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Design of a cooperative eco-driving rail control system, an experimental study.

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Abstract

The paper proposes an original framework to design cooperative eco-driving (Economic Driving) rail control system called CEDRICS. A generic method to design cooperative support system is applied to build CEDRICS by taking into account real human behaviors in order to recalculate on-line advices for train eco-driving. An experimental study on a tramway simulator was performed to compare different configurations of CEDRICS t considering or not human behavior constraints with same interfaces. Results show relevant benefits in using CEDRICS face to complex environmental contexts involving interactions with cars and/or pedestrians.

1 Introduction

New advances in research and technologies offer new possibilities of human-machine interactions. Those interactions aim at supporting cooperative activities between human operator and technical intelligent system.

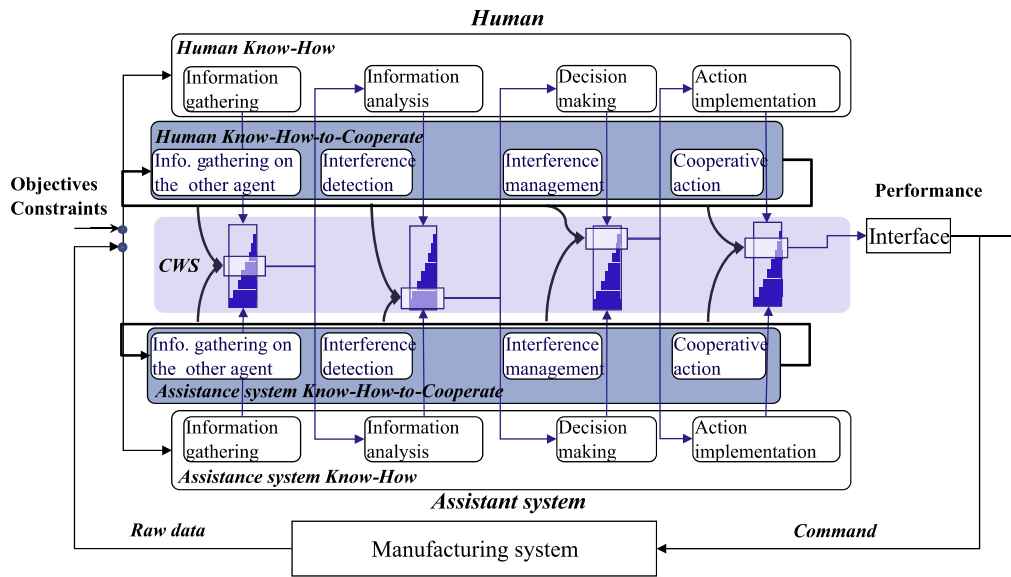


Figure 1. Human-machine cooperation model from (Pacaux and al. 2017).

The cooperation between technical advanced systems and human operators can be modeled regarding four kinds of activities (Pacaux et al., 2017), i.e. information gathering, information analysis, decision making, and action realization, as suggested by (Parasuraman, 2000) and referring to two kinds of knowledge and skills, Figure 1: the Know-How as capabilities, knowledge to realize or participate to a task, and the Know-How-to-Cooperate as knowledge and means used to facilitate the cooperation. This figure presents a model of Human-machine cooperation where the human operator and the technical system are supposed to achieve a common objective.

Regarding the capabilities of the different agents (human operator or technical system), the four main activities can be shared, traded and combined. On the figure, the closer the slider is on human side, the more the activity is realized (and under the responsibility) of the human operator. This distribution of implication level for each activity is supported by a Common WorkSpace (CWS) allowing communication and interaction between agents.

Both aspects are important. If the design of a cooperative assistance is only based on the capabilities of the human operator and of the technical system, then the cooperation activity will not be optimal and could be rejected by the user.

In order to design a cooperative system:

- Capabilities of the different agents must be evaluated;
- Regarding these capabilities, tasks can be allocated to the agents;
- Specific cooperation supports must be developed.

The cooperation activity usually evolves in a dynamical process. This dynamic context needs to assess dynamically the capabilities of agents or to forecast their evolution in order to adapt the way of cooperation (Vanderhaegen, 2012). These dynamic capabilities can be identified through a triplet (Vanderhaegen, 2017): the knowledge of the agents, their availability to act and the possibility to act through Human-Machine Interface (HMI).

For Human-Machine Systems (HMS), HMIs are the main cooperation support systems. Several information are transmitted by HMI: synchronization of actions, information communication, advices... The given information can be transmitted by

different channels: video or audio signal, haptic feedback, etc.. This transmission can also take different forms; for instance, a temperature setpoint can be transmitted within different visual forms: a text, a bar graph, or a picture.

Regarding evolvments of the controlled system state and of the human operator's state, the assistant cooperative device must be adapted to the kind of information, the channel and the form used to transmit this information.

Then, in order to design a cooperative system respecting these properties a specific methodology in five steps is proposed (Figure 2):

1. The first step is the identification of tasks to be shared between the support system and the human operator.
2. The second step consists in developing the abilities to the technical support system for solving the overall or a sub-part of the problem addressed. These abilities may concern one or several activities presented before (i.e., from information gathering to action implementation).
3. The third step aims at considering the human operator. It is important that the support system is developed by considering a human operator model.
4. The fourth step aims at identifying different situations of cooperation. Due to human state evolution or due to possible change of other tasks, the modality of cooperation may be adapted.
5. The last step concerns how this cooperation will work:
 - Which kind of information/advices will be transmitted,
 - Which transmission channel will be used,
 - Which communication form will be used.

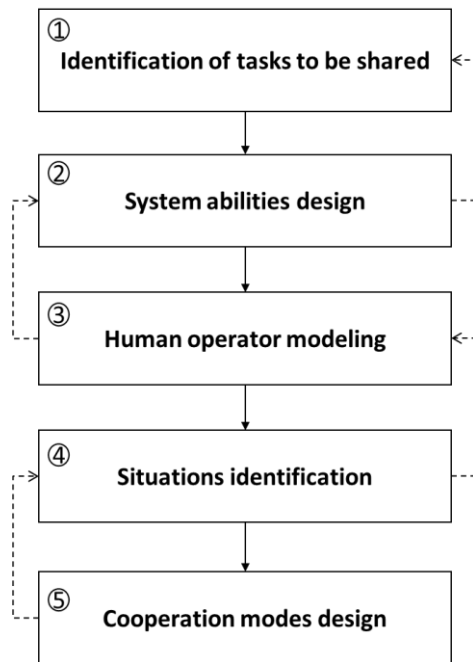


Figure 2. five steps method to design cooperative support system.

After a given step it is possible to update and revise the previous one. The following parts illustrates how this method is applied used to design and study a so-called Cooperative Eco-Driving Rail Control System (CEDRICS) for tramway.

2 Design of CEDRICS

One of the main challenges for the tramway operators is to increase the railway traffic flow and, in the same time, to reduce the associated energy consumption. Recent researches aim at reducing energy consumption by developing innovative vehicles thanks to the mass reduction and the integration of hybrid technology for instance. However, most of these contributions are limited to technical approaches without considering any human factor. The driver behavior characteristics are other factors that require interest to reduce vehicle energy consumption.

2.1 Identification of task shared (Step 1)

In this paper, CEDRICS cooperates with a human driver. Driving a tramway is a complex task that need to consider several constraints: security/safety, timetable, management of passengers, interaction with the environment (e.g., interactions with other vehicles, with pedestrians, etc.). The new constraint of energy consumption and its environmental impact are complex to take into account because several parameters such as the weight of the tramway,

the speed limitations, the acceleration limitations, and the geometry of the track must be considered.

Usually, ADAS (Advanced Driver Assistant System) are implemented into the driver cabin to help the eco-driving behavior. The eco-driving behavior must reduce the energy consumption and the ecological impact. (Nouvelière, 2010, Mensing, 2014, Gastro Garcia, 2014, Backhauss, 2014) explain in their works that energy consumption and ecological impact are linked and both are reduced in the same time when the control system (included into ADAS) is optimized. These systems dedicated to eco-driving are called EDAS (Eco-Driving Advisory System). They aim at defining an operational driving strategy that reduces fuel consumption and at assisting the driver to apply the eco-driving principles while reducing the cognitive load of the driver compared to an eco-driving performance without assistance (Saint Pierre et al., 2010; Yamabe et al., 2011; Andrieu et al., 2014; Barbé et al., 2014). In railway transport, several studies investigate the problem of an eco-driving system based on velocity of the train. They consider the research of the speed profile as an optimal control problem that minimizes the energy consumption under time constraint (Howlett, 1996; Klaučo et al., 2017; Yin et al., 2017; Lagos et al., 2000; Liu et al., 2003, Boukal et al., 2019). They focus on an optimization problem of a high-speed train and of varying track gradient to determine speed profile which is given to driver thanks to Human-Machine Interface (HMI). The advantage of these approaches is the development of automated vehicle, but this is not possible for the application domain such as the tramway field where the presence of human operators remains necessary. Moreover, such an automation raises new questions as about system reliability when disaster occurs for instance. An EDAS is rarely designed considering the driver behavior and consequently cannot ensure the best performance of the eco-energetic advice because of safety, traffic flow or human cognitive state constraints.

A driver assistance system advice the driver. But he/she can decide not to apply the proposed eco-driving command due to several reasons (safety for instance). This requires the reassessment of the optimal eco-driving advice by considering such human behavioral errors. In this context, a behavioral error is defined as the gap between the command applied by the driver and the command advised by the ADAS. This control can be solved by applying the principles of Human-Machine cooperation which consist in dynamically sharing tasks between the human operator and an automated system. Tasks are shared at each stage of a decision from the detection to the action (Vanderhaegen, 1999a; Zieba et al., 2011; Vanderhaegen, 1999b), during a specific task, such as the diagnostic task (Vanderhaegen et al. 2004), an air traffic control task (Vanderhaegen, 1999c; Vanderhaegen, 1999d), a

knowledge based conflict detection task (Zieba et al., 2011; Vanderhaegen, 2016; Polet et al., 2002; Pacaux-Lemoine et al., 2013), or a driving task (Sentouh et al., 2009; Sentouh et al., 2006; Sentouh et al., 2013; Soualmi et al., 2014; Zieba et al., 2011). The adaptability of the human operator makes it a complex system but essential to the optimal functioning of a Human-Machine System. In order to prevent the driver from adapting to an EDAS, new interactions are implemented. Several transmission channels such as haptic interfaces or head-up-display systems were proposed (Azzi, 2012; Tretten et al., 2009). The use of a haptic interface reduces driver fatigue when it is necessary to maintain a constant position of the accelerator pedal of the vehicle (Kaim et al., 2010; Abbink et al., 2011; Coughlin, 2012). Nevertheless, this advice is not adapted to a driver-vehicle system because it tries to control the driver's behavior. The head-up display is used for communicating information beyond the windshield. This aims at reducing the driver's head movements due to the research of relevant data into the car, train or aircraft cabin, at reducing the human workload, and at increasing the detection performance of unsafe situation (Liu et al., 2004; Davies et al., 2012; Oppenheim et al., 2010).

In the proposed CEDRICS, several constraints are treated: speed limitations, acceleration, jerk, inter distance and timing, short time to drive between two stations and presence of pedestrians and car drivers. The driving mode is manual, and a predictive control model is proposed to determine an optimal speed profile related to eco-driving goal and the urban driving constraints. The main difficulties of such an implementation relate to the identification of the driver behavior characteristics and their integration into the control optimization problem of a tramway to compute the speed profile which minimizes the energy consumption. Driver's behavior is dependent of human factors as fatigue, attention, vigilance, workload, situation awareness (Oppenheim et al., 2010; Salvendy, 2012; Liukkonen, 2009). The paper details the CEDRICS support which is an EDAS considering human behavior characteristics to compute the on-line eco-driving speed profile.

The next sections define the CEDRICS structure and functioning. Then the last section proposes an experimental validation process of CEDRICS.

2.2 System abilities design integrating the human operator model (Step 2 and 3)

The objective of the research work is to propose an EDAS which adapts the eco-driving advice to human factors. Firstly, the proposal minimizes the consumption of a tramway. The implementation of a driverless EDAS dedicated to a tramway considers the train movement from a given station to the next one. This movement is carried out in a predefined timing

(Howlett et al., 1994; Howlett, 1996; Liu et al., 2003). The corresponding driverless EDAS computes an optimal control strategy to reach the next station without any delay. This strategy can be translated in terms of a speed profile, or an acceleration profile for instance. These profiles are computed into a multi-model-based controller. This controller requires the implementation of the motion and consumption models. When the vehicle is autonomous and when there is no environmental perturbation, a computed direct eco-driving control can be applied (Figure 3). To determine this eco-driving velocity, the controller needs the current vehicle velocity $v(t)$, the current acceleration and its location on the track $p(t)$.

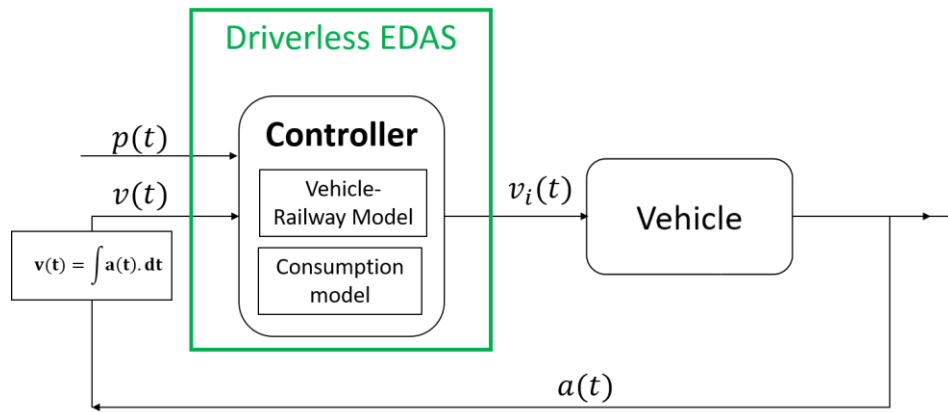


Figure 3. Driverless EDAS configuration.

Unless a full traction control is adopted, the tramway driver is in charge of the urban train constraints and the eco-driving control. The driving action can be modelled by the driver's behavior on the throttle manipulator. The eco-driving command requires a support for HMI (Figure 4). The driver then receives an advice to be applied in order to optimize the energy consumption by considering a possible delay. This advice could be a velocity, a throttle manipulator position noted $\gamma_c(t)$, etc. The throttle manipulator position transmitted by the driver, noted $\gamma_i(t)$, is converted into an electrical power for the vehicle. This activates the electrical motor which is transformed into an acceleration $a(t)$. The integral of the acceleration is computed to send the current velocity of the vehicle in the controller. The current vehicle position in the track is also transmitted to the controller to compute the optimal eco-driving advice. In this article, this EDAS is called as HMI-EDAS.

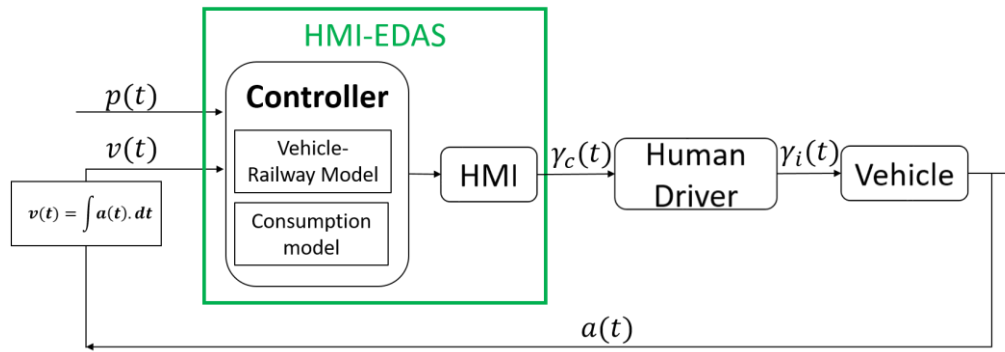


Figure 4. HMI-EDAS configuration.

HMI-EDAS integrates the vehicle model into the optimization problem but the human behavior is not considered. Therefore, CEDRICS is proposed (Figure 5). CEDRICS integrates the human behavior by the way of a Driver-Vehicle-Railway (DVR) model. Nevertheless, the integration of the driver behavior model in the optimization problem is not enough:

- Drivers must adapt their behavior to the assisting support system.
- The performance of the drivers depends on the work conditions and on the cognitive state of the driver (Hermannstädter et al., 2012, 2013; Macadam, 2003).
- The driver state changes during the driving task (Hermannstädter et al., 2013; Macadam, 2003; Pilutti et al., 1999);
- The cognitive and physical states of the driver depend on human factors such as fatigue, workload (Hermannstädter et al., 2012, 2013);
- level of vigilance (Pilutti et al., 1999);
- etc.

For CEDRICS, the human factors' evolution during the driving task changes the driver's behavior and consequently the parameters of the driver model from McRuer (McRuer et al., 1974), as the compensation gain K , the response time and the neuromuscular time. HMI-EDAS does not have the possibility to consider such an evolution of the behavioral model parameters of the driver during the driving task because the parameters of the Driver-Vehicle-Railway (DVR) model are fixed in the control optimization problem.

CEDRICS computes the real-time eco-driving instruction. In order to improve the eco-driving performance, the driver is invited to respect these instructions. The optimal control problem of CEDRICS considers a DVR model from which it calculates an eco-driving set-point. It uses a multi-model approach minimizing the vehicle's energy consumption (La Delfa et al., 2016). It integrates two models: a consumption model, a Driver-Vehicle-Railway model.

CEDRICS adapts itself to the behavior of the human driver thanks to an identification algorithm. It allows, unlike HMI-EDAS, to modify the parameters of the DVR model from the identified parameters of driver model modelling the human operator behaviors.

CEDRICS identification algorithm used to identify the driver behavior model parameters, and to represent the driver vehicle model, is the Recursive Least Squares (RLS) algorithm. The identification of the parameters is carried out from a database in which the eco-driving instruction and the control applied by the human driver are stored. The identified parameters are then used in the control optimization algorithm to update the DVR model.

CEDRICS is then a driver-oriented EDAS that adapts itself to the behavior of the driver during the driving task. A RLS algorithm assesses the parameters of the driver model and updates the DVR model of the optimization control problem during the driving task. The DVR model parameters are then updated in order to adapt the advice to human driver relatively to the current driving situation and the current human behavior (Figure 5).

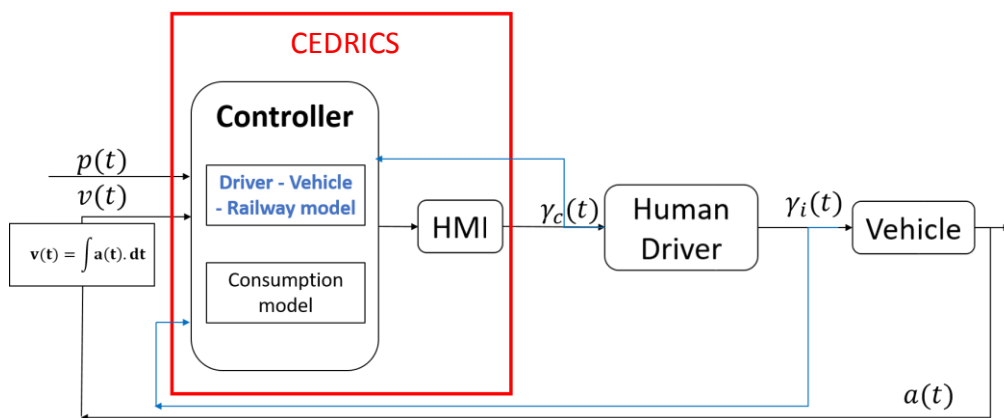


Figure 5. CEDRICS configuration

- The controller in Figure 6 is composed to RLS, and an optimal control problem. The inputs of the RLS algorithm are the current advice transmitted to driver $\gamma_c(t)$, and the control applied $\gamma_i(t)$. Two main reasons may influence the driver response: his/her own state (for instance drowsiness) and external event requiring more attention and/or to modify speed (braking) for safety reason (pedestrian on track). No sensor is used to analyze the environment of the tramway. This identification algorithm permits updating the driver model parameters in the Driver-Vehicle-Railway (DVR) model. The optimal control problem has the following inputs: the current acceleration $a(t)$, speed $v(t)$, and the current position $p(t)$ of the tram and for output the advice $\gamma_c(t)$. It computes the acceleration profile which minimizes the vehicle consumption. It is composed of four elements. The first element is the DVR model, the second is the

vehicle consumption model, the third is the travel time and the last component, the constraints such as the speed limitations. The DVR model is composed by two merged models: the driver model: used to integrate the driver behavior in the optimal control problem;

- The Vehicle-Railway model: defined the vehicle motion.

The vehicle consumption model is used to define the cost function to minimize the optimal control problem. The travel time is used to define the optimization horizon and the constraints represent some characteristics of the vehicle, the railway (speed limitations, slopes and curves), safety, and comfort constraints.

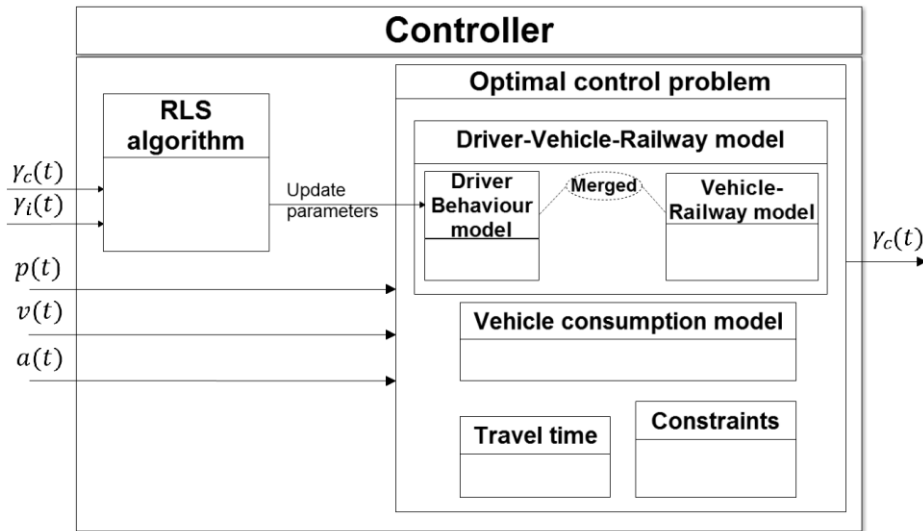


Figure 6. CEDRICS architecture.

CEDRICS operating procedure algorithm is given in Figure 7. It presents a recursive algorithm which manages the controller's algorithms. The first algorithm is used to identify the driver behavior model parameters. After the identification, the DVR model is updated. Then the optimization problem is defined and the acceleration profile in function of time travel which minimizes the energy consumption is computed. The optimal control problem considers the time spent by the tramway to join the next station. The speed profile computed permits to transmit the eco-driving advice by the HMI presented next section. The eco-driving recommendation and the real input control applied by the driver are recorded in a data base. This data base will be used to assess human behavioral gaps and to solve the identification problem to determine the parameters of the driver behavior model. If the final conditions which are to join the next station in a time course, the speed, and the throttle manipulator position at the neutral position, so the algorithm stops and the next journey is updated in the

optimization problem otherwise if the condition is not respected then all steps are recursively called.

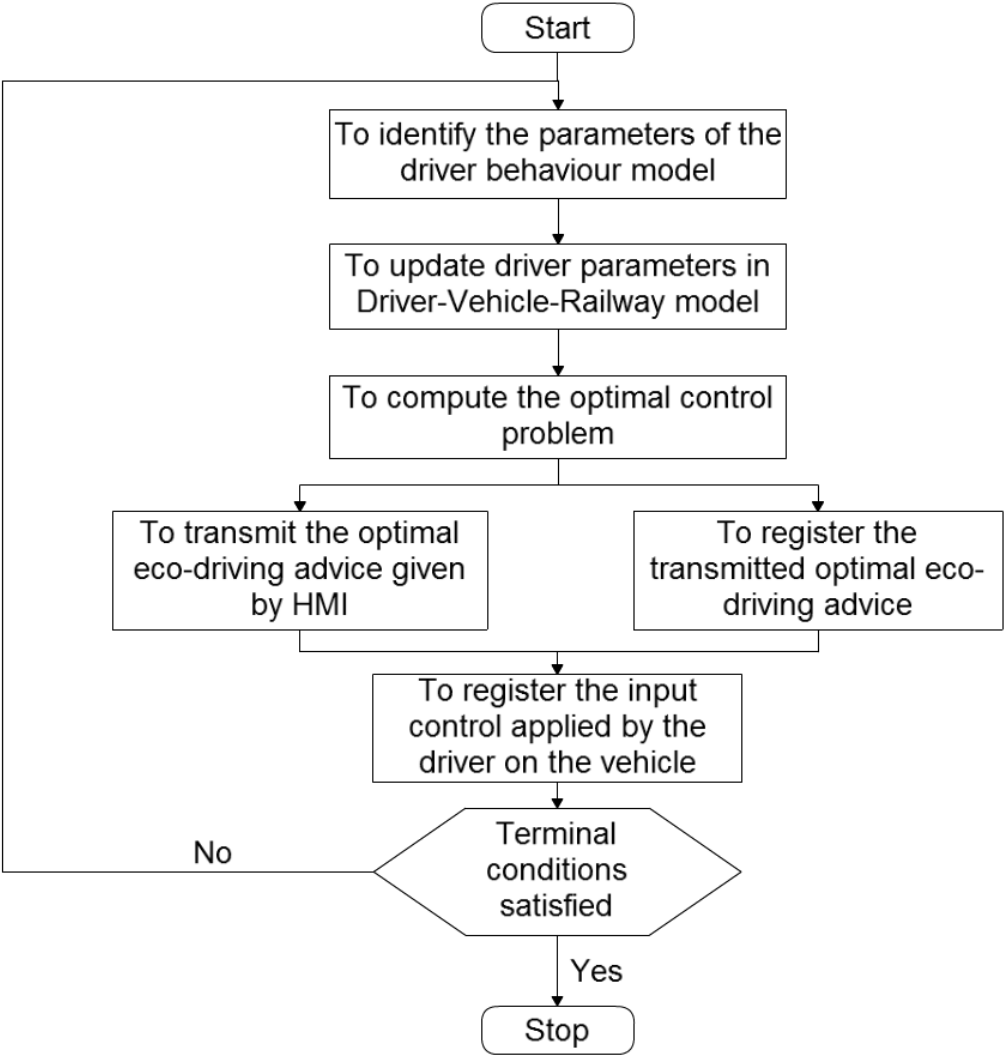


Figure 7. The recursive CEDRICS algorithm principle.

Unlike HMI-EDAS, the displayed eco-driving advice given to the driver is not necessarily identical to the eco-driving command. The advice displayed on CEDRICS interface considers the human driver performance to tracking the last advices. This guideline makes it possible to consider the probable driver follow-up error due to the human factors evolution to allow the follow-up of the eco-driving command. Regarding a classical HMI-EDAS approach, the novel point of CEDRICS is the integration of a human behavior model to handle the eco-driving command. Therefore, CEDRICS includes a human error tolerant controller that takes into account the dynamic constraints of the vehicle and of the driver to define an optimal eco-driving set-point.

2.3 Cooperation modes design (steps 4 & 5)

Human driver must manage the movement of the tramway, respecting speed limitation, timetable, safety of passengers and interactions with other vehicles and pedestrian. The density of interaction may affect the workload of the human operator. Three categories of density of interaction may be distinguished:

- No interaction: the tramway is driving in area where there is no pedestrian and no other vehicle.
- Strong interactions: the tramway is driving in area with a lot of pedestrians crossing tracks, with other cars on the road.
- Mixed interactions: there are some interactions, but the density is light.

2.3.1 kinds of information:

For safety reasons and technological limitations environmental information gathering is affected to the driver, information related to the vehicle is gathered by the technical system. Safety information analysis is mainly done by the driver, speed calculation and optimization are realized by the technical system. The technical system (CEDRICS) advises the driver regarding decision to brake or accelerate.

2.3.2 transmission channels:

Two different transmission channels were used in order to communicate with the driver:

- Haptic feedback information with a throttle manipulator,
- Visual information
 - with a head up display based on CEDRICS principle
 - with a head up display based-on MPC.

2.3.3 Communication form:

The control of the tramway requires the use of a traction manipulator. The traction manipulator is divided into structural zones dedicated to different operations:

- Traction zone (green zone of Figure 8.): this zone increases or maintains the tramway velocity;

- Braking zone (yellow zone of Figure 8.): this zone reduces the tramway velocity or stops slowly the vehicle;
- Neutral/coast zone (white zone of Figure 8.): the tramway advances according to its inertia because the traction level of the manipulator is equal to zero;
- Emergency braking zone (orange and red zone of Figure 8.): the tramway brakes stronger for an emergency stop.



Figure 8. Throttle manipulator.

The tramway drivers must respect the VACMA system constraints. The VACMA is a dead man's switch that sends stimuli to the drivers who must react in order to confirm their presence into the cabin. If there is no answer by the human operator after these stimuli occurrence, the vehicle automatically engages an emergency braking.

The HMI for HMI-EDAS and CEDRICS are the same. The eco-driving advice is given via a Head-Up Display (HUD), Figure 9.

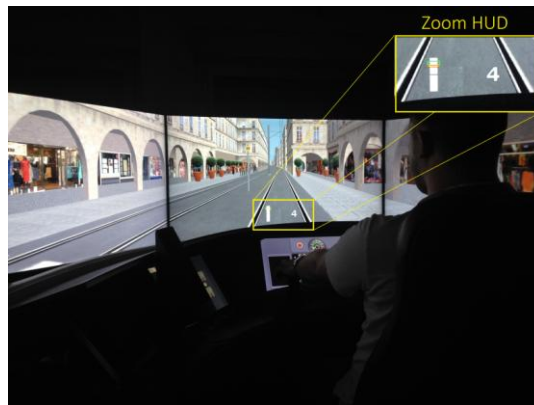


Figure 9. Driver cabin

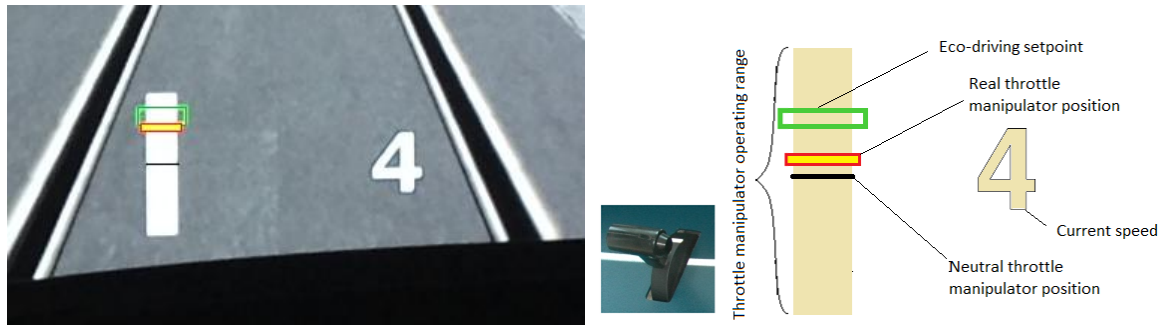


Figure 10. Human-Machine Interface in Head-Up Display (HUD).

The second driver task consisted in tracking the eco-driving advice with the traction manipulator. This task is considered as a secondary task because the priority task is the safety one. The HUD (Figure 10) returns several data to the driver. The trackbar represents the traction manipulator range. The neutral position of the traction manipulator is represented by a black bar and the advice related to the manipulator position to be achieved is given by a green box. The current traction position is displayed by a red and yellow box, and the tram velocity is displayed on the right part of the trackbar.

In the next section, the experimentation which confronts CEDRICS to HMI-EDAS with tramway drivers is presented.

3 Experimentation

This section presents the experimental protocol implemented at the University Polytechnique Hauts-de-France to compare CEDRICS and HMI-EDAS performances.

3.1 Experimental protocol

The driving task is implemented in a rail simulator (Figure 11.) developed at the University Polytechnique Hauts-de-France.



Figure 11. The rail simulator of the University Polytechnique Hauts-de-France.

This simulator integrates a realistic model of a tramway called Citadis 302. A generic environment is implemented to confront the operator to realistic situations. Drivers were invited to participate to the experimental protocol to compare their performances between a HMI-EDAS and the CEDRICS.

Twelve drivers, aged between 24 and 38 years, executed the driving task with the Rail simulator.

They drove twice on about 2500 meters for 10 minutes. The proposed driving scenario is in an urban environment with slopes, curves, velocity limitations and an environmental condition. Three kinds of environmental contexts are proposed:

- In the first environmental condition, cars and pedestrians do not occur;
- In the second environmental condition, cars and pedestrian occur permanently throughout the duration of the scenario;
- In the last environmental condition, cars and pedestrian occur intermittently.

Before the experimentation, a training phase is realized for 2 minutes in another environment. The objective of the training phase is to facilitate the use and the understanding of the platform behavior, the VACMA system functioning and to account for the vehicle inertia. After the training phase, each participant drove on the same route but did not use the same support system. Six drivers used the HMI-EDAS system and the others used CEDRICS.

In same environmental conditions, drivers had to respect the safety constraints (travel time schedule, velocity limitations, etc.) and to reduce the consumption of energy of the vehicle.

During an experiment, all information about the vehicle and the driver is recorded each 0.1 second. These data are used to compare the eco-driving command tracking performance and the energy consumption obtained by the human operator for each route and eco-driving system.

3.2 Results

Table 1 presents the CEDRICS eco-driving tracking task performances compared to those obtained with a HMI-EDAS. The second, third and fourth column give the results obtained for each environmental condition. Therefore, column 2 entitled “no interaction” relates to the scenarios without any occurrence of pedestrians or cars. Column 3 called “strong interaction” displays the results obtained during the scenarios involving interactions with pedestrians and cars. Column 4 called “Mixed” contains the results of the scenarios with intermittent occurrence of pedestrians and cars. The second line of Table 1 concerns the eco-driving control tracking performance obtained with the HMI-EDAS system, in the third line the performance obtained with the CEDRICS. The driver performance is noted in percent in the third and fourth row. This performance must be near 100% which corresponds to a perfect tracking performance. The last line presents the improvement of the tracking task obtained with CEDRICS. When the result is positive, the tracking task performance is improved by using CEDRICS.

Table1. Comparison of the Eco-driving command tracking performance

Environment	No interaction	Strong interactions	Mixed
Eco-driving command tracking performance with HMI-EDAS	76%	67%	70%
Eco-driving command tracking performance with CEDRICS	81%	82%	82%
Improvement of tracking performance obtain with CEDRICS	+6.5%	+22%	+17%

CEDRICS increases the eco-driving control tracking performance and maintains the level of eco-driving control tracking performance in the three environmental conditions compared to the performance obtained with HMI-EDAS. CEDRICS reduces the possible negative impact of the environmental condition and leads to adapt the advice regarding the driver behavior.

The table 2 presents the benefits of the improvement of tracking performance obtained with CEDRICS compared to HMI-EDAS in terms of electric force and consumption reduction. In the third line, a positive percentage represents a reduction of the transmitted force applied to the vehicle. The reduction of force applied to the vehicle motor is supposed correlate at the reduction of the electrical energy consumption. The improvement of the electrical energy consumption is defined by a positive percentage in the last line of the table. The results are given for each traffic conditions (no interaction, strong interactions and mixed).

Table 2. Comparison of the performance of the minimization of the consumption function of CEDRICS regarding HMI-EDAS

Improvement obtained with CEDRICS regarding HMI-EDAS			
Environment	No interaction	Strong interactions	Mixed
Quadratic power saving (u^2)	+15%	+8%	+31%
Energy saving ($u * v$)	-6%	+9%	+14%

CEDRICS increases the performance of reduction of the force applied to the vehicle. In the strong and in the mixed interaction environment the reduction of this force applied to the electric motor of the vehicle is correlated to the reduction of the electric energy consumption. The reduction of the force of about 31% applied to the motor is correlated to an improvement of the energy consumption of about 14% in mixed environment condition. In strong interaction environment, the reduction of 8% of the force applied to the motor is associated to an improvement of 9% in terms of energy consumption. However, when the driver is not disturbed by traffic conditions, this correlation is not valid. It is possible to consider that the minimization of the force applied to the vehicle is sufficient to reduce the energy consumption in medium and high traffic density contexts related to the presence of threats as pedestrians or cars.

A statistical analysis was performed with the Statistica software. The normality of the distributions is examined by the Shapiro-Wilk W test. If the normality is verified, the

comparison between the performance obtained to track the eco-driving command with CEDRICS and the eco-driving tracking performance with HMI-EDAS is carried out by the independent t-test, otherwise the Wilcoxon Mann Whitney's nonparametric test is applied. All statistics are relevant when the error probability level is under 5 % ($p < 0.05$). Table 3 presents the variable used to show the probabilities results.

Table3. Variable used to present probability test

Parameters	Signification
M	data Mean
SD	data Standard Deviation
t	t-test result
U	Mann Whitney Wilcoxon result
p-value	Probability compared to the significance level. If p-value is lower than P the error significant level so the difference between the two systems is significant

To confirm the results of the tables 1 and 2 this statistical analysis was done. For the first environmental condition data do not follow the normality distribution. Then, the Wilcoxon-Mann-Whitney test was applied. There was not a relevant difference in the performance of the tracking task with the CEDRICS ($M=0.816$, $SD=0.116$) and the HMI-EDAS ($M=0.758$, $SD=0.181$); $U(38) = 241$; $p=0.273$. These results confirm that CEDRICS does not influence the eco-driving command tracking task when there is no pedestrian nor car.

The t-test is applied for the second environment because the data respect the normality distribution. There is a relevant difference in performance between the CEDRICS ($M=0.817$, $SD=0.091$) and the HMI-EDAS ($M=0.667$, $SD=0.210$); $t(38) = 2.932$; $p\text{-value}=0.006$. These results suggest that CEDRICS improves the eco-driving command tracking when there are a lot of interactions between the driver and the environment.

For the last environment, the t-test is used. There is a significant difference on performance between the CEDRICS ($M=0.816$, $SD=0.116$) and the HMI-EDAS ($M=0.699$, $SD=0.192$); $U(38) = 281$; $p\text{-value}=0.029$. These results confirm that CEDRICS influences the eco-driving command tracking when the driver involved in the third environment.

Table4. Statistical analysis

Environment	Test	System comparison	Results
No interaction	Mann Whitney Wilcoxon	CEDRICS (M=0.816, SD=0.116)	U (38) =241; p=0.273 CEDRICS does not influence the eco-driving command tracking
		HMI-EDAS (M=0.758, SD=0.181)	
strong interaction	t-test	CEDRICS (M=0.817, SD=0.091)	t(38) =2.932; p-value=0.006. CEDRICS improves the eco-driving command tracking
		HMI-EDAS (M=0.667, SD=0.210)	
Mixed interaction	Mann Whitney Wilcoxon	CEDRICS (M=0.816, SD=0.116)	the U (38) =281; p-value=0.029. CEDRICS influence the eco-driving command tracking
		HMI-EDAS (M=0.699, SD=0.192);	

4 Conclusion & discussion

CEDRICS proposes a new multi-model approach to design an eco-driving cooperative system integrating the human behavior. The goal of CEDRICS is to reduce the energy consumption and to increase the tracking task performance of the eco-driving control of the human driver.

The design of this cooperative support system followed a methodology on 5 steps : the first step at identifying tasks shared between agents, the second step consists in developing abilities to perform these tasks (or parts of them), the third step aims at modeling the human operator, the fourth step identifies the different situations in which agents will be confronted, the last step is dedicated to the different cooperation modes specification.

The comparative study demonstrated that eco-driving command tracking performance was better and stable with CEDRICS (82%). CEDRICS is a cooperative support system considering the human state variation. This adaptation is based on human and situation modeling as proposed in our five steps method to design cooperative support system.

This was an exploratory study to validate the concepts presented in the article on CEDRICS.

Although the experimental campaign involved a small number of participants, it allows to establish a first exploratory study on the feasibility and the validity of the concepts presented in the article on the CEDRICS system. Moreover, statistical tests dedicated to small sample size were positive. A second validation step will consist in studying the impact of the use of CEDRICS in the short, medium and long term, on the same line or several tramway lines, with one or more drivers on these lines. These experimental campaigns can be done in simulation or in the actual driving cabin, in collaboration with railway operators or train builders.

The proposed multi-model-based controller implemented into the CEDRICS aims at considering the driver behavior to compute the optimal eco-driving advice. The results of an experimental protocol confirmed that CEDRICS reduces the negative impact of human factors and facilitates the control of a tracking tasks dedicated to the eco-driving whatever the environmental conditions. This means that CEDRICS facilitates the human ability to track the eco-driving control and increase his level of attention and vigilance.

This research work assumes that the minimization of the force applied to electric motor could reduce the energy consumption. The results of the experimentation prove the link between the force applied to the electric motor and the energy consumption. However, an environment where there is no pedestrian and no car does not validate this hypothesis.

Therefore, future research work will aim at studying the human driver eco-driving performance in low traffic density regarding human factors such as workload, attention or vigilance. This implies, the need to consider more parameters into the human behavior model. Moreover, a new way of improvement will consider the CEDRICS as a cooperative system to share the driving task control between the human driver and the CEDRICS. Another improvement will consider a solution based on a multi-controller approach in order to assess the optimal setpoint via several assessments adapted to the environmental situations.

A driverless configuration could be applied where there is no interaction with pedestrian and car driver to increase the human driver attention and vigilance and to increase the eco-driving performance as in Rao's Work (Rao et al., 2016). When the vehicle interacts with pedestrians, cars and other trains, CEDRICS may activate another controller that assesses an advice dedicated to the human operator to support the manual eco-driving. Real-time constraints can also be solved by computing other controllers based on the principles developed on this paper and mixed with the so-called mirror-effect learning developed on (Vanderhaegen, 2016). Regarding the previous evolutions of technical, human, environmental and organizational factors, the multi-model base controller presented on this paper will be used to assess the

optimal setpoint. A data base will mirror a part, or the totality of the real occurred data and the multi-model-based controller will associate to each input vector the optimal setpoint. This avoids the reassessment of this setpoint related to the current and previous data.

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