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Vehicle's energy efficiency via pilot work's efficiency in Shell Eco-marathon competition

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Abstract. Shell Eco-marathon is a competition about energy efficiency and the first thing one have to do, is to design and build lightweight, aerodynamic vehicle with fine mechanical transmission and tires with low rolling resistance. Depending on power unit type, there is a need of perfect way of transforming chemical or electrical energy to mechanical one. In addition, almost every team develops their own driving strategy, applied by the pilot in the competition. Doing this, in the best way they can do, most competitors decide before-mentioned is the maximum, but if one can look to the vehicle plus the pilot like a system, there is more possibilities for improving the efficiency of that system. This paper includes analysis of vehicle control functions and specific organizational distribution and design of vehicle's controls, in accordance with the capabilities of the pilot.

1. Introduction

In the history of mankind all types of vehicles: ground, marine and aerial were design and build to multiply human abilities in transportation of materials, goods, people etc. There were, there are and there will be extreme examples of that vehicles with no utilitarian but specific function: scientific, research, sport competition, which helps people to extend their knowledge about the nature and the man as part of it.

Shell Eco-marathon is competition with extreme, efficient vehicles, which are built with and use for their movement minimum natural resources.

2. Analysis of vehicle control functions

Every vehicle is a mechanical system, which main function is: movement and main sub functions are: steering – giving direction of moving; acceleration – getting from state of resting to state of moving or getting to move rapidly; deceleration (braking) – getting from state of moving to state of resting or getting to move slowly. Without control of those sub functions, state of movement will be impossible or chaotic. While the steering must be applied permanently without interruption through the whole process of movement, acceleration and deceleration have to be applied successively without overlapping and discretely.

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2.1. Steering

Steering is the sub function which needs most of all precision. That's why almost every vehicle is steered by hands, or by hands and foot in addition.

There are exotic examples of vehicle steering with arms, legs or weight of the driver. Sledge is one of them.

To steer the sled, the slider uses his or her calves to apply pressure to one of the runners, deforming it slightly in turn direction, or shifts their weight sideways using their shoulders (Figure 1).

Figure 1. Lugers on double sled [1]

Historical sight in watercraft and ground vehicles will show that first steering control was simply lever called tiller. It was used in the first and not big in dimensions watercrafts and ground vehicles. Tiller provides leverage in the form of torque for the helmsman (Figure 2) or the driver (Figure 3) to turn the device that changes the direction of the vehicle, such as a rudder on a watercraft and the wheels on cars and two or three wheeled vehicles. Bicycles and motorcycles use some kind of double tiller called handlebar (Figure 4).

Figure 2. Boat tiller [1]

Figure 3. Tiller on a car [1]

Figure 4. Bicycle's handlebar [1]

In bigger vehicles the force to operate the tiller is bigger too and at one point it is impossible for human being alone to steer the vehicle. The solution is to use intermediate leverage or reducer between the control and steering device. In this case the force to steer the vehicle becomes smaller but the movement of the control becomes bigger and as a rule there is not enough space for this. Using wheel (boat's wheel (Figure 5) or steering wheel (Figure 6)) as a control solves this problem.

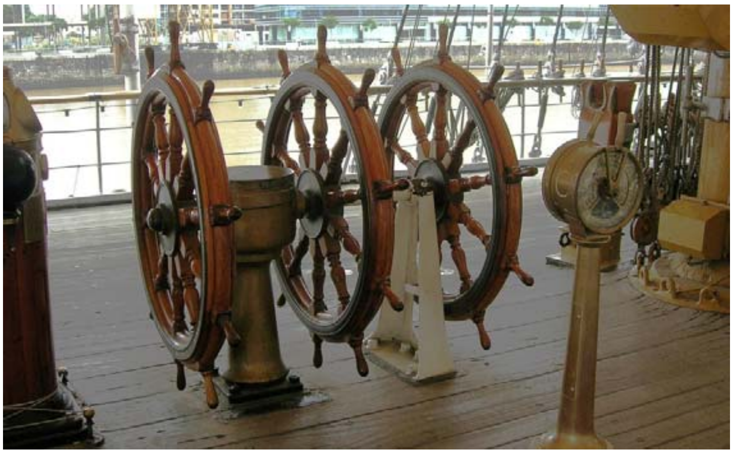

Figure 5. Boat's wheel. [1]

Figure 6. Steering wheel of a car [1]

In modern vehicles the use of power steering or drive by wire systems, with hydraulic or electric actuators, size of the wheel becomes smaller or even is replaced by joystick (Figure 7).

Figure 7. Joystick in a car [2]

Analysis of human-machine interaction [3] and steering sub function of a vehicle in detail can be made and one can see the following:

The grasp of standard car and truck steering wheels is variable and has three main variants:

- Basic - the steering wheel is hold with the whole hand - all fingers and palm are involved.
- Grasp for operating the controls behind the wheel - the thumb and palm are constantly involved in steering and the other fingers are used either to work with the controls or for additional holding, to help the palm.
- Grasp for operation with the controls on the front of the steering wheel - the palm and four fingers are involved in steering without the thumb, which works with the controls.

The grasp of motorcycle and bicycle steering controls is variable, and there are three main variants too:

- Basic - the steering wheel is hold with the whole hand - all fingers and palm are involved.
- Grasp for operating the controls in front of the handle - the thumb and palm are constantly involved, and the other fingers are used either to work with the controls or for additional holding, to help the palm.
- Grasp for operating the controls on the inner side of the handle - involves the palm and four fingers without the thumb, which works with the controls.

Acceleration and Deceleration are sub functions which need precision only in ground vehicles, because of the character of the environment of moving.

2.2. *Acceleration*

In common case sub function - acceleration is linked with process of active moving when the driver have intention to move faster or to keep moving with constant speed (when acceleration equals to zero). This means that handling the controls of acceleration is constant thru the process of moving such like the handling of the control of steering and consequently controls of acceleration is possible to operate with the same limb only if the operator have constant contact with both controls – steering and acceleration. This requirement is fulfilled in motorcycles and other light vehicles where the steering is conducted by handlebar where in the process of steering motorcyclist as a general rule have to keep his /her hands on the handlebar permanently, instead car driver have to grasp the steering wheel alternatively with right and left hand during bigger turn. These are the reasons, we have the control of acceleration – in form of a pedal, operated by foot in the cars and twisting handle or small lever operated by hand or thumb in the motorcycles.

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2.3. *Deceleration (Braking)*
This sub function refers to passive part of moving where the vehicle decreases its speed when no engine power is supplied due to different drag forces or when active brake force is applied to the vehicle. This function is randomly used and in most of the cases when the vehicle is moving straight forward (not in a turn). This means that one can use any limb, doesn't matter it is used in steering or not, to operate this function in sense of overlapping actions. Another important moment in the process of choosing how to operate brake controls is the force needed to. That's why in bigger ground vehicles like cars and trucks (especially before the invention of servo systems) logical choice was leg to operate brake controls and in small two to four wheeled vehicles hand or hand and foot because of the combinations with other controls.

3. Analysis of Shell Eco-marathon prototype class vehicle control functions

3.1. *Shell Eco-marathon rules*
In Shell Eco-marathon 2019 Official Rules, Chapter I, one can read:

"ARTICLE 42: TURNING RADIUS AND STEERING

a) Only front wheel steering is permitted. If the Organisers are not satisfied with the effectiveness and/or control of a vehicles steering system, this vehicle will be removed from the competition.

b) The turning radius must be 8 m or less. The turning radius is the distance between the centre of the circle and the external wheel of the vehicle. The external wheel of the vehicle must be able to follow a 90° arc of 8 m radius in both directions. The steering system must be designed to prevent any contact between tyre and body or chassis.

c) Electrically operated indirect steering systems are permitted providing they are operated by a steering wheel or similar (rotary potentiometer), joystick operation is not permitted. If electronic steering systems are used, in the event of system failure, the vehicle must be equipped with manual steering override.

…

ARTICLE 43: BRAKING

a) Vehicles must have with two independently activated braking systems; each system must comprise of a single command control (lever or foot pedal), command transmission (cables or hoses), and activators (callipers or shoes). Brakes that act on the tyres are not permitted.

i. One system must act on the front wheels, the other must act on the rear wheel(s). For the front wheels, there must be one activator (calliper or shoe) for each individual wheel, with both activators commanded by the same command control. In addition, the right and left brakes must be properly balanced.

ii. The rear system must act on each wheel, unless they are connected by a common shaft in which case, they can have a single system.

iii. It must be possible to activate the two brake systems at the same time without taking either hand off the steering system.

…

d) A single foot-operated hydraulic brake is recommended for the front wheels. For 2020, foot-operated front brakes will be required." [4].

3.2. Battery - electric prototype specific features
Battery electric prototype propulsion system usually consist of electric motor, one-way clutch, transmission and driving wheel. In this case there is need of only one control – accelerator and there is no need of clutch control.

The vehicle has as a rule three wheels two in front and one at the rear. Tyres' plane of rotation should be strictly perpendicular to the ground thru the movement for minimal rolling resistance.

For the DTT-3 battery – electric prototype of University of Ruse, team "Avtomobilist" geometric parameters are:

wheelbase - 1450 mm
front track – 510 mm.

To fulfil Article 42, “a” and “b”, turning angle of the front wheels must be 9.96 deg for the outer wheel and 10.60 deg for the inner one.

3.3. Requirements for the sub-functions performance

Because of the small turning angles needed for front wheels and relatively small mass of the vehicle and the pilot (between 70 and 85 kg) steering control could be something like handlebar rather than steering wheel. Accelerator control could be operated with hand or foot. Front brakes foot operation is mandatory (Article 43, “d”) and rear brake control could be operated with hand or foot.

Proper organization and distribution of these controls is the base for fast and precise, in other words effective way of driving the vehicle [5].

4. Concept for the controls

4.1. Distribution

To eliminate errors in the processes of acceleration and deceleration, which results in loss of energy or can provoke accidents, one can decide to separate these two controls between different limbs. And once the front brakes are mandatory to be operated with foot, it’s logical and natural to operate rear brake with foot too. This is the reason why in DTT-2 and DTT-3 vehicles front and rear brake controls, are in form of a foot pedal.

Steering and acceleration which needed highest possible precision was decided to be operated with hands and fingers.

4.2. Organization

Taking in account that fact that more people are right-handed (and pilots in the “Avtombilist” team too) front brake control is operated with right foot for bigger precision and sensitivity and rear brake control is operated with left foot like emergency brake used in addition to the front brake or separately.

For the same reason acceleration control is oriented to the right hand and fingers.

There are additional sub functions that are very important for safety reasons – horn, for example which can be operated with fingers.

4.3. Construction

Compared to the motorcycle and car steering controls in the new steering wheel, the *main concept* is that the grasp has only one variant: *ulnar-palmar grasp* (Figure 8) and is performed only by the ring finger and the little finger (in which the ulnar nerve ends) and the palm of the hand. The thumb, forefinger and middle fingers operate on the controls or complement the grasp.

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Figure 8. Ulnar-palmar grasp of the steering control

The steering wheel consists of three main elements: left and right handles and a main body. The handles lie on opposite sectors of the thought circle passing through them. The three elements are connected into whole one by means of transversely located on each handle a bridge connecting the middle of the handle with the upper end of the main body. In this way, the handles acquire a T-shape, turned horizontally. In the lower part the zones for realization of the ulnar-palmar grasp are formed, and in the upper part - zones for placement of controls (buttons) and surfaces for supplementing the grasp (Figure 9).

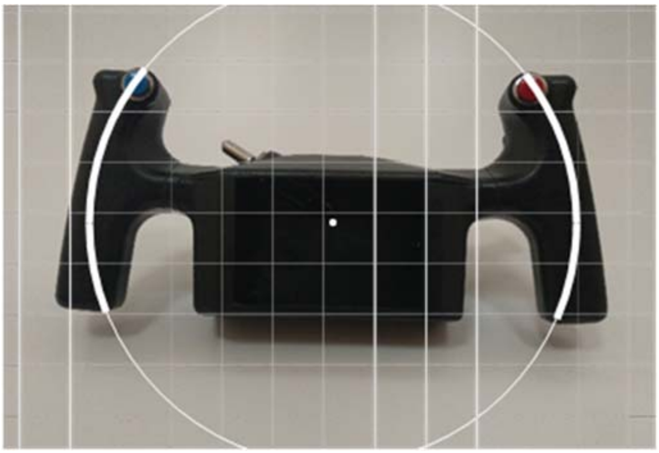

Figure 9. New steering wheel

According to scientific studies [6] [7] [8], control and display locations must be determined very carefully for both accuracy and safety reasons. In this extreme but not complex case, controls and display were arranged in a way of avoiding action overlap in a process of controls use by analysis of timing of action.

On the front wall of the main body there is a display, located at an angle to the axis of the steering shaft for better visibility. In the central part of the rear wall of the housing there is a flange element with oval (slot) holes arranged in a concentric circle, designed for fine adjustment of the position of the steering wheel relative to the steering shaft (Figure 10).

Figure 10. Steering wheel - features

Behind the right handle, a finger pedal is positioned for controlling the speed and acceleration of the vehicle, and it is operated with forefinger and middle finger simultaneously (Figure 11) [9].

Size and all dimensions of the steering wheel are consistent with ergonomic requirements. [10]

Figure 11. Accelerator control operation

5. Conclusion

The steering wheel is designed for precise and safe driving of the vehicle by:

- All operations with the controls can be performed without leaving the steering wheel grasp ensuring that it can be gripped continuously with both hands without the need to release it when performing other basic or additional activities in the steering process;
- The controls are positioned to require minimal effort and movement from parts of the human body, which reduces fatigue and therefore improves driving efficiency and safety.
- Every control is operated with different limb or finger, or combination of them that leads to situation of coding control commands by place, by executable part of the human body and by it specific movement during the operation which is base for a faultless and efficient driving.

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