Abstract: The idea of this paper occurred in one car dealer sales company in Estonia. The problem is that some vehicles are stagnated in the warehouse for months for some reason. It requires additional resources, retail space on the trading floor and, of course, each day of car downtime reduces it cost on the market. All these circumstances lead the company to the specific losses, what are not acceptable for the used car dealers. In this research the general trends for increasing competitiveness of used cars on the market and reducing their environmental impact will be considered.

Key words: Life cycle extension, dynamic modelling of used vehicles.

1. INTRODUCTION

This study provides a framework for understanding overall vehicle economics and key economic variables in relation to individual ownership costs, operating decisions and replacement intervals, in combination with a parallel study of vehicle end-of-life possibilities. The results are considered in terms of annual car sales numbers, stagnated vehicles in warehouse and storage costs for ownership by the company. The present study considers an annual decision for a vehicle owner: “keep the existing vehicle, or replace it with a new one?” or “how green the customer becomes by replacing the old vehicle“. Survey of US buying companies showed that the people buying a car take into account quality, price, safety, fuel economy, mileage of car and comfort above all (see Table 1).

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>19%</td>
</tr>
<tr>
<td>Fuel economy</td>
<td>18%</td>
</tr>
<tr>
<td>Quality</td>
<td>18%</td>
</tr>
<tr>
<td>Styling</td>
<td>11%</td>
</tr>
<tr>
<td>Price</td>
<td>16%</td>
</tr>
<tr>
<td>Warranty</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 1. Customer preference attributes [1]

The main goal of this research is to develop approach for determination of the optimal vehicle retirement age and minimize it environmental impacts. Also must be taken into account interests of cars end users and sales companies. The optimal vehicle retirement age was estimated through inputs and outputs (emissions and energy consumption), associated with different car models and ages.

It is also important to highlight that the energy consumption is growing every year in the world. The price for every kind of petrol is growing in the same fast manner. More detailed overview and some forecasts are presented in next chapter.

2. PETROLIUM PRICE AND NEW TRENDS IN CARS DEVELOPMENT

Several oil market analysis groups produce world oil price and production forecasts. In figure 1 is introduced oil price history [2]. Impact on oil prices depends from growing demand in developing Asian countries. Strong demand kept crude oil benchmarks above the $100-a-barrel mark for most of 2011, despite multiple economic shocks. With limited alternatives, prices will continue to increase in the future with rising demand constraining reserves.
Forecasts of the price of oil (and the price of its derivatives such as gasoline or heating oil) are important in modeling investment decisions in the energy sector, in predicting carbon emissions and climate change, and in designing regulatory policies such as automotive fuel standards or gasoline taxes [3,4].

Most developing nations that are driving global economic growth are highly dependent on energy consumption. Although the U.S., EU, and Japan consume large amounts of energy, these nations have less leverage to the price of oil in relation to their GDP.

Consumer demands and new regulations will heavily influence the development and marketability of innovations in the car industry. First among these demands is fuel efficiency, which will lead to new (or improved) powertrain technology.

Oil price multiplied by Inflation will make Electric vehicles the reality in the nearest future, see figure 3 [5]:
• Electric vehicles will be the minority of auto sales in the short and medium term, but then become the majority.
• EVs will have a 5.5 percent market penetration globally in 2020 and 15 percent by 2025.
• The internal combustion engine will still dominate with 85 percent of the market, but EVs will move from rich man’s toy to mass market.
• High oil prices will make EVs more popular and in 30 years EVs will be the bulk of the market.

Green alternatives, such as electric cars will likely find more consumer interest in wealthier countries while flex-fuels, such as ethanol and natural gas will find wider adoption in emerging markets where the local climate or resource base favors these fuels over petroleum.

While consumers await a more EV-friendly world, hybrid vehicles will serve as transition technology in developed and developing markets. Hybrids feature lower carbon emissions, greater fuel efficiency, and are less infrastructure intensive than EVs [1]. They also aid in the switch from full-combustion engines to electric motors. Due to all above mentioned energy consumption issues, it is very important to plan the used vehicle end-of-life scenarios long before the proposed optimal life cycle. The optimal period of vehicle life cycle can be calculated by using Life Cycle Assessment tool.

3. CARS LIFETIME

Statistic of Automobile Medium Lifetime [9] (shows that cars after 12 years loses his survival rate and needs modernisation.
Data from sales company (figure 4) shows that there are not cars older than 13 years.

Cars are retired from the service after 20 years of physical life. The average age of passenger cars in EU [7] in 2006 was 7.65 years. The age of passenger’s cars has been decreasing primarily on account of the policy of encouraging the replacement of older vehicles with new ones.

An intermediate phase between the purchase of a new car and its eventual scrapping is the sale of the car as a used car. Statistics at an EU level show that the used car market is very active, in most cases larger than that for new cars.

### 3.1 Stagnated cars in the sales company

As figure 5 shows the longest period of car life cycle is usage time. The environmental aspect is very important, nevertheless the satisfaction level of end user during this whole period is playing significant role. On the one hand the vehicle producers have to follow the restrictions set by governments all over the world, than take into account all the environmental aspects and after all think about the end user satisfaction level.

According to statistics gathered from this car dealer company (figure 5), the vehicles stay in warehouse for more than one month due to they have the wrong cost (the purchase price is higher than the market one), there are certain serious technical problems or the customer is not anymore satisfied with the car options and features.

Normally the used cars have to be resold in one month, but what to do with these problematic units? The best solution has to be found by used vehicles reselling company for car life cycle extension and user satisfaction: reasonable price – optimal fuel consumption – good quality. End users are not thinking about environmental impact. By optimising the fuel consumption and reconstruction internal combustion engines into electric ones the environmental issues will be fulfilled by default. In this paper these factors will be taken into consideration.

### 3.2 Solutions for used cars

When the product has distinguished the end of its life cycle the proper decision has to be proposed. In fact, the end of product life cycle can be different, based on the optimal cash-flow measure [10]. The totally new solution has to be proposed in order to intrigue the future customer.

The typical problem seems to appear here is that companies do not think about what to do with unsold and returned used cars, their parts, which have left from production, old or obsolete products [11]. Most managers consider it as wastes. But if a one business thinks in ‘Green’ way, there are several options to follow:

- First one, the smartest: develop or upgrade used car with a possibility to use parts or subassemblies from previous product. In this case study the used car reconstruction into electric car is observed.
- Another option: collect and recycle products, parts, and material. There is a
possibility to recycle old crushed cars what can not be repaired / remanufactured / reused into spare parts with clear history (true readings, year of manufacturer
• Finally, worst and simple option is a landfill. Unfortunately it is the most widely used option nowadays.

4. CARS LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) provides the environmental profile of a system and evaluates the distribution of the burdens and impacts across life cycle stages. LCA uses a systematic and comprehensive approach to assess environmental burdens associated with products, and it has been used as an analytic tool for pollution prevention, life cycle design, and optimization modelling [6]. A vehicle life cycle consists of the following generic stages: materials production, manufacturing, use, maintenance, and end-of-life. The environmental burden of each stage shows different profiles for various categories. For instance mid-sized car, the use phase contributes 85% of the total life cycle energy consumption based on 120,000 miles (ca 193,121 km) of service life. On the other hand, the use phase contributes only 19% of the total solid waste produced while the materials production phase contributes 58% [7]. In order to compare the environmental performance between old, retiring vehicles and new replacement vehicles in the context of scrappage programs, LCA models need to be developed for each model year as a function of vehicle age. In this paper, the dynamic model is developed for the period of time from usage to end-of-life stage.

4.1 LCA model construction

A standard mathematical model to find optimal vehicle retirement policy, as presented in figure 6, is constructed using the following notation:

Assume that, at time 0, a decision maker tries to minimize the environmental burden of a criterion within the time horizon $N$ based on information the decision maker has regarding the environmental performance of future vehicles.

In order to compare the environmental performance between old, retiring vehicles and new replacement vehicles in the context of scrappage programs, LCA models need to be developed for each model year as a function of vehicle age. According to this research the LCA model has to be developed for the specific period of vehicle life cycle.

Vehicle LCA studies have mostly focused on measuring the environmental performance of specific model year vehicles or propulsion systems. However, such methods fall short of describing high or low emitters since these studies report average environmental performances based on functional units (e.g., 120,000 miles of driving) [8]. In order to compare the environmental performance between old, retiring vehicles and new replacement vehicles in the context of scrappage programs, LCA models need to be developed for each model year as a function of vehicle age. In this paper, the dynamic model is developed for the period of time from usage to end-of-life stage.

The decision maker seeks a solution of the form “Buy a new vehicle / upgrade the used one at the start of year $0$ and keep it for $\alpha$ years and retire it; then buy a new vehicle at the start of year $a$, and keep it for $b$ years and retire it, etc. As an example, consider four policies depending on the decisions at $T_a$ and $T_b$. It is assumed that retiring a vehicle and buying a new vehicle occurs simultaneously.
1) If the vehicle owner keeps the initial vehicle throughout the time horizon N, the cumulative environmental burden \( B \) will result in \( B_1 \). The slope change between \( T_b \) and \( N \) represents vehicle deterioration expected for older cars.

2) If the vehicle owner replaces the initial vehicle with a new vehicle at time \( T_a \) and keeps the new vehicle until \( N \), the cumulative environmental burden \( B \) will result in \( B_2 \).

3) If the vehicle owner replaces the initial vehicle with a new vehicle at time \( T_a \) and replaces this second vehicle again at \( T_b \), the cumulative environmental burden \( B \) will result in \( B_3 \).

4) If the vehicle owner replaces the initial vehicle at time \( T_b \) with a new vehicle and keeps the new vehicle until \( N \), the cumulative environmental burden \( B \) will result in \( B_4 \), which is the minimum possible outcome. With this hypothetical example, policy 4 is the optimal policy and the optimal vehicle lifetimes are \( T_b \).

However, in a real-world problem with a longer time horizon, the number of possible policy choices is often enormous. If a decision maker seeks an optimal replacement policy during a time horizon \( N \) with a new vehicle at the beginning of year 0, and the vehicle replacement decisions are made at the beginning of every year from year 1, the number of possible outcomes is \( 2^N \). In addition, the environmental profiles of \( N \) different model years need to be considered based on vehicle age.

The figure 6 shows \( n \), first year of the study; \( N \), last year of the study; \( M \), maximum physical life of a vehicle; \( BM(i) \), environmental burden of the materials production of model year \( i \) vehicle; \( BA(i) \), burden of the manufacturing of model year \( i \) vehicle; \( BU(i,j) \), burden of the vehicle use during year \( j \) of model year \( i \) vehicle's service; \( BR(i,j) \), burden of the maintenance during year \( j \) of model year \( i \) vehicle's service; \( BE(i,j) \), burden of the end-of-life stage of model year \( i \) vehicle retired at the end of year \( j \); and \( u(i,j) \), burden of purchasing (producing) a new vehicle at the start of year \( i \) and keeping it for \( j \) years.

For any model year \( i \), \( u(i,0) = 0 \) and represents the case in which a new vehicle is not purchased in year \( i \). [8]

\[
\begin{align*}
    u(i,j) &= B_{\alpha}(i) + B_{\xi}(i,l + j - 1) + \sum_{k=1}^{j} (B_{\psi}(i,k) + B_{\eta}(i,k)) \\
    u_m(i,j) &= B_{\varepsilon}(i,i + j + 1) + \sum_{k=1}^{j} (B_{\upsilon}(i,k) + B_{\eta}(i,k) + B_{\varepsilon}(i,k))
\end{align*}
\]

4.2 LCA for car modernization

In current research is considered car modernization instead car replacement. In the mathematical model in this case we not take in account burden of the materials production \( B_{M}(i) \) and manufacturing \( B_{A}(i) \), of vehicle. But use new parameter \( B_{V}(i,k) \), environmental burden of the vehicle modernization. Value of this parameter is more less than \( B_{A}(i) \).

This model helps to focus more attention on possible end-of-life strategies analysis.

\[
\begin{align*}
    u_m(i,j) &= B_{\varepsilon}(i,i + j + 1) + \sum_{k=1}^{j} (B_{\upsilon}(i,k) + B_{\eta}(i,k) + B_{\varepsilon}(i,k))
\end{align*}
\]

Schematic example of the environmental burden influence for vehicle modernization is shown in figure 7.

Fig. 7. Schematic example of the life cycle optimization by car modernization

The dynamic programming optimality equations are constructed as follows: \( f(i) \) be the minimum possible burden accumulated from the start of year \( i \) through the end of year \( N \) given that a purchase is made at the start of year \( i \). Then:
\[ f(j) = \min_{x_i \in \{1, 2, ..., M\}} \{ u(i, x_i) + f(i + x_i) \} \] (3)

Where, \( x_i \) is the decision variable representing the number of years owning vehicle of model year \( i \).

For each criterion, this model seeks to minimize the burden from the life cycle of model years \( n \) to \( N \) by deciding how long to keep each vehicle before purchasing a new vehicle or reconstructed one.

5. CONCLUSION

The amount of vehicles, needed for society, constantly grows in operation. However, the used vehicles impact to the environment is enormous throughout the life cycle, for instance: energy and resource consumption during the use phase, waste management during new products manufacturing, and disposal at the end of its life. In this research the approach for determination of the optimal car lifetime was introduced. The mathematical tool was represented in order to find the right moment for old car replacement or modernization. This way of thinking prioritizes the possible upgrade of used vehicles from the energy saving point of view. It gives additional advantages to cars sales companies to increase competitiveness on used cars market by offering unique services and products.

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7. REFERENCES


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