TECHNOLOGICAL VALUE ANALYSES OF MECHANISMS USED IN AMUSEMENT PARKS

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In amusement parks there can be found various mechanisms used either as entertainment or as outdoor sport equipment. One of their major issues is the fact that it involves a complex experimental observation from a technological and economic point of view, also taking into account the impact on the environment. In the literature, all these analyses are known as "sustainable development". In this paper it was analyzed this approach because it offers an overview on the research methodology, having as a final result the evaluation of the added value as a product.

Keywords: added value, technological evaluation, computer modeling, FAST method.

1. Introduction

Using analytical methods, kinematics analysis and static equilibrium of a 1-dof planar mechanism composed of five mobile rigid links and seven joints are developed in this paper. The value of a product can be interpreted using different methods, usually using the same common characteristics as: a level of performance, capability, emotional appeal, style etc. usually relative to its cost. This can be expressed as a maximum function of a product relative to its cost:

$$Value = (Performance + Capability)/Cost = Function/Cost \quad (1.1)$$

The value is not increased only by cost minimization but this must be done by increasing its function (performance or capability). This is the concept of functional worth which is important because it is not focused only on lowering the cost to provide a given function. The basic function of the product (which

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responds to the question “Why the product was made?”) defines the success of any product and the cost to perform that function is inversely proportional to its importance. But few people purchase consumer products based on their performance or based on the lowest cost of basic functions only, because when a product is purchased it is assumed that the basic function is operative and the attention is directed to those visible secondary support functions or product features, which determine the worth of the product. Secondary functions which are incorporated in the product enhance the basic function and help sell the product. The primary objective of value analysis or function analysis is to improve the value of the product by reducing the cost-function relationship by eliminating or combining as many secondary functions as possible. One of the methods to implement value analysis is FAST (Function Analysis System Technique) created by Charles Bytheway [1]. FAST permits people with different technical backgrounds to communicate and resolve multi-disciplinary issues and builds upon value enhancement by linking the simply expressed, verb-noun functions to describe complex systems. FAST contributes significantly to the most important phase of engineering which is the function analysis by creating the FAST diagram or model. Using the verb-noun rules in function analysis, a multi-disciplinary and multi-technological language is made. With this method the built models or the results are no right or wrong because the focusing is on the problem solving. The designed process is finished when the product designers are satisfied and the real problem is identified.

2. Creating a FAST model

The FAST model has a horizontal directional orientation based on an HOW-WHY dimension (HOW and WHY questions are asked to structure the logic of the system's functions). In the designed process, the questions HOW that function is performed to develop a specific approach is asked. The question WHY is asked that function performed to abstract the problem to a higher level.The FAST model has a vertical orientation described as WHEN direction, which is not a time orientation, but indicates cause and effect.

The boundaries of the study are the scope lines and the objective or the goal of the study is called the "Highest Order Function", which is located to the left of the basic function(s) and outside of the left scope line. Any function to the right of another function is a "lower order" function and represents the purpose of the product or process under study and it is called Basic Function(s). This function, once determined, will not change because if the basic function fails, the product or process will lose its value.After giving description of the functions which define and dimension the product it is important to associate information to those functions. So, the FAST dimensions can include, but are not limited to the following information: budgets, costs, responsibility, subsystem groupings, placing quality control and test points, manufacturing processes, positioning design reviews and others. In the next chapters of the article, the technological value analyses based on the model presented in the figure 2.1 will be made.

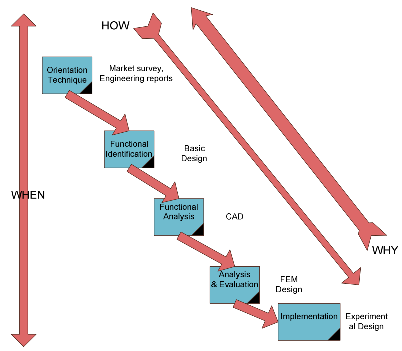
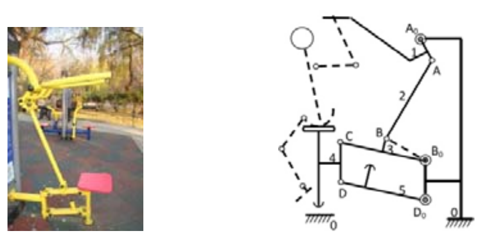


Fig. 2.1 Fast model from the mechanism used in amusement parks

3. Basic design

Having the kinematic mechanism the functional parameters scheme can be calculated. There are many papers with the mechanism kinematics modeling [9-10]. We use in this paper a simple method to analyze the mechanisms from amusement parks starting with the mobility degree calculus which can be realized using kinematics scheme (Fig. 3.1 b) and formula (3.1).



a) *b)*

Fig. 3.1 a) The mechanism b) Kinematic scheme of planar kinematic elements mechanism used as fitness equipment

$$M = (6-f)\cdot n - \sum_{k=1}^{5}(k-f)\cdot C_k = (6-3)\cdot 3-(5-3)\cdot 4 = 1 \qquad (3.1)$$

in which:

f - represents the mechanism's family (in the studied case, f = 3);

n - the number of mobile elements (n = 3);

k - the number of constraints (k = 5);

C_k - the number of kinematic couples of k order (C_5 =4).

The degree-of-freedom value of the mechanism can also be given, using the Grübler-Kutzbach criterion expressed by the general equation

$$M = \lambda (N - J - 1) + \Sigma Fi = 1 \quad (3.1.1)$$

with the notations

$\lambda = 3$ - degree of freedom of the space in which the mechanism is intended to function

N = 6 - total number of links in the mechanism, including the fixed link

J = 7 - total number of joints

$\Sigma Fi = 7$ - total number of relative motions permitted by joints

Starting from the formula 3.1, the mechanism was analyzed from the kinematic point of view, using the method developed by several authors, [2-6] and taking into account the following dimensions of the kinematic elements: AB=0.80; $B_0B=A_0A=0.15$; $D_0D=B_0C=0.35$; $B_0D_0=CD=0.25$; $B_0C= B_0B$ $XA_0=0$; $YA_0=0$; $XB_0= XD_0=0.1$; $YB_0= -1.0$; $YD_0= -1.30$ ω1=0.01. The movement of the mechanism is constrained by the angle Φ1 that vary between 240^0-260^0. The vector equations are:

$$\bar{r}_A + AB \cdot \bar{u}_2 = \bar{r}_{B_0} + B_0B \cdot \bar{u}_3 \quad (3.2)$$

$$\bar{r}_C + CD \cdot \bar{u}_3 = \bar{r}_{D_0} + D_0D \cdot \bar{u}_3 \quad (3.3)$$

The position equations of RRR dyads are obtained by projecting the vector equations on the axis:

$$\begin{aligned} &x_A + AB\cos\phi_{20} - x_{B_0} - B_0B\cos\phi_{30} = 0 \\ &y_A + AB\sin\phi_{20} - y_{B_0} - B_0B\sin\phi_{30} = 0 \\ &x_C + CD\cos\phi_{40} - x_{B_0} - D_0D\cos\phi_{50} = 0 \\ &y_C + CD\sin\phi_{40} - y_{B_0} - B_0B\sin\phi_{50} = 0 \end{aligned} \quad (3.4)$$

According to the angular positions, one determins the angle ϕ_{10} and the angular positions ϕ_{20}, $\phi_{30}, \phi_{40}, \phi_{40}$ which represent the unknown kinematics elements of relation (3.4). To calculate these positions, a mathematical calculation model developed by us using specialized software has been used [6], [7]. The results are graphical by represented in Fig. 3.2-3.3.

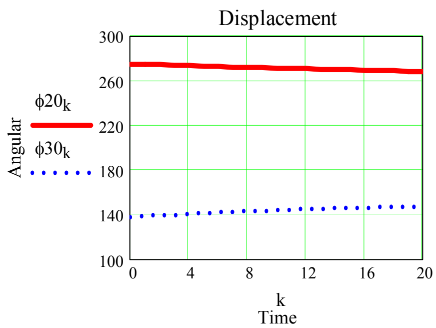


Fig. 3.2. Parameters of the dyad (2,3)

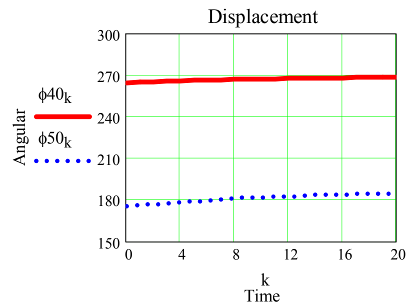


Fig. 3.3. Parameters of the dyad (4,5)

The force of gravity is applied on a simple element (Fig. 3.3) and is acting in the center of gravity with the direction on the vertical axis, direct proportional of the mass.

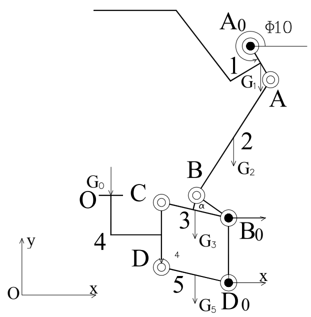


Fig. Fig. 3.3. Force of gravity of the elements of the mechanism

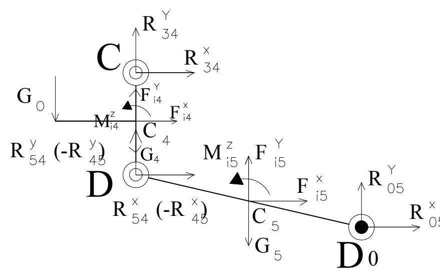


Fig. 3.4. The static kinetics model of the dyad (4.5)

The static kinetics model of the dyad (4.5) - RRR is shown in Fig. 3.4.

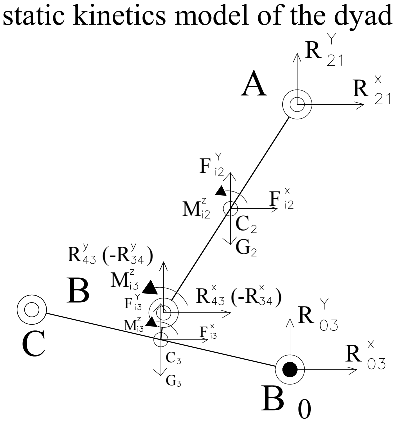


Fig. 3.6. The static kinetics model of the dyad (4.5)

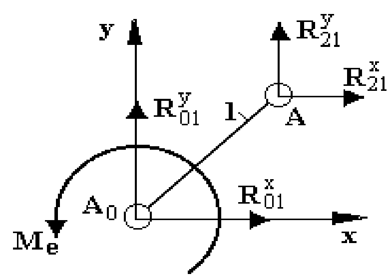


Fig. 3.8 The static kinetics model model of the crank

Static equilibrium equations for each element are:

$$R_{34}^{x} + R_{54}^{x} + F_{i4}^{x} = 0 \quad R_{05}^{x} - R_{54}^{x} + F_{i5}^{x} = 0 \quad R_{05}^{y} - R_{54}^{y} + F_{i5}^{y} - G_5 = 0 \quad R_{34}^{y} + R_{54}^{y} + F_{i4}^{y} - G_4 = 0$$

$$R_{34}^{x}\cdot CD\sin\varphi_4 - R_{34}^{y}\cdot CD\cos\varphi_4 + F_{i4}^{x}\frac{CD}{2}\cdot\sin\varphi_4 - (F_{i4}^{y}-G_4)\frac{CD}{2}\cdot\cos\varphi_4 + M_{i4}^{z}=0$$

$$R_{05}^{x}\cdot DD_0\sin\varphi_5 - R_{05}^{y}\cdot DD_0\cos\varphi_5 + F_{i5}^{x}\frac{DD_0}{2}\cdot\sin\varphi_5 - (F_{i5}^{y}-G_5)\frac{DD_0}{2}\cdot\cos\varphi_5 + M_{i5}^{z}=0 \qquad (3.6)$$

For this mechanism it was taken into account a man's body mass of 100 [kg] and a force applied on the element 1 which is a force developed by the muscles of the user (between 30-40 N) obtaining a variation mode of reaction forces in time (crank position) presented in Fig 3.5a-b.

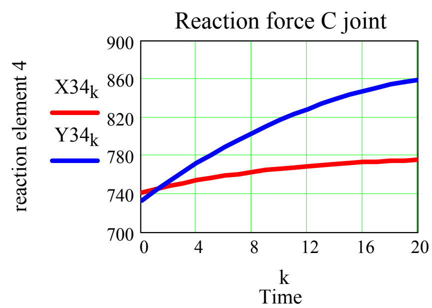


Fig. 3.5. a) Reaction of the element 4

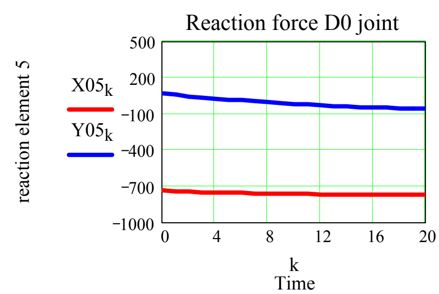


Fig. 3.5.b) Reaction of the element 5

Based on the static kinetics model of the dyad 4.5 it was obtained the model of the dyad (2.3) - RRR which is shown in Fig. 3.6., applying the formula (3.7) and the results being graphical presented in Fig 3.7a-b:

$$R_{12}^{x}+R_{32}^{x}+F_{i2}^{x}=0\quad R_{12}^{y}+R_{32}^{y}+F_{i2}^{y}-G_2=0\quad R_{43}^{x}-R_{32}^{x}+F_{i3}^{x}=0\quad R_{43}^{y}-R_{32}^{y}+F_{i3}^{y}-G_3=0$$

$$R_{12}^{x}\cdot AB\sin\varphi_2 - R_{12}^{y}\cdot AB\cos\varphi_2 + F_{i2}^{x}\frac{AB}{2}\cdot\sin\varphi_2 - (F_{i2}^{y}-G_2)\frac{AB}{2}\cdot\cos\varphi_2 + M_{i2}^{z}=0$$

$$R_{43}^{x}\cdot BB_0\sin\varphi_3 - R_{43}^{y}\cdot BB_0\cos\varphi_3 + F_{i3}^{x}\frac{BB_0}{2}\cdot\sin\varphi_3 - (F_{i3}^{y}-G_3)\frac{BB_0}{2}\cdot\cos\varphi_3 + M_{i3}^{z}=0 \qquad (3.7)$$

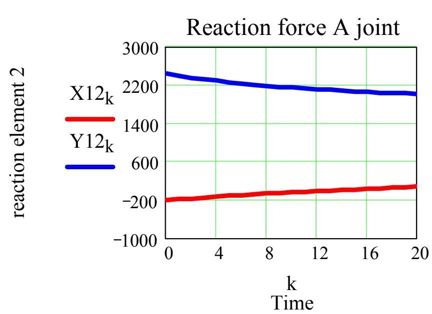


Fig. 3.7.a) Reaction of the element 2

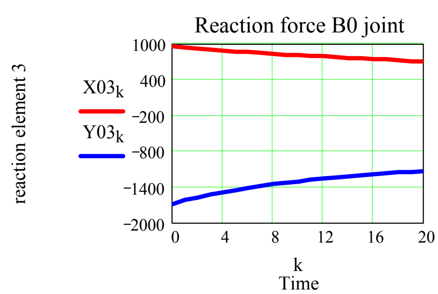


Fig. 3.7.b) Reaction of the element 3

Based on the two model presented here the static kinetics model of the crank was modeled in Fig. 3.8 using the following static equilibrium eq. (3.8):

$$\sum M_{A_0}=0 \quad \Rightarrow \quad M_e + R_{21}^y \cdot x_A - R_{21}^x \cdot y_A = 0 \qquad \sum F^x = 0 \quad \Rightarrow \quad R_{01}^x + R_{21}^x = 0$$
$$\sum F^y = 0 \quad \Rightarrow \quad R_{01}^y + R_{21}^y = 0 \qquad (3.8)$$

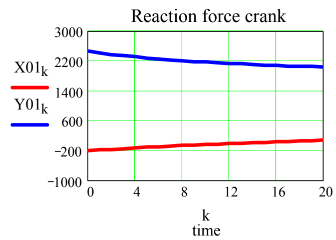


Fig. 3.6.a) Reaction of the element 2

Based on the basic modeling presented here we can conclude the following:

- the mechanism has the desired mobility:
- using the force of the arms (the actuation mean) the body will be lifted.
- we obtained the reaction forces in each joint which can be used in structural design.

4. Structural and FEM design

After achieving and analyzing that the mechanism works (basic design) we are going to build a 3D model of the mechanism (Fig. 4.1) aimed to be used in a FEM program iteratively modifying the dimensions of the elements, but keeping the lengths of the elements.

In order to realize the static analysis of fitness mechanism, a FEM software was used [8]. The material is a plain carbon steel with the specified properties in Table 1. This material has been chosen because it is very cheap and easy in manufacturing. For each element it was settled the fastening mode which allows obtaining a statically determined system which is graphical presented in Fig. 4.1-4.4. As input a user weighting 100 [kg], mounted on the element 4 and an inertia-traction force F_t=40N have been chosen.

Table 1

Material Proprieties

Property Name	Value	Measurement Unit
Elastic Modulus	210000	N/mm^2
Poissons Ratio	0.28	N/A
Shear Modulus	79000	N/mm^2
Density	7800	kg/m^3
Tensile Strength	399.83	N/mm^2
Yield Strength	220.59	N/mm^2
Thermal Expansion Coefficient	1.3e-005	/K
Thermal Conductivity	43	W/(m·K)
Specific Heat	440	J/(kg·K)

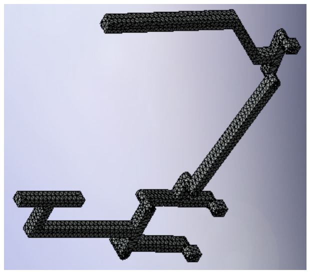


Fig. 4.1. 3D model Mesh

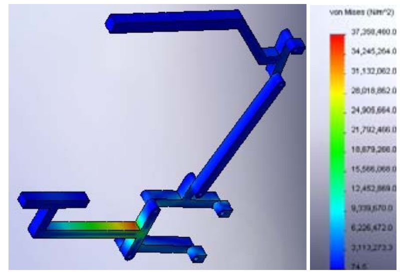


Fig. 4.2. Static analysis of the whole mechanism - Stress

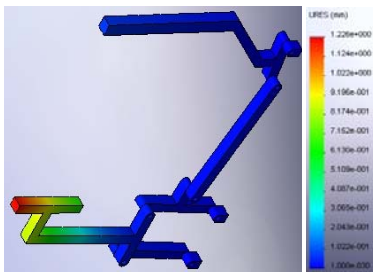


Fig. 4.3. Static analysis of the whole mechanism - Displacement

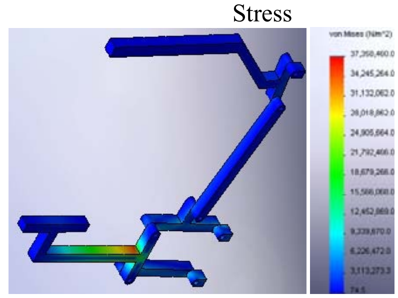


Fig. 4.2. Static analysis of the whole mechanism - Strain

The presented FEM analysis was used to design the effective dimensions of the mechanisms. Based on this analysis we can proceed to the final analyses of our FAST model namely sustainable design.

5. Sustainable Design

In this analysis, we used the model obtained in FEM analyses and the following starting parameters: the weight of the whole mechanism is 19.75 [kg] (obtained from Structural and FEM design presented before), manufacturing time considered from the starting of the manufacturing to the time the product is available in shops - 30 days, time of life - 3 years. The Sustainable Design is taking into account 6 different analyses (Fig. 5.1):

1-4 System manufacturing represents the cycle of manufacturing processes that converts materials into parts and products and starts immediately after the raw materials are either extracted from minerals or produced from basic chemicals or natural substances and consists of the following sub-processes:

- raw material extraction (it is not taken into account because the manufacturing process is starting after the process of obtaining the raw material),

- material processing (for this analysis was taken into account that the components were obtained by casting). Usually, the processing materials are presented as series of operations that transform industrial materials from a raw-material state into finished parts or products. Metallic raw materials are usually produced in two steps. First, the crude ore is processed to increase the concentration of the desired metal, typical beneficiation processes include series of operations which are crushing, roasting, magnetic separation, flotation and leaching. Second, additional processes such as smelting and alloying are used to produce the metal that is to be fabricated into parts that are eventually assembled into a product. The processes used to convert raw materials into finished products perform one or both of two major functions: first, they form the material into the desired shape; second, they alter or improve the properties of the material.

- part manufacturing (all components of the product are manufactured in Europe),
- assembly (was done by welding).

For manufacturing analyses it is necessary to select a manufacturing region to determine the environment impact of the energy sources and technologies used in the modeled built for the steps of the life cycle of the product.

5 We take into account the *product use* because the analysis has assessed the environmental impacts during use and this type of system is void and must be assessed for maintenance costs. Because this mechanism is designed to be used three years, maintenance costs are 0.

6 Another important parameter set is *end of life* which refers to the average in using and has a direct impact on the efficiency of investment. In this sense, the product is used for a longer time and its depreciation can be set to a small value. All the components of the product will be recycled 100% because carbon steel is used which can be casted after the end of life of the product.

The Environmental Impact of the manufacturing process (calculated using TRACI impact assessment method) is presented in graphics in Fig. 5.2-5.5.

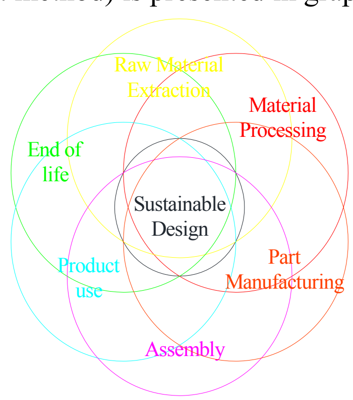


Fig. 5.1 Sustainable Design

Once setting the impact areas, which are worth to looking at them, whether because of the significance, whether because their differences from alternatives or other reasons, the next step is to look for ways to reduce those impacts effectively as possible. In many cases, there are certain elements of the design or product life cycle that generate most of the impact. It's often given the classic example of the 80/20 rule, that 20% of the design has an impact of 80% to the whole quality of the product. The four major areas taken into account by TRACI method regarding the environmental impact are carbon emissions, polluted air, used water and consumed energy, provided by a top of six components of the mechanism that are presented in Table 2.

Tabel 2

Environmental Impact

Component	Carbon	Water	Air	Energy
Part 6	110	9.2E-3	33	1300
Part 5	48	4.1E-3	15	600
Part 4	33	2.8E-3	10	410
Part 3	26	2.2E-3	8.1	320
Part 2	13	3.8E-3	2.0	270
Part 1	2.5	3.5E-4	0.535	34

One of the main impact and concern in manufacturing of the product by casting is the carbon footprint which represents the carbon-dioxide and other gases which result from the burning of fossil fuels accumulate in the atmosphere which in turn increases the earth's average temperature, see Fig.5.2. Carbon footprint acts as a proxy for the larger impact factor referred to as Global Warming Potential (GWP). Global warming is blamed for problems like loss of glaciers, extinction of species, and more extreme weather, among others.The total energy consumed is another important environmental concern and provide a quantification of the non-renewable energy sources used and associated with the part's lifecycle in units of mega joules (MJ), see Fig.5.3. This impact includes not only the electricity or fuels used during the product's lifecycle, but also the upstream energy required to obtain and process these fuels and the embodied energy of materials which would be released if burned. Efficiencies in energy conversion (e.g. power, heat, steam etc.) are taken into account.

Regarding air acidification (sulpfur dioxide, nitrous oxides and other acidic emissions to air) which is graphical by presented in Fig.5.4, this causes an increase in the acidity of rainwater, which in turn acidifies lakes and soil. These acids can make the land and water toxic for plants and aquatic life. Acid rain can also slowly dissolve manmade building materials such as concrete. This impact is typically measured in units of either kg sulpfur dioxide equivalent (SO_2) or moles H^+ equivalent. When overabundances of nutrients are added to a water ecosystem, eutrophication occurs, this process being known as "water eutrophication" (Fig.5.5). Nitrogen and phosphorous from waste water and agricultural fertilizers causes an overabundance of algae to bloom, which then depletes the water of oxygen and results in the death of both plant and animal life. This impact is typically measured in either kg phosphate equivalent (PO_4) or kg nitrogen (N) equivalent. The most precise and objective metrics come in the form of specific numbers representing impact levels. These usually take two forms, one impact-specific and the other a standardized conversion into a single proxy number.

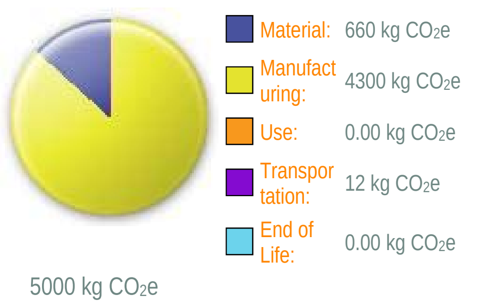


Fig. 5.2. Carbon Footprint

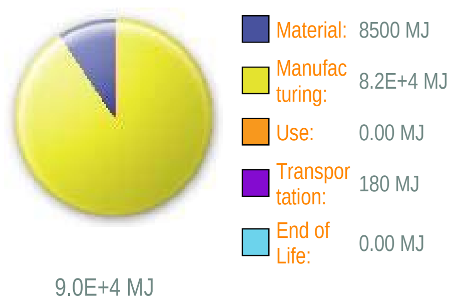


Fig. 5.3. Total Energy Consumed

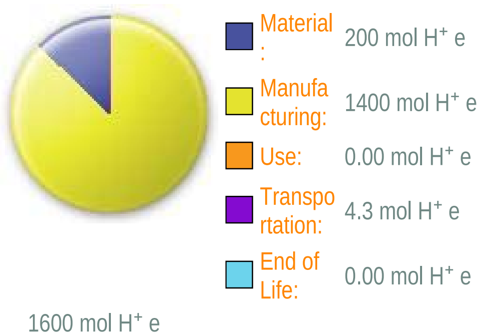


Fig. 5.4. Air Acidification

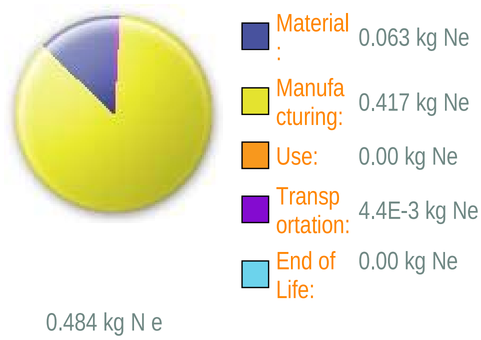


Fig. 5.5. Water Eutrophication

The impact-specific metric is usually expressed in equivalencies of a certain key component of that impact, such as kilograms of CO_2 for global warming. In this case, no matter what the source of the impact on global warming, it would be converted into the equivalent kilograms of CO_2 (often written as "kg CO_2e," "kg-eq CO_2", "kg-eq CO_2" etc.) using standardized equations. The advantage of variable weighting approaches is that they can be customized to fit an organizations goals and values. For instance, one of our analysis priorities is global warming. As long as the weighting remains constant within its own assessments, the disproportionate weight it gives to this category is fine. In some cases, there may be external reasons for giving some impacts priority. For instance, there are some sustainability accounting and reporting standards that focus almost exclusively on greenhouse gas emissions, making it useful for organizations using them to put most, if not all, of the weight on that subset of impact factors. Of course this works in reverse if the company doing the sustainable design is a supplier itself. By generating parts that take into account environmental impact, they are influencing the sustainability of downstream products. It also makes it easier to comply with any impact requirements or guidelines the customer may have.

6. Conclusions

This paper aimed to use a method technological value analyses of mechanisms used in amusement parks using the FAST method. These researches have been carried within the PhD program POSDRU60203. Although one of the main challenges of these mechanisms was complexity, there were taken into account the technological and economic approaches, the impact on the environment named “sustainable development”, having an important role. The overview on the research methodology had as a final result the evaluation of the added value of the product. The future works will focus on the validation of the approach described above, also finding new experimental methods which can validate this one.

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