Route Adaptation of Control Strategies and Driver Assistent System for City Buses

Jan Andersson
Roger Axelsson
Bengt Jacobson

Machine and Vehicle Design
Chalmers University of Technology
S-412 96 Göteborg, Sweden
www.mvd.chalmers.se

Abstract

A series hybrid city bus with diesel engine and electric batteries is studied on a specified route. The study uses two different basic control strategies, *"On/off"* and *"Continuous"* strategy. These basic strategies are complemented in two ways. First, an *"Adviser"* strategy which filters the driver commands and gives driver support feedback based on the route data. Second, an *"Adapter"* strategy, which adapts the control to the route, using different control depending on the present position of the vehicle. Simulation results are presented. They show that the adviser and adapter strategies improves both emissions and fuel consumption. As an additional study, the advisor concept was tested on a conventional diesel bus with an automatic traansmission.

Introduction

If hybrid vehicles are to be judged in a fair way, the whole system has to be taken into consideration. A design process is proposed in Figure 1. This includes not only the specific vehicle with its software, but also the driver and the environment (including the transport task) in which the vehicle is driven. Simulation is an important tool for evaluations in this process.
Hybrid systems have an extra high potential in city buses, if the software takes the specific route and time table into consideration.
Increased computer power and newly developed and improved simulation tools make it more and more efficient to simulate relevant, mathematical models over such long transport tasks that it covers a whole bus route.
The problem area can be divided into three different subareas:

- Hybrid propulsion concepts
- Simulation models and tools
- Control strategies

An example of a hybrid concept is the Volvo Environmental Concept Bus, see [6], and two examples of developed simulation tools are VehProp, see [10], and FASIMA II, see [12]. Control strategies that consider the whole vehicle system are more hard to find but some aspects can be found in [3].
The objective of this work is to analyze buses with hybrid propulsion systems in city traffic. Of special interest is to see if and in what way the control strategy can be improved by using information on the transportation task, see Figure 2. Two different approaches are tested, as Figure 2 shows.
Figure 3 shows schematically the information flow of different bus concepts.

System Description

There are some aspects that distinguish city bus traffic from other types of traffic:

- The city bus traffic includes very transient driving, i.e., lots of accelerations and decelerations
- The route is known in advance and often repeated many times each day
- The bus stops are known in position and, in some extension, also in time (the time table)
- The weight of the vehicle changes during the ride due to changes in the number of passengers

In vehicle simulations it is common to use "inverse dynamics" which means that the calculations are made in the opposite direction, compared to the natural, physical causality. It is also common with no or very simple driver models and the environment is often described by a measured or synthetic developed speed. The concept used here is an attempt to model the system in the same way as the natural physical system. Figure 4 shows an example of the causality fora conventional city bus.

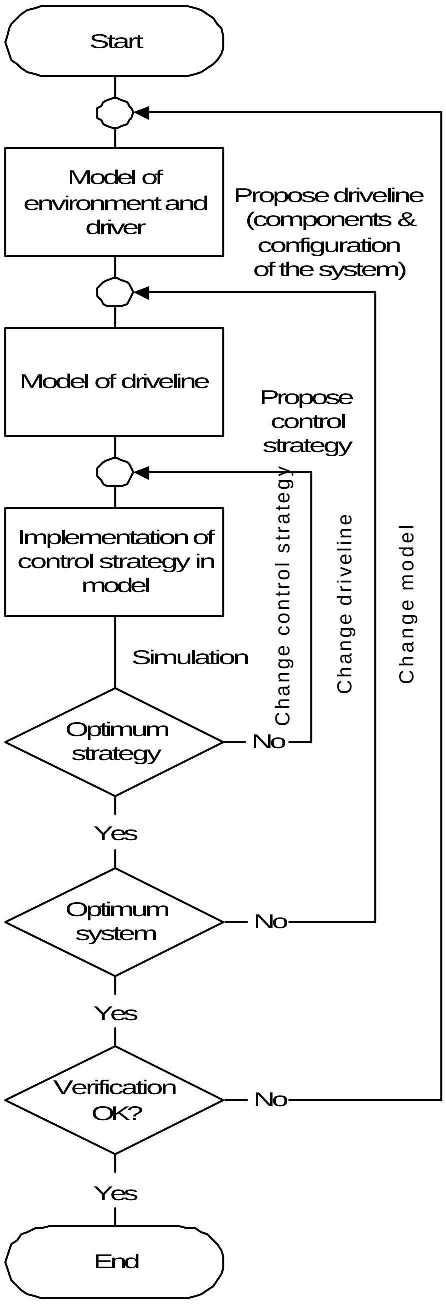

Fig. 1 Design process for a propulsion system.

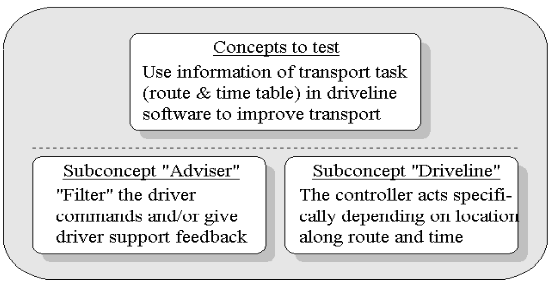

Fig. 2 Concepts of this work. The first one, which is called subconcept "Adviser", is like a filter that helps the driver to drive in an efficient way. The second one utilizes directly the information on the transportation task to control the propulsion system, without affecting driver.

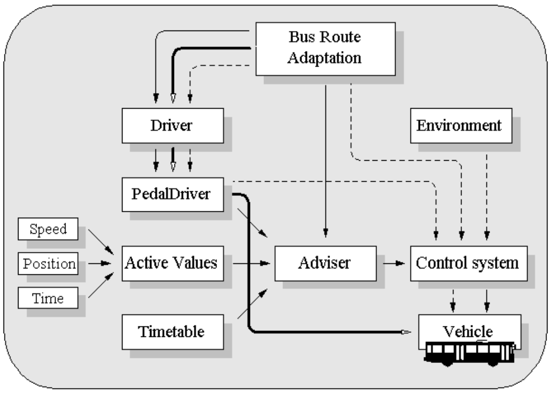

Fig. 3 Information flow for bus route adaptation. The thick line shows the condition for a conventional bus, where only the bus driver has information of the route and time table. The information flow for the "Adviser" is marked with narrow lines and the "Adapter" concept with dashed lines.

Bus Driving

As shown in Figure 5, the working situation of a bus driver can be relatively complicated, which means a considerable cognitive work load. Among others Alm, [1] and Galer-Flyte, [2] have studied how mental work load and driveability are affected when new advanced technical systems are introduced. Their results show that an increase in information quantity leads to a higher state of stress and therefore a poorer driving performance i.e. decreasing ability to react, to keep track and to keep the distance to vehicles in front. The consequence will be a growing probability for accidents.

In purpose to reduce a driver's work load it is of great interest to develop automatic supporting systems. It is likely that keeping the time table is one of the worst factors that increases the driver's stress level. In this work a first attempt has been made to develop a system that helps the driver to keep the timetable but also to reduce fuel consumption, emissions and wear and finally to raise travel comfort.

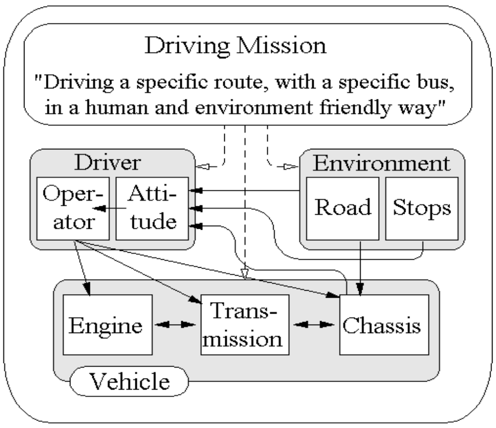

Fig. 4 The natural casualty for a conventional city bus. The "Driving mission" gives input to the driver in the form of route, time table and what vehicle to use. When the driver performs the mission, his "Attitude" part makes decisions which are carried out by the "Operator" part. The response of the vehicle is registered by the driver. The environment affects the vehicle as well as it gives input to the driver in form of suitable speed and positions where to stop.

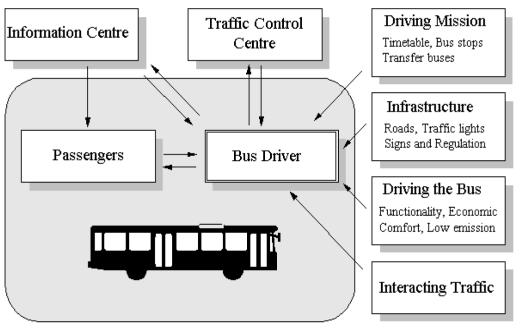

Fig. 5 Information flow from a bus driver's point of view.

Control System

Basic Strategies

Two different basic control strategies are used in this work: The "*On-off*" and the "*Continuous*" strategy. The idea of the first one is to let the "*Prime mover*", in this case an internal combustion engine (ICE), to work in its most efficient working point as often as possible. When the maximum energy level in the "*Energy storage unit*", here a battery, is reached the engine is shut off or put to idling. Figure 6 shows the result from a simulation by using this control strategy.

The idea of the "*Continuous*" strategy is to let the engine work continuously. Depending on the energy level in the battery a suitable amount of power is produced by the engine. The engine works in the most efficient point for the current engine power. Figure 7 shows the result from a simulation by using this control strategy.

Adviser Strategy

The adviser model is a route adapted control system which can be added to an arbitrary basic strategy. It supports the driver to drive in accordance to a time table. The adviser consists of four parts namely an environment model, a driver model, an optimizatio-model and a weight function, see Figure 8.

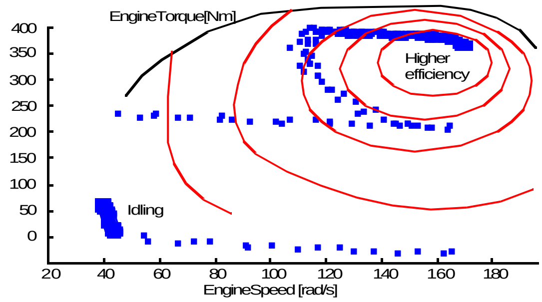

Fig. 6 Simulated conditions for the diesel engine when using the "On-Off control strategy". Approximated values for maximum torque and constant efficiency lines for steady-state condition are also shown.

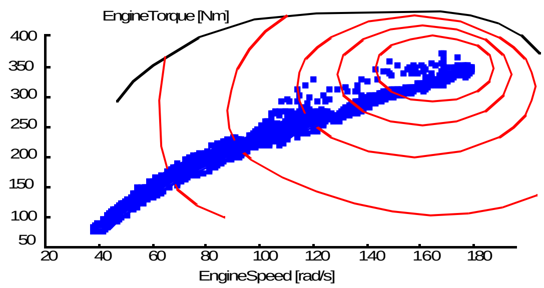

Fig. 7 Simulated conditions for the diesel engine when using the "Continuous control strategy".

The optimization model calculates a speed factor on the basis of a route's speed profile, knowledge of bus stop locations, actual speed and position. The result will be an appropriate speed limit that the driver model uses to determine a pedal request. This request is then weighted together with the pedal request from the real driver and the output is used by the power train control unit. Since the optimization and the driver model utilize appropriate values of deceleration and acceleration from fuel and emission point of view it will support the driver to drive economic and comfortable.

There are several possible ways to activate the adviser. One way, used in simulation in this work, is to introduce a click function on the accelerator at 50% deflection. Of course it is possible for the driver to choose higher or lower acceleration or deceleration just by change pedal deflection. A suggestion of how an advisor could be implemented in a real bus is given in appendix 2.

Adapter Strategy

The Adapter strategy can also be added to a basic strategy. This strategy uses the knowledge of the position of the bus stops. These stops will always be preceded by a retardation. Conventional buses use the brakes when they approach a stop and thereby converts the kinetic energy to heat. Hybrid vehicles can in some extension regenerate this energy and this is what is done in this work. The Adapter extends this ability.

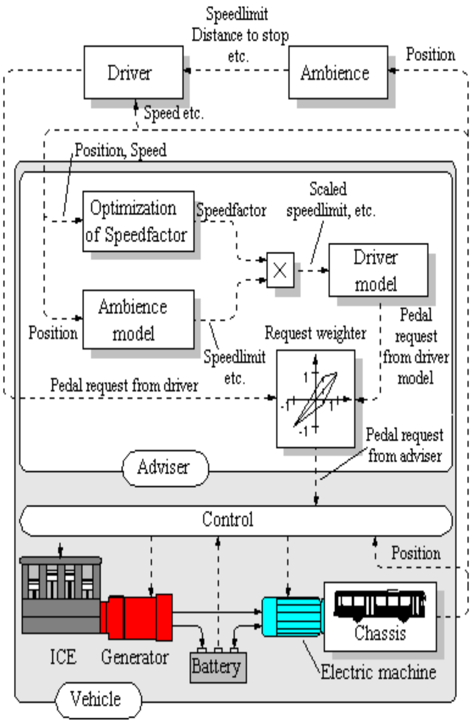

Fig. 8 Layout for the information flow for the whole simulated system.

Simulation and Results

Figure 9 shows a part of the bus route that has been studied and Figure 10 shows examples of simulations with and without Adviser. Letters in both figures show correlation between route and driving pattern. Depending on the road conditions different speed limits are used, e. g., this limit level is lowered for crossings, turnings and road bumps. The speed limit should be regarded as the recommended speed, if the route should be driven with neither stops, time table nor other events to consider.

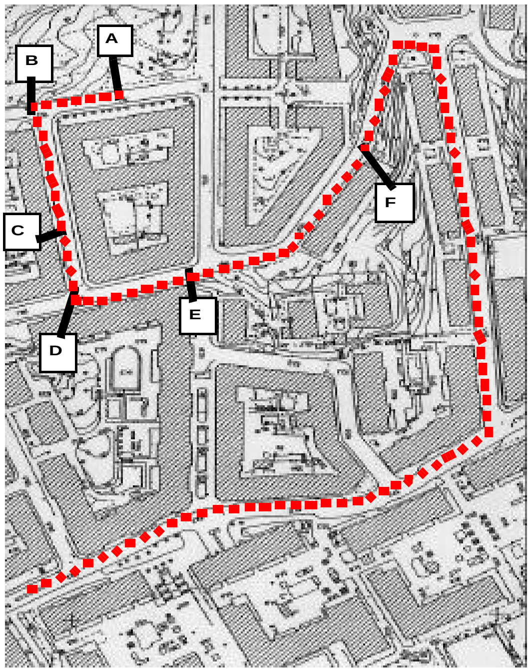

Fig. 9 A part of the bus route. The dashed line show the route and the marked positions corresponds to the positions in Figure 10.

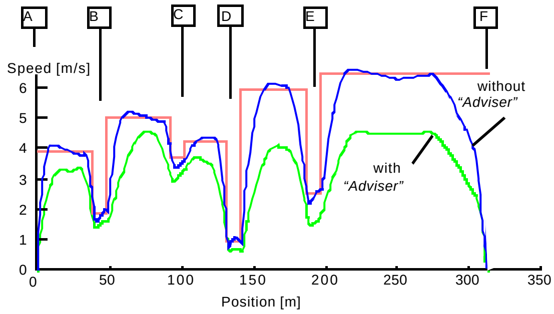

Fig. 10 The plot shows the result from a simulation where a bus is driven between two bus stops.

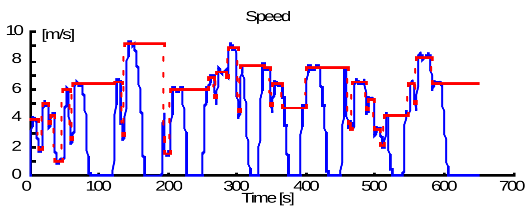

Fig. 11 "Speed Limit" and speed for a simulation including eight bus stops over 2.5 km.

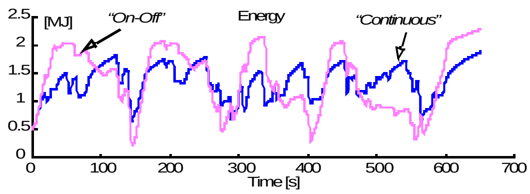

Fig. 12 The energy in the storage unit for the "On-Off" and the "Continuous" control strategy.

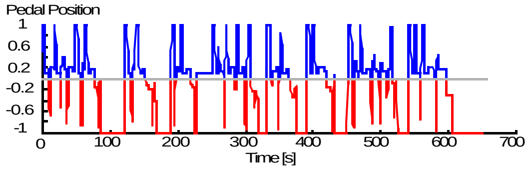

Fig. 13 The pedal position from the driver. Negative values indicates braking.

A typical speed profile for the complete driving mission is shown in Figure 11. It covers ten minutes driving.
The energy level in the energy storage unit differs depending on the control strategy used. This is shown in Figure 12 where the dotted line represents the *"On-Off"* strategy.
One thing that affects the simulation result is the behavior of the driver. An aggressive driver, compared to a calm one, will pump the pedals up and down more frequently. The pedal position from a rather aggresive but law-abiding driver is shown in Figure 13.
Eight different simulations has been performed and the results from this are put together in Table 1. The difference of energy, left in the energy storage unit, between the simulations can be neglected. The results are normalized to the first row.
When comparing results from Table 1it is important to note that only one specific transport task and driver is treated. Since neither of the two basic strategies is optimized, which was proposed in the "optimum strategy loop" in Figure 1, no fair comparison can be made between On-Off and Continuous strategies. However, more fair comparisons are possible within a certain basic strategy when studying the effect of the add-on strategies.

Table 1. Simulation results

Basic strategy	Add-on strategy	Fuel Cons.	NO_x
ON-OFF	no	1	1
ON-OFF	Adapter	0.97	0.97
ON-OFF	Adviser	0.96	0.95
ON-OFF	Adapter & Adviser	0.95	0.95
CONT.	no	0.88	0.87
CONT.	Adapter	0.87	0.87
CONT.	Adviser	0.84	0.83
CONT.	Adapter & Adviser	0.83	0.83

As a complement to this study the advisor concept has been evaluated for a conventional diesel bus as well. This part is described in appendix 3.

Future Work

The following items are important to consider:

- Traffic interaction with other vehicles
- Redundancy between environment and model of environment (e.g., unexpected stops)
- Other ways to optimize speed limit (instead of overall multiplication with speed factor)
- Investigate driver acceptance of pedal filtering and/or feedback
- Better models of energy distribution and buffering system
- Validation through experiments

Conclusions

This work shows that adaptation to a specific route increases the potential for hybrid buses in city traffic. Another aspect is that the whole system must be considered which limits the possibilities of using advanced optimization methods. However, still much can be done in this area.

Acknowledgment

We would like to thank Professor Mart Mägi and M.Sc. Lars Lundmark for their help and support. Financial support was provided by Volvo Bus Corporation, Thoreb AB and the Swedish Automotive Research Program (PFF).

Appendix 1: Model Description

An overview of the model is given in Figure 8. The model is developed from the model library VehProp, [10], which is developed in the software Dymola, [7]. The model has a hierarchical depth of 6 levels and approximately 1150 equations. It has 9 important (continuous) state variables and about 20 discrete state variables. The continuous states are:

- In ICE: crankshaft angle, crankshaft speed, turbo shaft speed, captured air mass in intercooler
- In energy buffer: accumulated energy
- In chassis: position, speed
- In driver: pedal position
- In "adviser": pedal position of driver model

The discrete states are typically the speed limit in the road model or the mode of the driver.

Environment model

The environment model describes the road in segments, of typically 10-100 m length. Each segment has a speed limit and a slope defined. The stops are defined in position and minimum time to stay at each stop. Also, each stop has a desired start time, corresponding to the bus time table. It might be noted that this is a "true" environment model, i.e., not a traditional driving cycles with speed prescribed vs. time. The environment model, see Figure 14, is a developed version of the one described in [8].
Numerical values used are derived from a real bus route in Göteborg, covering a distance of approximately 2.5 km and 8 bus stops.

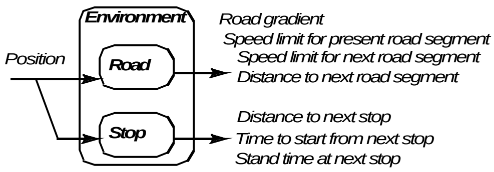

Fig. 14 Principles of the environment model.

Driver model

The driver model, Figure 15, is composed of a strategic part (“attitude”) and an operative part (“operate”). The concept is developed in [8]. The strategic part takes input from the environment model and decides when to switch between different “places” (i.e., circles in Figure 15). The “transitions”, A-E in Figure 15, defines when to switch between modes. E.g., the condition for transition B reads approximately: “***ReqDec***” `becomes > ` “***PrefAcc***”, where “***ReqDec***” is the required deceleration calculated to meet the speed limits and stops along the road. “***PrefAcc***” is a driver model parameter which corresponds to the preferred acceleration. Depending on which place is active, desired acceleration is calculated differently and handed over to the operate part. The operate part decides the pedal input to vehicle. Roughly, the pedals are the integrated values of the acceleration error.
It is known, e.g., from [5], that drivers considerably change their way of driving when they switch from conventional to hybrid vehicles. The driver model, in combination with the environment model, described supports this situation much better than conventional driving cycles.

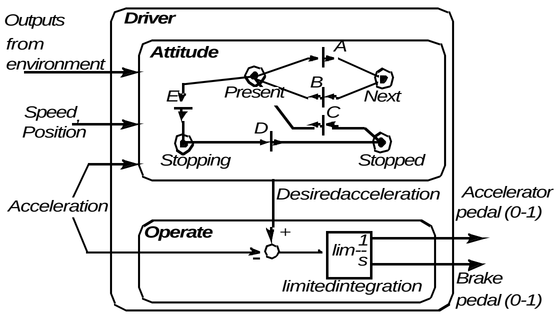

Fig. 15 Principles of the driver model.

ICE model

A scaled version of a model of a turbo charged diesel engine, verified in [3], is used. It is a detailed dynamic model with fuel consumption and emission calculations. The numerical values used, corresponds to a maximum engine power of 72 kW.

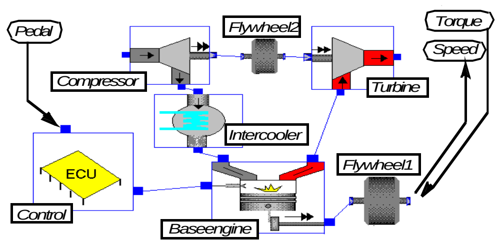

Fig. 16 Computer screen dump of ICE model with its natural causality shown by the arrows.

Energy distribution and buffering system model

The system for transfer and storage of energy between the ICE and the chassis, see Figure 17, is modeled rather idealized. There are no losses modeled, except for a power dependent efficiency applied on the power P3. There is no limit modeled for the range of energy stored, but the control makes the buffer cover a range about 2 MJ.

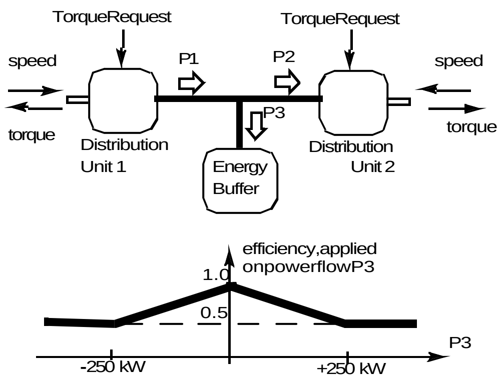

Fig. 17 Model of energy distribution and buffering system.

Chassis model

The chassis model is rather simple. It is, roughly, a translating mass, driven by the traction torque and braked by driving resistance. The mass changes according to number of passengers, which is changed at each bus stop typically between 14-18 tons. No tire slip is modeled.

Appendix 2: Advisor implementation in real buses

Several alternative advisor implementations have been evaluated, the most promising one is presented below, see Figure 18.
In this concept the driver indirectly acts on the control system of the vehicle and the advisor via an interpreter adjusts the positions of the accelerator and brake pedal. Feedback from the advisor is given as a force and position from the accelerator and brake

pedal into the driver's foot. With the advisor i operating mode, the accelerator and brake pedals will move in the same way as if an ideal driver would have driven the vehicle. If the driver has a demand that differs from the proposed, he just has to increase the pressure on the pedals. In order to make the driver observant on that he deviates from the proposition of the advisor, a spring is introduced that has to be compressed before the driver's intention will reach the control system of the vehicle. This concept has in this work been called a "Task adapted variable speed cruise control" implying that the driver just has to act if his requirements differ from the suggestion of the advisor. This type of feedback can mentally be treated at the skill based level, i.e., no significant consideration from the driver is demanded, see ref. [11].

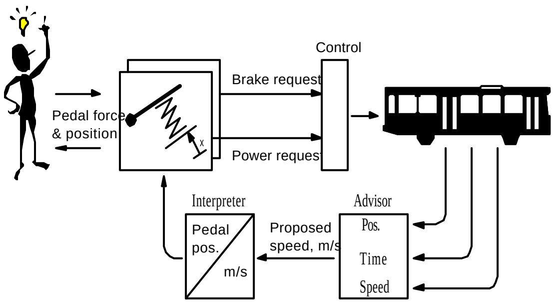

Fig. 18 Driver indirectly affects the control system of the vehicle and the advisor gives force and pedal position feedback via an interpreter.

An interpreter is introduced between the advisor and the position controlled pedals, see Figure 18. The interpreter translates the proposed speed in m/s from the advisor into appropriate accelerator and brake pedal positions. The pedals is physical adjusted by an electric step motor.

The principal characteristics of the whole system is shown in Figure 19. As already described the pedals will move according to the suggestion from the advisor. If the brake pedal has the position, indicated by "A" in Figure 19 and the driver wishes to increase the brake power, he has to increase the force on the brake pedal in order to compress the spring in the pedal and thereafter the brake pressure will increase. The pedal has now the position indicated by "B". If the driver on the other hand wants to increase the speed, he push the accelerator pedal, first the spring will be compressed, then break pressure will decrease and thereafter when the brakes are released the vehicle can accelerate. The pedal has now the position indicated by "C".

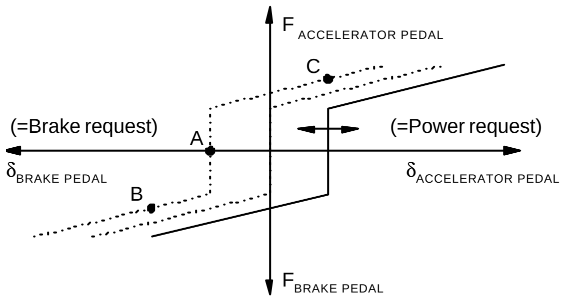

Fig. 19 The principal characteristics of the adjustable accelerator- and brake pedals.

Appendix 3: Advisor in conventional diesel buses

As mentioned earlier, the first part of bus route 85 in Göteborg has been used in order to investigate the potential of an advisor system. In this study a conventional diesel bus with an automatic transmission has been in focus.

The concept has been studied through simulations with both active advisor and with the advisor deactivated. Activated advisor means that, the advisor defines the speed profile, which is followed by the driver without regarding the actual environment. Deactivated advisor means that, the driver, represented by a model of his behaviour, follows the speed profile from the actual environment in a deterministic manner. The simulations with deactivated advisor have been used as a reference case, i.e., the fuel consumption and NOx emissions have been given the value 1.

During the simulations four different advisor algorithms have been used namely, the algorithm for scaled speed, ASS, the algorithm for reduced maximum speed, ARS and two special cases of the ARS algorithm with reduced acceleration level and reduced retardation level, respectively. The ASS algorithm is, roughly, based on the principle that the vehicle "tries" to drive according to actual speed limit profile of a route. The speed limit profile will then be reduced by multiplication with a scaling factor and the result will be a proposed speed. The scaling factor will be adapted to the timetable. ARS is in a corresponding way based on the principle that the vehicle "tries" to drive according actual speed limit profile but the speed limit profile will then be changed in such a way that the proposed speed is adapted to the least of maximum speed and speed limit. Maximum speed will be adapted to the timetable. A more complete description of how the advisor and the different algorithms works can be found in [3].

During real conditions with considerable traffic intensity, the possibility to control the driving behaviour in detail is limited, why the potential for lower fuel consumption will be reduced.

The simulation results concerning fuel consumption and NOx emissions are presented in Table 2. The simulations in Table 2 covers approximately 100 seconds of driving, between two bus stops. The "Adivser off" case in Table 2 arrives at the bus stop approximately 20 seconds too early, according to a realistic time table. All the other cases arrives more or less exactly on time table. It should be observed that the values presented in Table 2 are not absolute measures in the real sense of fuel consumption, but rather a normalized value with the numbers in the first row as a reference. Since all modules of the total system model used have not been verified, the result presented cannot be seen as exact numbers but the result indicates clear improvements.

From the result one can see in general that relatively large improvements can be achieved for the conventional diesel bus. A reason for this is that the advisor tends to level out transient driving which the conventional diesel bus can make profit from. Generally one can say that conventional diesel buses take benefit from lower speed levels since those give shorter acceleration times. Lower acceleration levels are not as important from the fuel consumption point of view, since diesel engines usually have relatively high efficiency at heavy load. There are, of course, a connection between acceleration levels and acceleration time, to reach a proposed speed. The comfort and component wear criteria limits the acceleration level.

One of the most significant factors is the behaviour of the driver. An aggressive driver, compared to a calm one, will pump the pedals up and down more frequently and this will definitely result in larger fuel consumption and higher emission levels. Therefore, the effect of an advisor system should not be underestimated.

Table 2. Simulation Results

	Conventional Diesel Bus	
	Fuel Consumption	NOx Emissions
Advisor off	1	1
ARS	0.79	0.78
ASS	0.92	0.92
Lowacc	0.87	0.86
Lowret	0.84	0.84

References

[1] Alm, H., Nilsson, L., Changes in driver behavior as a function of handsfree mobile telephones. A simulator study. *Accident Analysis and prevention*, 26(4), 441-451., 1994

[2] Andersson, J., “*Control Strategies for Vehicles with Energy Buffering Propulsion Systems*”, Thesis for degree of Licentiate of Engineering, Machine and Vehicle Design, Chalmers University of Technology, S-412 96 GÖTEBORG, Sweden, 1997-10-20.

[3] Axelsson, R., “*Contributions to Improvement of Efficiency and Cognitive Workload of City Bus Drivers”*, Thesis for degree of Licentiate of Engineering, Machine and Vehicle Design, Chalmers University of Technology, S-412 96 GÖTEBORG, Sweden, 1999-09-10.

[4] Berglund, S. and Karlsson, J., “A Modular Diesel Engine Toolbox for Studies of Charging and Control System Influence on Emissions and Performance”, *30th International Symposium on Automotive Technology & Automation*, Firenze, Italy, June 16-19, 1997.

[5] Berta, G. L., Durelli, E., Nymann, I. *“Simulation models for hybrid buses”*, Journal of Automotive Engineering, 1998 Vol 212, No D1, pp 59-72

[6] ECB Project Group, Built for the next century - the Volvo ECB. *Volvo Technology Report No. 2*, pp. 16-27., 1996

[7] Elmqvist. *Dymola User’s Guide*. Dynasim AB, Lund, Sweden, 1997. (See also web address: http://www.dynasim.se, information on the modeling and simulation software Dymola)

[8] Eriksson, Anders. *Simulation Based Methods and Tools for Comparison of Powertrain Concepts*, Thesis for degree of Licentiate of Engineering, Machine and Vehicle Design, Chalmers University of Technology, S-412 96 GÖTEBORG, Sweden, 1997-06-06.

[9] Galer-Flyte, M. D., The safe design of in-vehicle information and support system: the human factors issues, *Int. J. of Vehicle Design*, Vol. 16, Nos 2/3, pp. 158-169., 1995

[10] Jacobson, Bengt. *Final report from the project: Modular Simulation Tool for Vehicle Propulsion concerning Energy Consumption and Emissions*, Machine and Vehicle Design, Chalmers University of Technology, S-412 96 GÖTEBORG, Sweden, 1997. Web version: http://www.mvd.chalmers.se/~beja/simproj/index.htm

[11] Rasmusen, J. *Skills, Rules and Knowledge; Signals and Symbols and Other Distinctions in Human Performance Models*, IEEE Trans. on SMC, Vol. SMC-13, No. 3, pp. 257-266, 1983.

[12] Spörl, Th. Et al., “FASIMA II - Modellierung und Simulation beliebiger Antriebstrangkonzepte”, Rationelle Energiernutzung bei Hybridfahrzeugen, Munich, Germany, VDI-Berichte 1225, pp. 133-147, 19-20 October, 1995. (In German)