The Smart Powertrain, Clean, Efficient and Safe Utilization of Existing Infrastructure

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The Smart Powertrain

Clean, Efficient and Safe Utilization of Existing Infrastructure

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Abstract

In this paper a new project that is to be launched at the end of 2003 is described. The project is entitled "The Smart Powertrain" and is defined in the Netherlands where it is pending for governmental subsidy. The Smart Powertrain fuses Hybrid Powertrain Technology (HPT) with Advanced Driver Assist (ADA) Systems for improving both the efficiency of the powertrain and traffic. Break-through technologies on active and passive safety are an integral part of the project definition. The integration of HPT and ADA in one context will result in currently unforeseeable benefits on emissions and congestion, particularly since they are mutually enforcing mechanisms.
The paper describes the Smart Powertrain definition, motivation for this definition and preliminary results on fuel economy benefits. Highly specialized R&D that is currently performed in The Netherlands and runs ahead on the SPT program is briefly addressed throughout the paper.

Keywords: Hybrid Powertrain, Advanced Driver Assistance, Fuel Economy, Congestion, Drive Cycle, Mechatronics, Smart Systems

1. Introduction

The main societal and technical problems stemming from mobility are:

- CO_2 emissions and noise
- Congestion
- Safety
- Continuous strive for performance increase
- Sustainability
- Availability of energy/fuels
- Availability of space and reachability

Above problems are divers in nature and often result in conflicting solutions. The Smart Powertrain (SPT) focus is on finding innovative solutions for combinations of these problems into an integral context. Apart

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from the availability of energy/fuels and space/reachability, the SPT program addresses all above items. Others R&D on safety and the reduction of CO_2 and congestion focuses on the vehicle exterior, interior, auxiliaries, materials, mass and shape, or on chemistry of fuels, but also on infrastructure, politics, logistics and production. Within SPT, the concepting and development of a (smart) powertrain within a passenger vehicle is central.

The Smart Powertrain project is a consortium research program of eight research groups at the Technische Universiteit Eindhoven, 2 research groups at the HAN Automotive University, the recently launched Automotive Technology Centre, 4 research groups from TNO Automotive and 9 industrial parties. The total budget amounts up to 80 M€ and a 65% subsidy from Dutch government is pending. All consortium members are situated in the Netherlands or have a Dutch representation. The SPT research program aims both at increasing the knowledge infrastructure as well as the international position of highly specialized automotive industries in the Netherlands. Important national and international parties in politics, mobility and energy such as Shell, BP and Ford Research and the Dutch Ministry of Traffic Affairs have subscribed the relevance, prospect and definition of the project.

The main goal definition relates to reduction of CO_2 emission and congestion through exploiting the unexploited potentials of the powertrain, or better, the propulsion of the vehicle. Only few other research efforts define technological solutions for both problems into one entity as their ultimate goal.

Figure 1: Hybrid AVG Trambus “Phileas” (l) and Automated People Mover “Parkshuttle” (r)

It is well known that hybrid technology and renewable fuels are able to decrease the CO_2 emissions considerably. Less acknowledged is the notion that Advanced Driver Assist (ADA) and automated driving modes (*e.g.* Automated Vehicle Guidance , AVG) can also reduce CO_2 emissions significantly. Finally, it is virtually unknown that an optimal coordination of the two will lead to extraordinary CO_2 emission benefits. Positive experiences in this respect are already obtained through the development of the road-guided trambus “Phileas” in Eindhoven City, and the automated people mover “Parkshuttle” in Rotterdam City both in The Netherlands, see Figure 1.

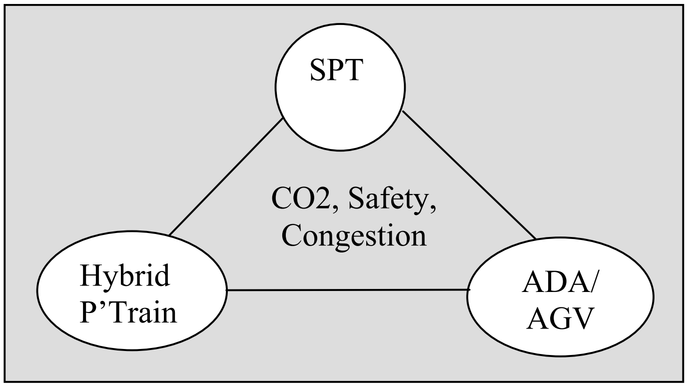


Figure 2: Smart Powertrain Scope.

In order to validate this hypothesis also for passenger cars, the powertrain requires information from the ambient world other than the inputs it receives from the driver. Thereto reliable looking-forward sensors based on radar and laser technology are being developed.

These sensors together with their image recognition software, information technology and active powertrain control aim at reducing congestion and increasing safety through anticipation, vehicle string formation and collision prevention. In this way the role of a powertrain as a propulsion means is broadened with active safety and congestion control features. Exactly this broader view defines the scope of the Smart PowerTrain as we entitle it, see Figure 2.

In this paper the potentials of the SPT is further explained. Thereto, the definition of the underlying research is described in Section 2. Section 3 outlines a technology statement pleading for hybrid propulsion with internal combustion engines. Section 4 describes the urge for Advanced Driver Assistance systems for a better throughput within existing road infrastructure. The fuel economy (and thus CO_2) emission potentials of the Smart Powertrain philosophy is presented in Section 5. Finally, Section 6 gives a conclusion and outlook for the SPT research project

2. Definition of the Smart Powertrain

The Smart Powertrain project aims at finding an total energy approach for a single vehicle within a (partly) automated vehicle fleet. As explained in the introduction it uses both

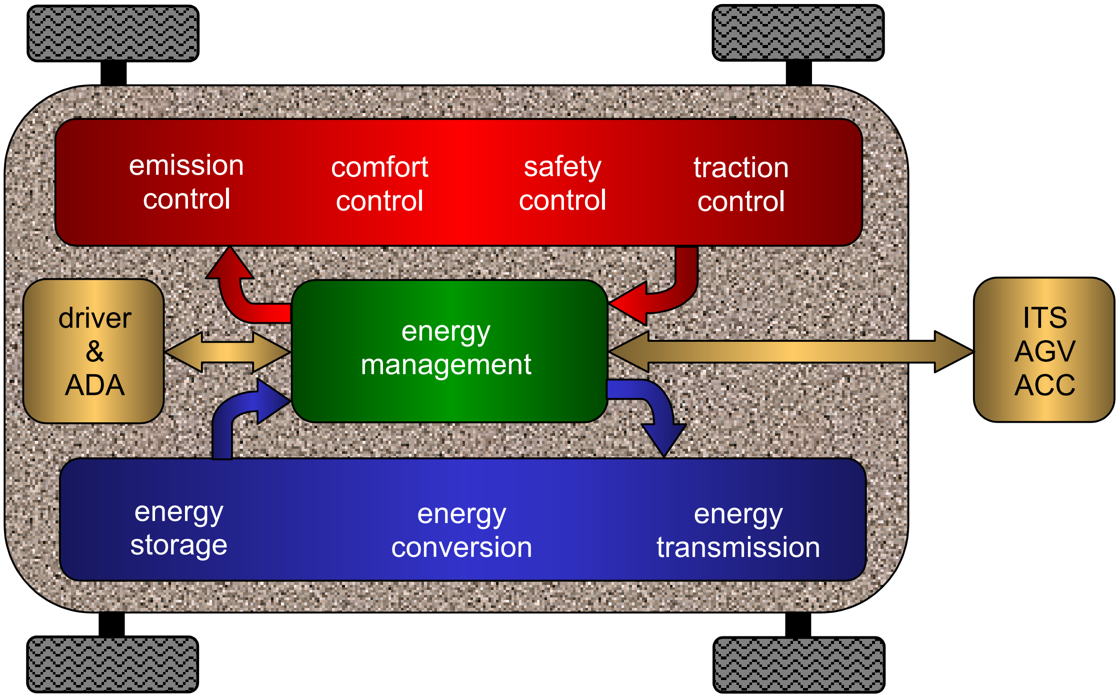


Figure 3. The Smart Powertrain: Energy Management, Control and Information Technology

optimal hybrid propulsion as well as advanced driver assist and automated guidance systems. Naturally, this provides opportunities for increasing the active and passive safety and forms an integral part of the program. The optimality between congestion, safety and CO_2 is determined both by the composition (energy management) and smartness of the hardware (control) as well as the use of information technology, see Figure 3. In Figure 3 it can be seen that the energy management is also driven by ambient information stemming from looking forward sensors and other telematic traffic information equipment.

The Smart Powertrain project is more than producing a strong technological feasibility study. Instead it aims at finding the design tools and methods for hybrid powertrain system innovation. The actual conception of the most feasible concept, that is “the winning” smart powertrain is only optimal in view of its context and constraint. Therefore, design and concepting tools and methods should preferably comprise a parametric approach besides vehicle-in-data simulation. This approach enables a rather straightforward change of constraints for finding a new optimum. The value of the mentioned tools is especially relevant when contemplating for example the Europe-ACEA convention (140 g/km CO_2), which is agreed for every OEM vehicle fleet manufactured from 2008 and beyond. The parametric approach together wit prospected model sales enables a fleet optimisation of CO_2 rather than individual model optima which is assumed to be considerably less costly.

Figure 4: Zero Inertia (ZI) Powertrain: CVT with powersplit-rotor (by Drivetrain Innovations)

The project starts off with a multitude on hybrid-electric powertrain concepts that are already available within the consortium. Some of these concepts find their basis within the so-called Zero Inertia Powertrain (Figure 4) conceived by Drivetrain Innovations, see [1].

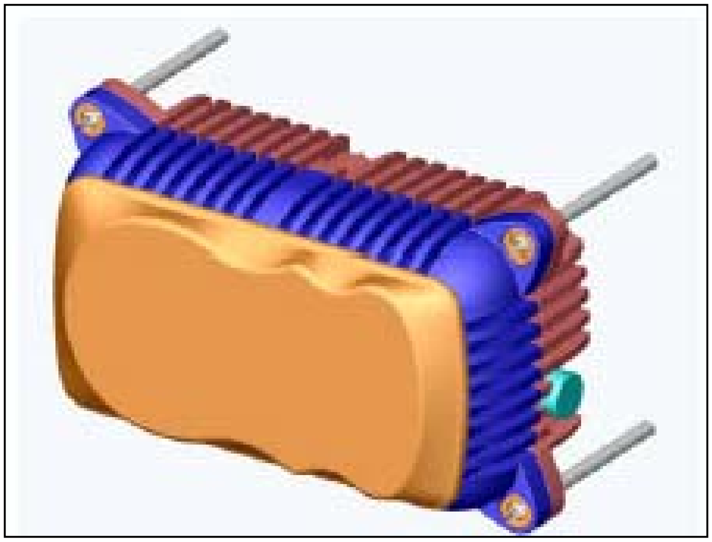


Figure 5: 2nd generation Forward Looking Radar (FLR) Sensor “RoadEye” (by Groeneveld)

As for the ADA systems the research consortium already has a headstart upon other research thanks to leading sensory technology, see Figure 5, and world’s first ADA/AGV laboratory, see Figure 6. Other research in this area used outdated and non-robust looking sensor equipment as well as unrealistically isolated road tracks.

Most of the algorithms tested there are adopted in SPT and their viability in all imaginative situations and the benefits for CO2 reduction can be validated using the ADA/AGV lab. Inevitably, this will bring important new insights in the true technological challenges of ADA/AGV resulting in new and more appropriate algorithms and techniques.

The increased safety of vehicles through ADA and collision avoidance and warning systems is further enhanced by researching the capabilities of so-called smart tyre concepts. The smartness of the tyres can be increased by using telemetric sensor technology that provide—besides pressure and speed—a tyre deflection state. This information is crucial to indicate the traction capabilities within (changing) road and manoeuvring conditions. The combination with a torque vectoring 4WD Hybrid Powertrain constitutes an important advancement in vehicle stability, and active/passive safety.

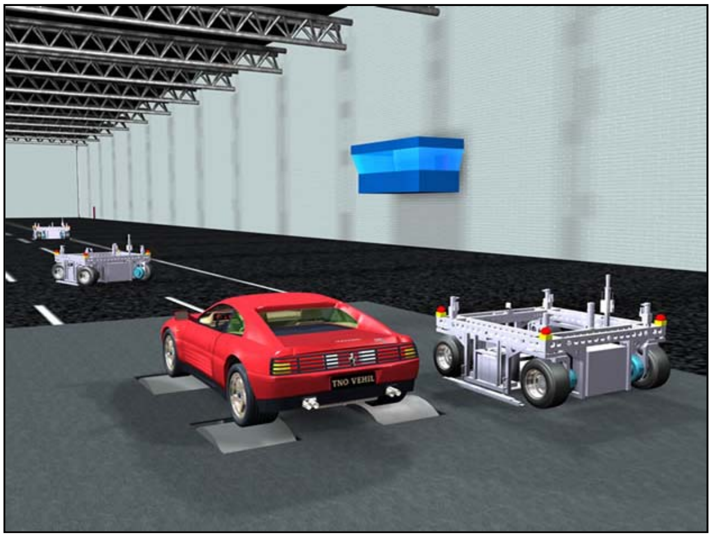


Figure 6: VEhicle Hardware In the Loop (VEHIL) Laboratory (by TNO Automotive)

The Smart Powertrain deliberately uses existing components, which in itself are innovated to fit optimally in the overall context. This enables a proven analysis on issues of life-cycle economics and environmental costs. The integration of the FLR sensor technology with the 4WD hybrid powertrain, smart tyres constitutes a break-through of the powertrain's smartness. In this way the potential of the powertrain to actively control the safety, traffic efficiency, comfort, cleanness and fuel efficiency of the vehicle very well motivates the name of the project.

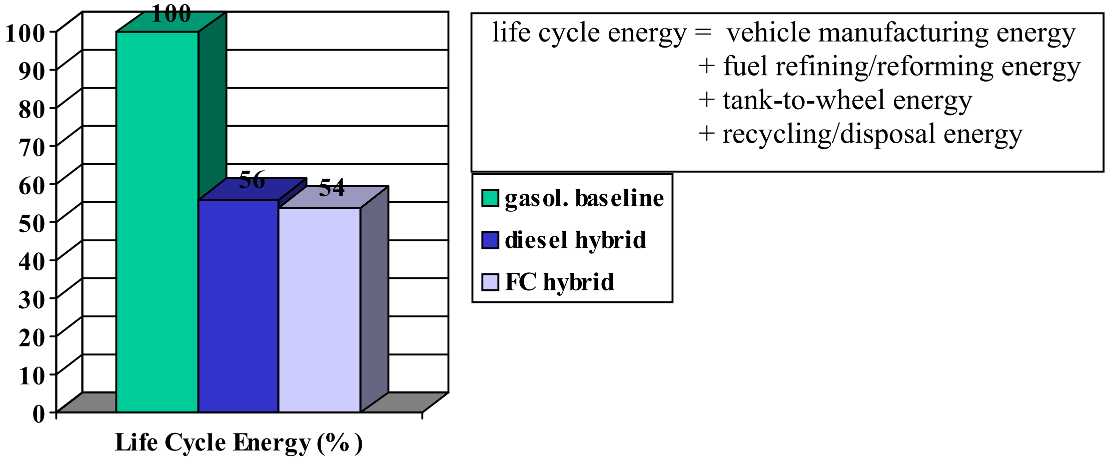
3. Existing Fuel Infrastructure demands Hybrid Powertrains

The Smart Powertrain intentionally does not concentrate on the further development of fuel cell and hydrogen (H_2) technology. The main reason is that it is unlikely to become a feasible means for mobility in the near future. Besides the fact that the complete overhaul of the fuel infrastructure is enormously costly it will not even be compensated by reduced life cycle energy of the fuel cell (FC) vehicles, see Figure 7 and reference [2].

Up to now H_2 is not produced in a renewable way, which means that the energy source is still fossil. The transformation from hydrocarbons into the H_2 energy carrier is extremely inefficient, virtually diminishing all its potentials before it even enters the car.

The main conclusion from this research is that if hydrogen propulsion stems from renewable energy it will become a true contribution to society. The research, developments and implementations that have to be undertaken to reach a renewable energy society is practically unbearable at this moment. Only if emissions require to be fractions of what is projected in the next decade or two, hydrogen energy carrying will become a feasible option, which is not to be expected within the coming 30 to 50 years or so.

The consortium acknowledges the massive works that has been done on the subject of hydrogen and fuel cell propulsion by Ballard, DC, Ford and many universities, research and test centres. However, much of this work has been concentrating on the combination of fuel cells and an electric propulsion motor. In many automotive applications this is not sufficient to meet all technological needs of the passenger car. Therefore, the SPT projects aims at finding hybrid-electric drivetrain concepts that equalize the technological specifications of both an internal combustion powered as well as fuel-cell powered vehicle. This backcasting within a technology roadmap enables a truly interchangeable engine and fuel cell, which is the most viable way for acceptation by industry and society in the long run.



life cycle energy = vehicle manufacturing energy
+ fuel refining/reforming energy
+ tank-to-wheel energy
+ recycling/disposal energy

Figure 7: Results life cycle energy analysis, Weiss *et al* [2], MIT.

The SPT program concentrates on the use of a multitude of (renewable) fuels. The challenge is to develop smart engine techniques that decouple the engine design from the stored fuel type. Solutions to this end could result in a propulsion system that is impartial towards socially accepted fuels, fuel distribution issues and geographically favored fuel types. This immediately poses the scientific problem that a multifuel engine in essence penalizes optimality (in efficiency and performance) compared to a single fuel engine. Fundamental research on the significance and main drivers of this gap in optimality on the one hand and directions for solutions on the other are key topics. This research will focus on real-time modelling and adaptation between various combustion principles.
Lower energy density of alternative and renewable (often gaseous) fuels is one of these penalties however small, especially in combination with a light weight filament winded high pressure fuel tank that is to be developed in the program. The reduction of (all types of) emissions through the combustion of clean fuels is potentially regarded as more effective than by control strategies only, e.g. [3]

4. Existing Road Infrastructure demands Advanced Driver Assist

Congestion on roads and highways seems to be unsolvable in the near future. Congestion is caused by inefficient use of roads causing a drop of average vehicle speed and large differences in traffic density. Human drivers are not able to anticipate and control adequately within a dense string of vehicles in order to prevent traffic jams and congested areas. Reasons are that traffic string dynamics are too complex and driver perception and anticipation capabilities decrease at increasing vehicle density.

There are several ways aiming at the an increased throughput or metering of traffic during daytime:

1. Stimulating public transportation by a variety of means and technologies, where cheap transportation on (near)demand is the most effective;
2. Expansion of road and highway grid;
3. Financial penalties within driving on congested areas or time windows (early morning and late afternoon);

4. Teleworking at one or more days per week to reduce the average number of vehicles actually driving towards and from working locations;
5. Adaptive vehicle speed signalling for driver assistance;
6. Telematic traffic control information and (adaptive) navigation systems;
7. Adaptive Cruise Control systems to reduce vehicle distance condensing;
8. Advanced Driver Assistance Systems and Automated Vehicle Guidance Systems for increased driver-traffic involvement (through an electric horizon) and increased automation of traffic dynamics (reducing driver-traffic involvement), respectively.

Items 7 and 8 are originally intended for increasing inter-vehicle safety and through collision avoidance and warning systems but are also very effective for smoothing the traffic dynamics and thus increased traffic efficiency and comfort, [4].
In the Smart Powertrain Project the focus is put these two items. The motivation for this choice is the relatively costly and/or ineffective adaptations of the existing infrastructure, policies and driver attitude involved with especially items 2 to 6. Furthermore, the SPT project consortium aims at finding solutions for individual mobility whereas other projects are focusing on public mobility, see also figure 1 and reference [5].

The development of a second generation advanced forward looking radar (FLR) sensor (see figure 5) fused with laser sensor technology enables a true implementation of the Advanced Driver Assists systems such as Adaptive Cruise Control, automated Stop-and-Go and co-operative vehicle control. This sensor technology is crucial in that it will give additional performance in terms of extended angular coverage and short range tracking. These capabilities allow the early detection of cut in situations, in curve continuous tracking and stop and go on highways. Several technologies will be developed to bring the cost of the sensor to a level that will allow introduction of the technology to the low and medium end of the automotive market.
The combination of forward looking sensor, information technology, inter-vehicle control and refined powertrain and energy control will ultimately lead to the capability to actively manipulate (control) the drive cycle that (fleets of) vehicles drive. Real-time control of the drive cycle can be regarded as the last far-reaching instrument for reduction of fuel consumption and emissions.

5. Fuel Economy Potentials through ADA systems

Apart from increased traffic efficiency, safety and comfort, the potentials for fuel efficiency improvement through Advanced Driver Assist Systems are enormous. In this section a first glance to these potentials is given. Thereto a basic vehicle with 5-gear manual transmission is driving in two extreme driving situations: stop and go jamming traffic and constant speed driving. For fuel and traffic economy, of course, the second way of driving is preferred. The vehicle data and is listed in Table 1.

In-house developed vehicle forward-simulation software is used to compute the fuel economy of the driving situations with the aboe test vehicle. The jam cycle is a sequence of stop& go actions with 2.78 m/s^2 acceleration and deceleration ramps and a 5 second constant speed driving at 30 km/h, see Figure 8. The fuel economy at constant speed driving is rated at 30, 40, 50 60, 70 and 80 km/h.

In Figure 8 the relative fuel economy of two driving modes are presented:

- constant speed driving with respect to the jamming drive cycle and
- jamming drive cycle using engine start/stop (mild hybrid) with respect to jamming drive cycle with idling engine during standstill

Table 1: vehicle data

Parameter	**petrol engine, 5MT, C-class vehicle**
Heat Engine	
type	Petrol
maximum power	74 kW
maximum torque	151 Nm @ 4000 rpm
min. Bsfc	244 g/kWh
Transmission	
type	manual 5 speed
efficiency	93%
upshifting engine speed	2500 rpm
coast-down shifting speed	1200 rpm
Vehicle	
CdA	0.64 m^2
rolling resistance torque	55 Nm
accessory load	800 W
test mass	1200 kg

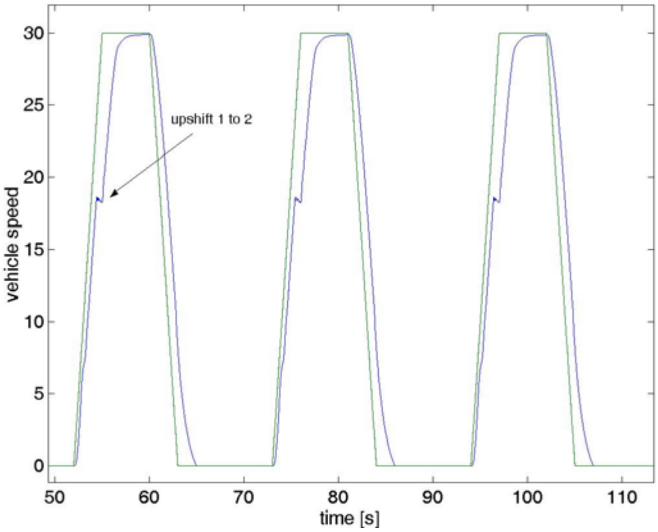


Figure 8: Jamming cycle: stop & go to 30 km/h

From figure 9 it can be observed that the potential for fuel economy with ADA systems that control the drive cycle (as close as possible) towards constant speed driving is much higher than (mild) hybridization only. In practice, an optimal combination of the two results in currently unforeseeable fuel economy potentials. As said earlier, the most important goal of the SPT project is finding the techniques and tools to design optimal combinations of Hybrid Powertrain Technology and ADA Systems. Utilizing a number of actual design cases (smart powertrain technology vehicles) will identify the true fuel economy benefits in a semi-real testing environment (see Figure 6).

6. Conclusion

This paper described the definition of a new project entitled “The Smart Powertrain”. This Dutch R&D program starts late 2003 and concentrates on the fusion of Advanced Driver Assist systems with Hybrid Powertrain Technology into one entity, *i.e.* a smart powertrain. Through state-off-the art radar and laser looking forward sensor technology, smart combustion and smart hybrid powertrain topologies the project aims at CO_2 reductions far below the Europe-ACEA convention of 2008. Furthermore, a practical solution for congestion reduction through active traffic smoothing is researched. The connection between emission and fuel economy and traffic smoothening is researched. The optimality between the two in terms of hybrid powertrain design & control and ambient driven energy management is investigated. The knowledge generated in the project is condensed in design and concepting tools that enable energy and emission minimization for entire OEM fleet models rather than individual car models. Preliminary fuel economy computations indicate the enormous fuel economy benefit that can be gained from active traffic smoothening (constant vehicle speed) in comparison with jamming traffic. An other benefit of this concept is that it initially starts with existing technologies rather than relying only on a sequence of new technologies. Sophistication of controls and total system approach will be the key to a truly optimized system. Through the Smart Powertrain technology CO_2 reduction, active/passive safety and congestion control all merge into a single smart and flexible system.

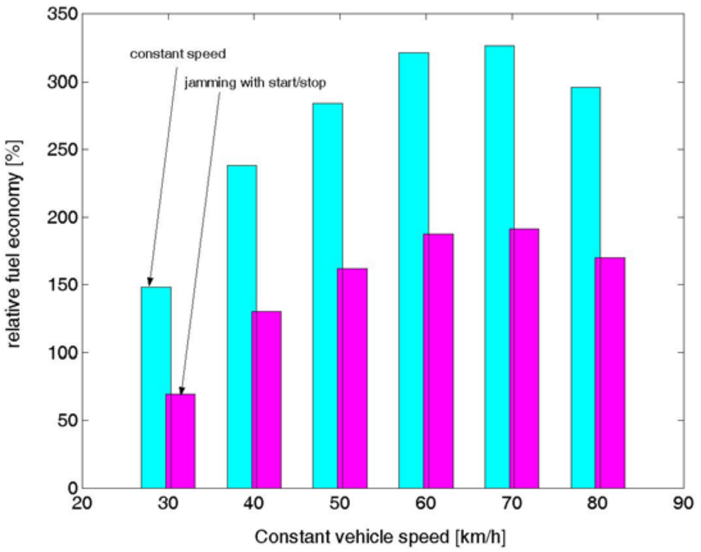


Figure 9: fuel economy potentials of constant speed driving and engine start/stop with respect to a jamming drive cycle (0-30 km/h)

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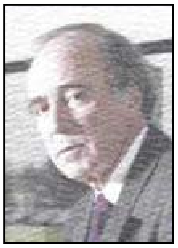
8. Authors

Alex Serrarens was born 6 september 1973 in Hulst, The Netherlands. In 1991 he started a curriculum in Mechanical Engineering at the Eindhoven University of Technology. He received his MSc-degree MechEng in april 1997. In 2001 he received his PhD degree from the same university in the field of powertrain control of passenger cars with CVT. He is one of the inventors of the Zero Inertia Powertrain. Currently he is business partner within Drivetrain Innovations (DTI) which is a licensing and contract-research center on automotive powertrains, transmissions and components in The Netherlands.



Nort Liebrand graduated from Mechanical Engineering at the Eindhoven University of Technology. He started working at Philips Electronics. First in the research dept. for peripheral computer equipment and later in the R&D dept. of medical X-ray diagnostic equipment. He joined Van Doorne's Transmissies (VDT) in 1994 were he became responsible for product & process development of CVT's and push belts. After the take-over by Bosch he became president of VDT. In 2000 he was appointed as part time professor at the TU/e with spearhead research & education on "Vehicle Drive Trains". Since 2002 he is also managing director of the "Automotive Technology Centre" (ATC), a Dutch center for innovation and promotion of Automotive Technology.

Maarten Steinbuch (S'83-M'89) received the M.Sc. degree (cum laude) in Mechanical Engineering from Delft University of Technology, Delft, The Netherlands, in 1984. From 1984 until 1987 he was a research assistant at Delft University of Technology and KEMA (Power Industry Research Institute). In 1989 he received the Ph.D. degree (Dr.) from Delft University of Technology on the subject of Modelling and Control of Wind Energy Conversion Systems.

From 1987-1998 he was with Philips Research Labs., Eindhoven as a Member of the Scientific Staff. From 1998-1999 he was a manager of the Dynamics and Control group at Philips CFT. Since 1999 he is full professor of the Control Systems Technology group of the Mechanical Engineering Department of Eindhoven University of Technology. Prof. Steinbuch has over 70 refereed journal and conference publications, and holds 2 patents. His research interests are modelling and control of motion systems. He was an associate editor of the IEEE Transactions on Control Systems Technology (1993-1997) and of IFAC Control Engineering Practice (1994-1996). He is currently associate editor of IEEE Control Systems Magazine, and editor-at-large of the European Journal of Control.