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Investigation on optimal mobility system using Axiomatic Design and Scoring Matrix: the “Drive Ability” experiment

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Abstract

The increase in the global population and the improvement of the life style of many poorer countries are leading to a relevant growth for mobility. Such increase in circulating vehicles would have a negative impact on environment pollution. Given this picture, the traditional internal combustion engine vehicles could not be the best solution for the future personal mobility. This problem is really critical especially for high population density cities, such as Firenze (Italy), where the large number of circulating vehicles must use a very old infrastructure that is constrained by all the historical sites widespread in the city, that are also very sensitive to air pollution. However, choosing between the possible mobility solutions could not be an easy task, also if using a structured approach. The challenge is, in fact, to assess a large number of variables for different solutions, process that could lead to a situation where all scenarios show pros and cons, and so all matrices will be decoupled and will not be possible to define which solution is the best. The aim of this paper is to define a new approach, based on a Scoring Matrix and on the Axiomatic Design, which overcomes this issue by using a multi-criteria evaluating strategy. This new approach has been tested on the city of Firenze (Italy) where the optimal mobility paradigm has been assessed from the sustainability point of view. As a result, the wireless charging system has been identified as the most suitable for the city and citizen needs. In addition, Axiomatic Design has been used to define how to overcame the technological barriers for its introduction: wireless charging introduction, in fact, could experience a stop due to the efficiency loss in case of misalignment. In this paper, the scenarios are introduced using the Axiomatic Design decomposition tree and the solution has been tested by using the information axiom.

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Introduction

In the last years the relevance of environmental impact of vehicles has experience a strong increase due to the approval of the new directives of the Kyoto protocol, the tests that prove effects on human health [1] and the more than ever evident corrosive effect on monuments and historical masterpieces [2]. This problem affects greatly the larger Italian cities: in fact, their historical centers often suffer for the centuries old road infrastructure that is usually responsible for traffic congestions and local pollution increase. One important example is the city of Firenze [4], where 5 km^2 of the city center has been declared UNESCO site and hosts a large number of historical buildings together with an high population density. Moreover the high concentration of tourists led to the need of mobility specifically in these historical areas, where the economy growth [5] is strongly related to the touristic presence. Another incentive purse a shift to an electrical based mobility is the ever increasing cost of fossil fuel: in the last years, gasoline and diesel have suffered a strong increase in their costs and alternative fuels can’t completely replace traditional ones at the actual state of technology [6]. Nowadays the available electrical mobility solutions have still some open issues that limit their mass introduction in the market. Probably the most limiting constraint is the battery autonomy and very high replacement costs, but also the lithium production can be an interesting challenge to be addressed [7]. For this reason, research is going to develop more performing solutions and strategies to overcome these limitations. To design a new mobility paradigm, however, is not an easy task; in fact, structured approaches are very useful when the parameters to be assessed are few. The aim of this paper is to introduce a new approach able to manage a large number of choosing

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parameters: the Scoring Matrix will investigate the most suitable mobility paradigm (screening approach) and then the Axiomatic Design will be used to go into design details.

1. Sustainability concept

A large number of studies have been performed to determine the optimal battery weight/volume for Pure Electric Vehicles (PEV), but they generally agree on the issue that the number of kilometers daily travelled are less than the capacity industrial battery equipped on PEVs [8]. In general, replacing the internal combustion engine with an electric one is the easier way to introduce electric vehicles in "all day life" and also the most similar to the traditional mobility model. Vehicle (electric/ICE vehicle) has a "tank" (the battery/the fuel tank) that is equipped on the vehicle and a fixed infrastructure (recharge columns/fuel stations) territorially distributed. However, at the actual state of the art, the speed to recharge the battery can't be compared with the speed to "recharge" the traditional fuel tanks and, most important, vehicles' battery energy density is extremely lower than fossil fuels one. These two limitations are strictly related to the sustainability of mobility. The definition of sustainability adopted in this paper includes both the environmental issues related to the vehicle pollution but also to the user acceptance; in general, a vehicle is not sustainable for an end-user if this introduce relevant limitations to his mobility or difficulties in its utilization [9]. In order to evaluate the best sustainable solutions among the available technologies, a Scoring Matrix that includes a larger concept for sustainability and provide a more objective analysis of the effectiveness of the studied solutions has been developed. The EV compared technologies are:

- Electric Vehicle with Internal Combustion Engine Range Extender.
- Electric Vehicle with Fuel Cell.
- Rapid Battery Change Station + Private Recharge with Columns.
- En Route Recharge System.

2. The Scoring Matrix

The data used to fill the matrix comes from literature [10] and from end users surveys.

The Scoring Matrix is a graphical representation of data where on the Y axis are reported "Choosing Parameters", "Direction of Improvement" and "Weighting system", on the X axis is reported the list of technologies to be evaluated as it is described in Figure 2 – *Part a* and *Part b*.. More in details:

- Technologies: the solutions to be evaluated.
- Choosing Parameters: the fundamental aspects to evaluate the performances of the different solutions. Later in this paper, developed parameters will be presented extensively. This model, however, also allows to add other if deemed important for the designer.
- Direction of Improvement: identifies if each parameter has a positive impact on the result if increasing (↑) or decrease sing (↓). i.e.: CO2 emission has a degradation effect on the environmental impact of mobility.
- Weighting System: weight for each parameter; it is a number between "0" and "1" and it is used to multiply the value of each parameter before calculating the final result. For the developed test, results of a survey on Firenze's inhabitants expressly built for the case study has been used.
- Values: performance values for each parameter and for each technology.

Once the matrix is filled, results are calculated. The results come from the following expression, for each column:

$$Score\ Technology\ j = \sum_{i=1}^{n} Parameter_i * Weight_i \quad (1)$$

with n=Number of Parameters.

The best technology will be the one with the highest value.

In addition, a diagram to relate the interactions between the parameters has been developed in order to understand the effect of parameters interaction. The relation diagram will be presented later on the paper.

3. The Parameters Tree

In this section the tree of parameters chosen to evaluate the different technologies are presented. To be sure that the parameters will cover all the important issues of the problem, a structured approach to find them has been used: the idea is to divide the macro-problem in sub-problems with increased level of details, according to the Axiomatic Design framework. It is important to notice that his is not a direct Axiomatic Design application, it is a preliminary study to identify the most promising solution to be deeply analyzed with the classic AD strategy and so it is not mandatory to use the zig-zag method. So, firstly two macro-areas have been defined dividing the parameters between "technical" and the ones that are relevant for customer satisfaction (they will be called from here "Technical" and "Customer"):

The technical ones will be strictly related to feasibility and costs and the customer ones will be the key factors to fast-forward the introduction of a new technology paradigm.

Afterwards, these two macro-categories have been divided in six more subsets; three more subsets for Technical parameters and three for Customer parameters. Technical parameters have been divided in "Feasibility", "Upgradeability" and "Environment", where the Customer parameters have been divided in "Satisfaction", "Delighters and "City Planning". More in details:

- Feasibility: numeric parameters related to the solution feasibility under the actual technological constraints.
- Upgradeability: Solution flexibility due to the technological continuous development. All the technologies are at early lifecycle stage, it is important understand the upgradeability (e.g. nanoscale supercapacitors with vs battery [15]).
- Environment: Environmental impact during all the product life cycle.
- Satisfaction: Key features needed by the customer; if this kind of properties are not guaranteed, the customer will never change his habits.