Advanced Research Strategy for Designing the Car of the Future

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Abstract: This paper describes a novel concept regarding the method for research and development of future vehicles. It is shown that the traditional rate of progress cannot keep up with the increasingly pressing issues of global warming and social sustainability. A new, holistic approach which takes into account the form, operation and social aspects of the future society is suggested. This approach tries to remove the boundaries between different sections of science and also accelerate the rate and speed of adoption of new technologies into the final, mass-produced vehicle. Such an approach can pave the way for the creation of a vehicle that reaches our goal of zero accidents and zero emissions.

Keywords: *Sustainable Transport, Social Sustainability, Future Mobility and Technology*

1. Introduction

The issue of global warming and its relation to human-induced emissions is well known. In 2009, both the European Union and G8 leaders agreed that CO_2 emissions must be cut by 80% by 2050 in order to stabilise the concentration of greenhouse gas (GHG) emissions in the atmosphere at a level of 450 ppm of CO_2 equivalent and keep global warming below the level of 2ºC. Transport accounts for about one-fifth of global energy use and one-quarter of energy-related CO_2 emissions [1]. To achieve the necessary deep cuts in greenhouse gas emission by 2050, transport must play a significant role and achieve 95% decarbonisation. Car ownership worldwide is projected to triple to over two billion by 2050 and, without strong global action, a respective growth of energy use and CO_2 emissions will occur [1]. Fig. 1 shows estimation for EU total greenhouse gas emissions. It can be seen that, following the baseline scenario which already includes large efficiency improvements, especially in industry, the emissions are expected to remain constant. The amount of additional effort that must be put in each sector in order to achieve the necessary emission cuts is clearly visible [2].

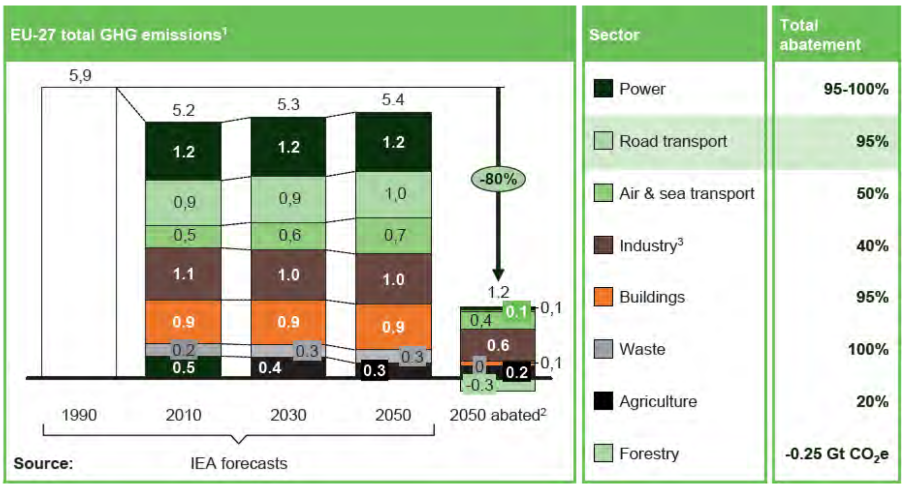

Fig. 1. EU total GHG emissions forecast for 2050 and comparison to target.

Similarly, annual global road-traffic fatalities sum to more than 1 million and injuries to more than 50 millions [3]. Awareness, technological advances and stricter legislation have lead to the reduction of injuries and fatalities in developed countries as can be seen in Fig. 2; however the increasing level of car adoption, especially in developing countries, means that the global number of fatalities and injuries is likely to increase [3]. The cost of road accidents, in both social and financial terms is not negligible. For example, the cost of fatalities in EU-27 during 2006 corresponded to approximately 2% of the total GDP [4].

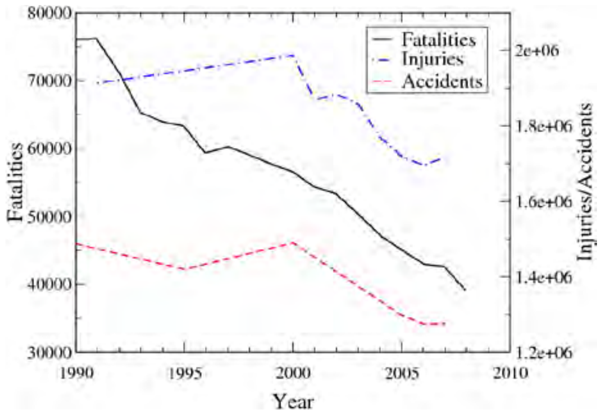

Fig. 2. Road accident statistics for EU-27 [5][6].

Current automotive technology improves at incremental steps, as conventional, long-existing concepts are optimised towards their theoretical limits. Compared to previous decades, current cars provide higher levels of safety and have a similar or lower environmental footprint at the same time. Stricter legislation and industrial competition have supported this trend by leading to the introduction of new or improved technologies in the course of the years. However, growing concerns of the climate change mean that this rate of progress is not viable, as shown in Fig. 1.

The introduction of the mass-produced automobile represented a revolution in affordable, highly flexible mobility and convenience. This flexibility makes its use appropriate especially in cases where large investments in mass transportation are not viable. Its usage has led to significant changes in society and has contributed to economic growth, supporting the growth of small and medium-size businesses over the years. Currently, transport is one of the backbones of European economy, accounting for about 7% of GDP and more than 5% of total employment in the EU. How can we continue to enjoy the benefits of car mobility in a sustainable way, without the associated risks of traffic accidents and accelerated climate change? In the following sections we try to share selected elements of our vision for research carried out in Toyota Motor Europe for creating the future image of automotive transportation, as well as the necessary technologies to make this sustainable. More specifically, in Section 2 we describe our research methodology. In Section 3 we outline our perceived image of the future car and present key technologies that will render it possible. Finally, in Section 4 we summarise our findings.

2. Research strategy

The automobile has evolved over several decades into a practical and reliable product by following a solid approach of thinking and engineering. This traditional approach is starting to become a limitation to the rate of further technology improvement, unable to keep up with the requirement for drastic changes shown in Section 1. The automotive industry is faced with a lot of challenges to deliver innovative products to its customers, and some will likely require a big innovation jump. Currently developed and emerging technologies need to be implemented in new vehicles rapidly, at a rate and on a scale that is unprecedented in the last 40 years of transport evolution. New technologies that deal with weight reduction, performance optimisation and efficient usage of energy resources need to be developed for reversing the trends of the past decades and achieving our targets in GHG emission cuts, without a negative impact on existing levels of quality and comfort. This will require answers to paradoxical questions such as how can we produce a vehicle which is extremely lightweight and completely safe at the same time? How can we manufacture a vehicle which provides complete freedom and pleasure to the driver and passengers, without any environmental impact? Such questions are indeed paradoxical when following the traditional way of thinking. A fresh, "out of the box" approach is therefore needed to provide answers and solutions which are realistic and feasible in a short timeframe compatible with our extremely challenging targets.

2.1. Limitations of current methodology

Before describing a new research strategy, we first reflect on the more than 100 year long automotive history in order to understand the logic and the potential of the current direction for improving the environmental performance of cars. Fig. 3(a) shows the history of average fuel consumption in Europe and the US for the period 1975-2002. In comparison, fuel consumption of the first mass-produced vehicle, Ford Model T, in 1908, was around 11-18 lt per 100 km [7]. It can be seen that after period of a relatively strong improvement in average fuel economy during the 70s, homologated consumption has roughly stabilised in the US and drops only slowly in EU. This can be explained by Fig. 3(b), which shows the relative evolution of vehicle mass, power and engine size in EU for the same period. It is clear that during the same period, vehicles have become heavier, more powerful and relatively faster. Increases in engine size and vehicle mass can partly be attributed to dieselisation (as diesel vehicles have a lower power/mass ratio), but even so it is evident that the trend for bigger, faster and theoretically safer cars has off-set the gains in efficiency.

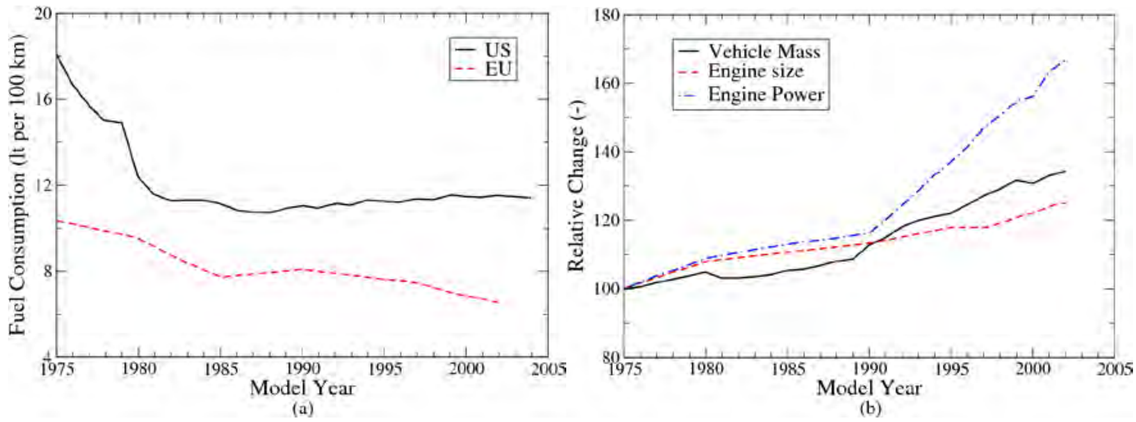

Fig. 3. Evolution of (a) US and EU motor vehicle economy from 1975 to 2003 and (b) average weight, power and engine size of new cars sold in EU from 1975 to 2002[8]

As a second example, Table 1 shows the evolution of a typical vehicle over the last decades. As specifications can vary a lot over different countries and model generations, some typical values are shown, corresponding to a compact sedan vehicle, with comparable acceleration performance. The trend of increasing weight and dimensions is obvious, with a current vehicle being more than 0.5 meters longer, and almost double the weight, compared to 40 years ago. It is also interesting to note that the average fuel consumption has had small fluctuations over the years, with significant reductions being achieved in the last decade, bringing us back to the levels of 1960's. These numbers also verify the findings of the average vehicle evolution trends, with the levels of safety and comfort improving considerably over the last decades at the expense of potential improvements in performance and fuel consumption.

Table 1. Evolution of Toyota Corolla Sedan typical specifications. Figures obtained from internal TME material.

Year	Length (mm)	Weight (kg)	Engine size (lt)	Power (kW)	Acceleration (s)	Cd (-)	CdA (m^2)	Fuel consumption (lt/100km)
1966	3848	700	1.2	50	13.7		0.6	6.4
1970	3945	801	1.4	63	11.6		0.61	6.82
1974	3995	930	1.6	61	12.6	0.43	0.776	7.92
1979	4048	821	1.5	55	11.5	0.43	0.798	7.51
1983	4135	920	1.6	62	11.6	0.37	0.696	7.22
1987	4191	955	1.6	70	11	0.33	0.62	7.22
1991	4270	1000	1.6	81	10.4		0.631	
1997	4295	1035	1.6	81	10.7	0.33	0.644	7.81
2000	4365	1125	1.6	81	10.3			
2006	4540	1310	1.6	97	10	0.3	0.73	6.4

The design and production of a car is a very challenging exercise, with many contradictory demands. Such demands, limited by existing practices and infrastructure investments, lead invariably to compromises in the final product, and do not allow the full potential of technology to be exploited. The shortcomings of this approach can also be noticed in the current development of new generation, alternative drive-train vehicles, which are essentially developed on the platform of traditional ICE cars with a direct replacement of engine and the addition of energy storage or conversion devices in space which could opportunistically be used for the comfort of the passengers or as optimised shape for drag reduction. Similarly, the current strategy of tackling the possible dangers that inherently quiet electric vehicles may pose to pedestrians by adding artificial noise is another example of lack of “new thinking” in what could be a chance for a significant reduction in urban noise pollution.

2.2. New approach

It becomes clear from subsection 2.1 that in order to induce the required paradigm shift, a new way of thinking and performing research is necessary. Since several years, we try to seek inspiration in all kinds of science around us. Such inclusive thinking incorporates cutting edge research in engineering. We can find interesting concepts in the work of several research groups. A recent example is the development of a battery which can also be used as a structural material [9], therefore removing significant duplication of the weight. Research from NASA has led to a self-sustainable marine vehicle [10], while Lotus Engineering has recently shown that a significant weight reduction can be achieved using relatively standard technologies and with a minimum impact in cost [11]. However, our truly multidisciplinary research approach extends beyond the conventional limits of engineering to concepts not directly related to vehicles, such as biology and social sciences, and can provide new seeds of technology which are not limited by topic and therefore also not in scope. In nature we observe many truly amazing technology-like functions, and we have long been looking here for inspiration to solve some of our fundamental engineering challenges related to both vehicle safety and sustainable energy efficiency. Another pillar of our approach is that we take into account the future society structure and operation and thus our real target becomes to increase the efficiency of the whole system, rather than a single component, as done traditionally. In such a holistic approach, we consider the automobile not as an individual unit, but as a living part of a bigger organism. This way, many of the existing obstacles can be overcome and a higher rate of development can be achieved.

In addition, we consider practical aspects such as the cost of new technology, investments in infrastructure, local energy resources availability, as well as human aspirations and market diversity. Sustainable mobility, apart from dealing with environmental and energy issues, must also satisfy the individual customer needs, meaning that it must maintain or improve upon the current acceptable levels of performance, safety, comfort and practicality. It must also respond and adapt to changes in lifestyle, such as urbanisation and network connectivity, converting such changes into opportunities for further improvements. Finally, it must maintain and extend the personal freedom of the driver and the passengers, keeping the aforementioned benefits of private transportation, in a socially and environmentally responsible manner.

Such a quest for a potentially sustainable automotive transportation technology, as described in Section 1, is slowly starting to gain traction globally. A recent example is the LA Auto Show Design Challenge which has been providing a platform for presenting new ideas over the past seven years. A different theme, relevant to different aspects of future car usage, is employed each year, and some interesting ideas can already be seen [12].

3. Image of the sustainable vehicle

Following the approach described in Section 2, we estimate that the amount of energy needed for car transportation by 2050 is possible to be one order of magnitude lower than current levels and the emitted greenhouse gases close, if not equal, to zero. By removing inefficiencies in all the subsystems and introducing new technology concepts, we are aiming at creating a vehicle which can propel itself without any fossil fuel derived energy support while maintaining the current levels of vehicle performance and occupants comfort.

3.1. Evolving society

The large-scale availability of affordable liquid fuels has essentially sparked a modern industrial revolution over the 20^{th} century and shaped the transportation sector. Today transport is at a transition point, as it is starting to become a victim of its own success. The genesis of our image for the future car should therefore be viewed in the context of its existence inside the future society. A society which we believe will be characterised by the lack in cheap resources, growing levels of population and urbanisation. This future society will be more extrovert and will strive to remove inefficiencies following a global optimisation approach. In such an environment, information will constantly be transferred and exchanged, allowing each subsystem to automatically adapt its operation in order to support a smooth global operation. New information technologies, providing immense wealth of information, are already starting to move in this direction [13].

Apart from the information exchange, which is necessary for a smooth coexistence of the different structures in a society, another important concept which needs to be materialised is that of energy exchange. By this, we mean the constant adaptation of energy resources used, in order to achieve the most efficient energy production, as well as the constant energy re-usage process, during which energy is converted into different forms without loss. The successful combination of energy and information exchange processes will ensure the achievement of such a smart and self-regulating entity.

3.2. Shaping the future car

In such exchanging society, different means of transportation have their own role to play. We believe that the desire for the pleasure, freedom and practicality of personal mobility will not be eclipsed, and therefore the personal car will continue to have an important role. By actively taking advantage of opportunities presented in the future society, automotive transportation can adapt and be optimised in order to achieve successful merging and co-existence in the daily life of its citizens.

A self-sustainable vehicle has, first of all, to remove the past inefficiencies. Fig. 4 shows the energy losses in two usual driving scenarios, according to [14]. It can be seen that the energy which finally results in the actual mobility of a conventional car corresponds to less than 20% of the available energy from the fuel. A lot of new technologies aim at reducing or removing such energy losses, although, arguably, the most significant of these losses is inherent to the historical operation of the thermal engine and is the hardest to tackle. Another source of inefficiency is the mass of the vehicle itself and the associated inertial effects. As shown in Section 2, the improvements in engine technology have been offset by the weight increase over the last decades, with the fuel economy not being able to improve as drastically as it could. It is highly paradoxical that a vehicle of more than 1000kgs is needed for the transportation of an 80kg person. It is clear that different technology is required in the design of future vehicles.

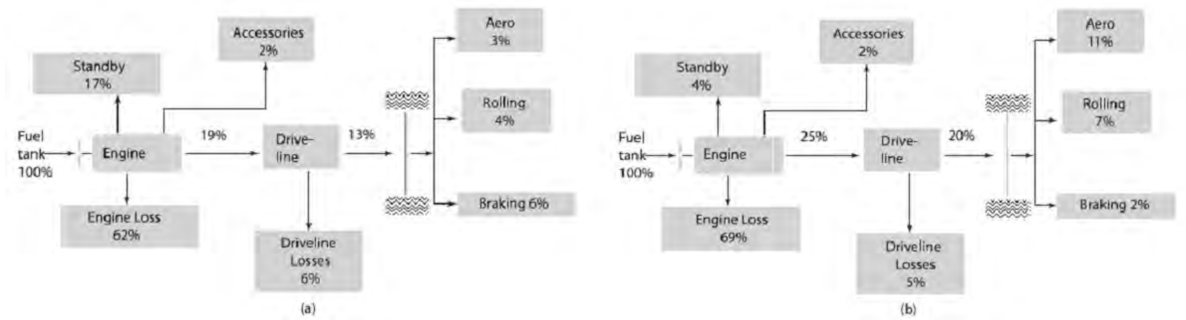

Fig. 4. Energy dissipation in (a) urban and (b) highway driving [14]

Completely in line with our image of the future society, the future vehicle takes advantage of all the available information and energy forms in order to maximise its potential and optimise its operation. Like the combined intelligence of a school of fish that travel together in a way that offers them safety and ensures the minimum drag during their movement in the water, our future vehicle can communicate with its surroundings and adapt its operation in a way that removes the danger of accidents, while respecting the individuality and the preferences of the driver. Moreover, this communication and adaptation allows the usage and re-usage of the available energy in the best possible way without losses, but with continuous transformation from one form to another.

A significant gain can be achieved by reducing the mass of the vehicle considerably. We envisage a five-fold reduction in this sector. A combination of ideas will be necessary for this target to be achieved. First of all, the novel intelligent safety systems will ensure that it is possible to avoid any dangerous situation at all times, and therefore reduce the reliance on increasingly stronger individual vehicle structures, which can be parallelised more to the sturdiness of an elephant, rather than the elegance and nimbleness of a bird. Then, a new generation of materials, inspired by nature and based on simple, cheap building blocks which gain their strength by their internal microstructure will allow the creation of vehicles which are more in line with their natural surroundings. The human organism consists of materials which do not necessarily have significant individual strength or potential. However, due to their relative organisation and control under powerful sensory and cognitive skills, they can be protected by catastrophic damage and are capable of achieving comparatively amazing results. Finally, the integration of multiple functions in fewer structures or components can remove unnecessary weight.

Such optimizations can significantly reduce the amount of energy which is necessary for mobility. This has initially a positive impact on the rate of existing resource depletion. More importantly, though, it can enable an era of desired self-sustainability, where the naturally occurring energy streams can be harvested and exchanged efficiently, thus minimising the link to fossil fuel consumption.

(a) (b) (c) (d)

Fig. 5. Example of image enhancement by novel night vision algorithm: (a) Original frame. (b) Tone mapped version. (c) After noise reduction. (d) After noise reduction with sharpening.[15]

Fragments of such ambitious thinking can already be seen in cutting edge research. An example of research is a novel night vision system, inspired by the eyes of nocturnal insects [15]. The algorithm developed in this project was born from understanding how an insect can hunt for food which is beautifully coloured flowers at night, navigating with its normal eyes. A sample result is shown in Fig. 5. Whereas traditional technologies might saturate in terms of performance, results obtained from such a holistic research framework can have the potential to leap-frog beyond current frontiers.

3.3. Contribution of the engineer

We are faced with the tough challenge of adapting this totally new knowledge back into existing systems and applications of our industry, to fully measure and evaluate its true potential, but it is a challenge which we are working hard to overcome. To do so, first we try to play a binding role by bringing different kinds of science together and removing the borders between them. Secondly, we try to identify the potential and feasibility of each technology, and quickly pursue its development and application into the final product through interaction with development, production engineers, marketing etc. For successful guidance in such an approach, we set a clear future target, like the one we are presenting in the current paper. We believe, based on our experience from ongoing projects, that this concept will allow a revolutionary design and integration of subsystems, paving the way to radically new implementations.

4. Summary

We have a dream of zero accidents and zero emissions for our future car. The pressing sustainability issues mean that our dream is relevant more than ever. In this paper, we propose the development of technologies which support the process of exchanging energy and information as a way to reach this target. By such challenging of traditional thinking we aim to spark innovation for game-changing technologies, leading to a truly sustainable mobility solution, from both an environmental and social point of view.

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