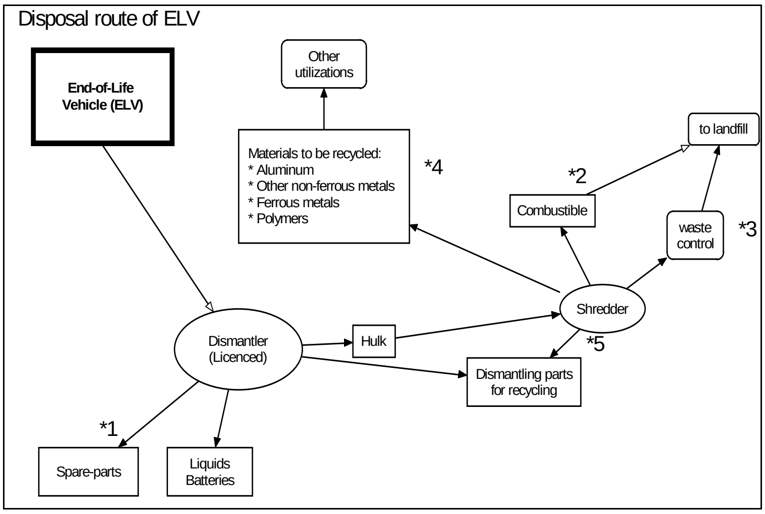

Fig. 3. Points to be improved in the disposal route.

For the application of the model in realistic processes, we observe and document the procedures followed by a plant for ELVs. This plant is one of the two in Greece that are officially commissioned to process ELVs. ELVs are gathered, spare-parts, liquids and batteries are separated and a queue is formed by the hulk. When the number of cars is appropriate or restoring space is off, the shredding procedure begins. Ferrous, non-ferrous, plastic and glass materials are separated.

Separation fracture (mass %)	
Ferrous	75%
non-ferrous (Al, Cu)	10%
plastic, glass etc	15%

Table 2. Separation fracture.

Electric energy consumption is highly depending on the amounts of hulk driven to shredding and separating procedure.

As facility today functions, energy consumed can be calculated by Eq. 1, giving the results presented in Table 3:

Energy per car mass unit	Energy per car mass unit in shredder	Energy for ferrous mass unit separation	Energy for non-ferrous mass unit separation	Energy for plastic/glass mass unit separation
43 Wh	28 Wh	6 Wh	5 Wh	4 Wh

Table 3. Real energy consumed.

Using our simulation model, we can have various scenarios, attempting to optimize parts of the procedure.

- Scenario 1: 100% increase of the incoming ELV. Requirements in facilities space availability, incoming and out coming on time materials capability, nr of employees increase etc have also to be considered.
- Scenario 2: Increase or the separated fractions. New technologies installation cost, nr of employees increase etc have also to be considered.
- Scenario 3: Increase of the CCPs controls. New technologies installation cost, nr of employees increase, delays in the production line etc have also to be considered.

In Table 4, simulation results about energy are presented for all of the tree alternative scenarios.

Scenario	Energy per car mass unit	Energy per car mass unit in shredder	Energy for ferrous mass unit separation	Energy for non-ferrous mass unit separation	Energy for plastic/glass mass unit separation
Running	43 Wh	28 Wh	6 Wh	5 Wh	4 Wh
1	36 Wh	24 Wh	4 Wh	4 Wh	4 Wh
2	48 Wh (43 Wh +5 Wh for extra separation)	28 Wh	6 Wh	5 Wh	4 Wh
3	45 Wh (43 Wh +2 Wh for extra control equipment)	28 Wh	6 Wh	5 Wh	4 Wh

Table 4. Energy consumed in alternative scenarios.

6. RESULTS AND DISCUSSION

Using a the simulation model, optimization in sectors as production scheduling, control strategies, reliability analysis, quality-control policies, just-in-time strategies etc can be achieved.

We have introduced several quantities in order to facilitate the quantitatively description of the processes. The determination of these quantities has led to the calculation of properties such as the required energy at each step and the grade of material separation and recycling.

We notice that a great amount of the energy goes to the shredding procedure and ways to improve this should be sought. In addition, equipment for more separation must be installed, as some fractions have to be more analytically separated. Additionally, products that for the time being are driven to landfill, have to be tested in lab in order to be driven to incinerator for extra energy savings.

By analyzing the different issues of EVL processing we find that there are several critical control points which must be considered in order to remove possible malfunctions of the procedures. The establishment of such CCPs in actual practice will help to monitor their effectiveness and also to show ways of improvement.

There are some additional aspects which are under investigation such as: the preparation of different scenarios and their merit through the time modeling of the procedures, and analysis of the materials to determine with analytical methods their chemical composition in order to monitor the existence of hazardous substances.

7. CONCLUSIONS

The processing of ELVs, with the new and under consideration requirements, is a novel and relatively large scale industrial function. A lot of study is needed in order to access the impact of the various parameters and to optimize many procedures and methods as there already exist strict environmental standards and need for control in the disposal chain. We have approached this problem by developing models for the qualitative and quantitative transformations of the energy and materials during the processing of the EVLs. We have applied the models for one of the two officially commissioned and operational ELV sites in Greece.

REFERENCES

[1] G. Keoleian, (2003), *Life cycle optimization of automobile replacement: model and application*, Environmental Science & Technology, Vol. 37, pp. 5407-5413.

[2] T. Graedel, (2002), *Getting serious about sustainability*, Environmental Science & Technology, Vol. 36, pp. 523-529.

[3] A. Fricker, *Waste reduction in focus*, Futures 35 (2003) pp. 509-519.

[4] A. Khare, (2000), *Economic issues in recycling end-of-life vehicles*, Technovation, Vol. 20, pp. 677-690.

[5] S. Das, (1995), *Automobile recycling in the United States: energy impacts and waste generation,* Resources, Conservation and Recycling, Vol. 14, pp. 265-284.

[6] C. Koshland, (1997), *Two aspects of consumption: using an exergy-based measure of degradation to advance the theory and implementation of industrial ecology*, Resources, Conservation and Recycling, Vol. 19, pp. 199-217.
[7] L. Averill, W. David Kelton, (2000), *Simulation Modeling and Analysis*, International Editions 2000, Singapore.
[8] S. Mutz, T. Chatziavgoustis, T. Pretz, (2005), 'Sorting of aluminum and its alloys within the European automobile recycling', *Proceedings of 5th International Exhibition & Conference on Environmental Technology, Athens Greece, 3-6 February, C81*.