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OPTIMIZATION OF DRIVING TECHNIQUE OF RWD RACING CAR FOR FASTER CORNERING

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Abstract

The paper deals with increasing performance of a sports car through multicriteria optimization of driver actions (14 decision variables describing application of steering wheel, brake and accelerator pedals). Numerical example considers extreme negotiation of a RH corner (medium grip) with LADA 2105 VFTS (RWD, 106HP) prepared for road racing. Model (called "miMa") of the vehicle with 26 state variables and 420 parameters was formulated and verified on the basis of road tests. The optimization goal function includes two criteria, i.e. section time and exit velocity. Different driving strategies giving an improvement are found.

Changing the driving strategy, according to the obtained optimization results (no21) utilizing genetic algorithms, the section time (t_{AB}) can be reduced by 2.5% and the exit velocity (v_B) can increased by 3.5%, what in a competition reality gives a tremendous progress. Formulated "miMA" soft enables also combined optimization of driver actions, vehicle chassis parameters and motion trajectory.

Keywords: *racing car dynamics, lap time optimization, race driving technique, rear wheel drive*

1. Introduction

Paper deals with increasing performance of a sports car through optimization of driver actions (using of steering wheel, brake and accelerator pedals) for a selected closed-loop maneuver on a racing track section. Typically, these characteristics are chosen based on many road test with trial and error methods [9, 10]. Inherent multidimensionality and nonlinearity make this process highly expensive (and frustrating). In order to reduce this development cost a model (called "miMA") of driver-vehicle-road system adapted for optimization problems was formulated (Fig. 1) in Matlab environment by the author [3-8].

In comparison to known procedures for addressing this problem [1,2], "miMA" soft is characterized by:

a. possibility of combined optimization of driver actions for closed-loop maneuvers, vehicle chassis parameters and motion trajectory;
b. actions of real and virtual driver are substituted by additional optimization variables, what emulates driver adaptation process of searching for speed (without need of modeling of a race driver!);
c. multibody spatial model of vehicle with discrete parameters specialized in motorsport applications;
d. implemented genetic algorithms enable search for global minimum of a highly nonlinear task;
e. decision variables with mixed continuous-discrete domain;
f. effective code yielding proper balance between model accuracy and computation time.

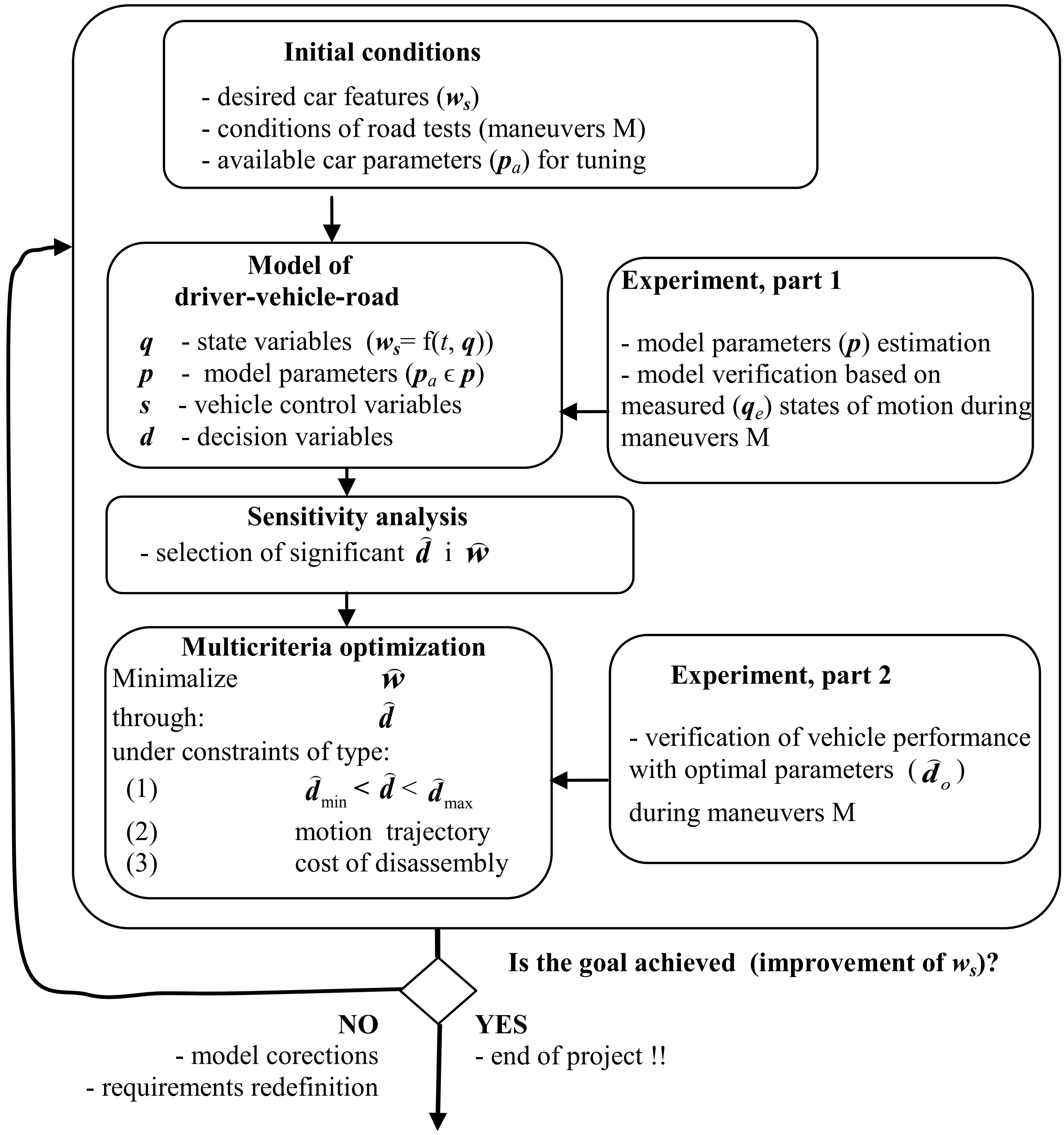

Fig. 1. "miMA" algorithm for a car performance increase through optimization of its computer model

2. "miMa" model of driver-car (Lada VFTS)-road system

Model of driver-vehicle-road system (Fig. 2) adapted for optimization problems was formulated by using Matlab soft. The vehicle model relates its design parameters ($\boldsymbol{p}$) and driver actions ($\boldsymbol{\delta} = [\boldsymbol{\delta}_h\ \boldsymbol{\delta}_b\ \boldsymbol{\delta}_a\ \boldsymbol{\delta}_c\ \boldsymbol{\delta}_g\ \boldsymbol{\delta}_e]^T$, steering hand wheel, brake and accelerator, coupler, gear shift, e-brake) with the vehicle dynamic characteristics, which can derived based on its motion states ($\boldsymbol{q}, \dot{\boldsymbol{q}}$). The driver model has to guide (P1) a car on a desired path and stabilize (P2) it, using ($\boldsymbol{\delta}$) steering wheel, brake and accelerator, based on observation of the selected vehicle motion states ($\boldsymbol{\zeta}$) and visual information from road. The road-environment model includes description of road profiles (h), friction potential (μ), wind velocity (v_w) and ambient temperature (T_a).

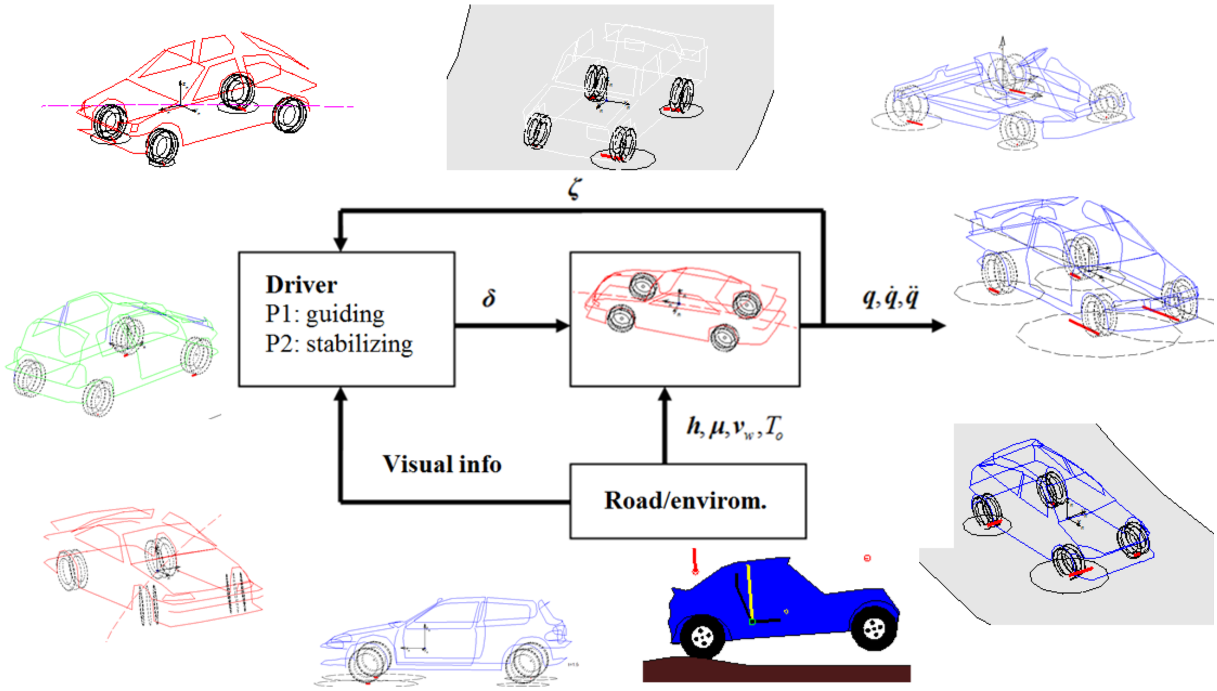

Fig. 2. „miMa" model of driver-vehicle-road system for optimization tasks in motorsport

Numerical example in the paper considers (Fig. 3) extreme negotiation of a RH corner (medium grip, even and isotropic road surface) with LADA 2105 VFTS (RWD, 106HP, 1050kg, limited slip differential, without aero effects, 180/60/13 slick tires) prepared for racing. Main components of the vehicle model, with 26 state variables (***q***) and 420 parameters, are described in Tab. 1.

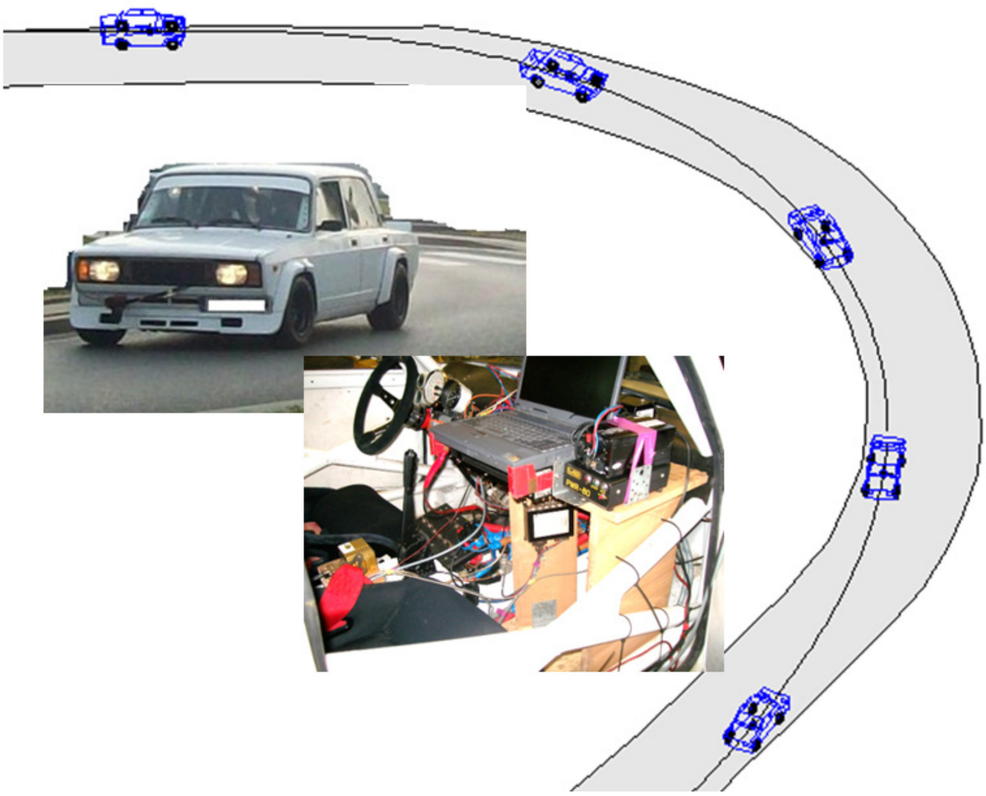

Fig. 3. „miMa" model of Lada VFTS on right-hand corner

Wheel suspension mechanisms (double wishbone in FR and rigid axle in RR) are described by spatial kineto-static models [7]. Nonlinear force characteristics of suspension springs and dampers are described by independent parameters [6]. Magic Formula with the first order dynamics and extended wheel camber effects was chosen as the tire model. Most of the model parameters were estimated on the basis of indoor and outdoor experiments. The vehicle model was verified on the basis of many motion states.

Verification results considering the selected RH corner negotiated by an expert driver, are presented in Fig. 4. The considered maneuver takes about 8 seconds and begins on a left side of straight section (A) with 83km/h initial speed (v_x in Fig. 4d). The driver still fully accelerates ($\delta_a = 1$, Fig. 4a) the car for 0.5 second approaching 85 km/h on the second gear. Then, slows down to 50km/h by application of brake pedal (δ_b, Fig. 4a) for 2.0s by using the right foot. Since the second phase of braking the driver starts overlapping the braking with a steering action (δ_h, Fig. 4b), what initiates the car turning to the right-hand corner. Lateral acceleration (a_y, Fig. 4e) and yaw rate ($\dot{\psi}$, Fig. 4c) grow in proportion to the steering wheel angle to maximum available values ($a_y = -8\text{m/s}^2$, $\dot{\psi} = -31\text{deg/s}$), when the vehicle approaches the corner apex.

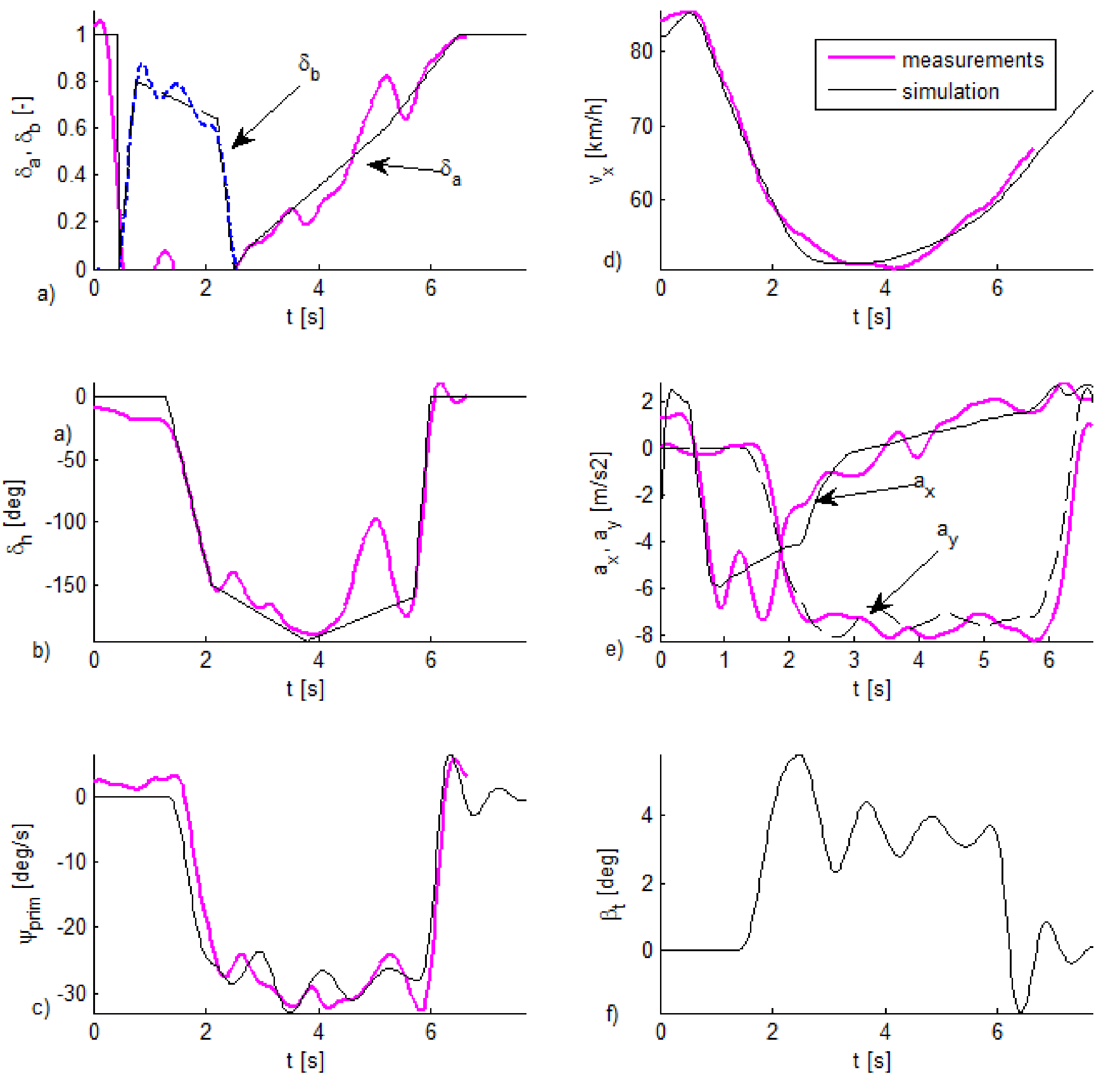

Fig. 4. Comparison of measured and simulated time profiles of RH corner maneuver with LADA VFTS

Next, the driver gradually applies acceleration pedal (δ_a) and reduces the steering wheel position heading the vehicle to the corner exit (B) with increasing velocity ($v_{x,\mathrm{B}}$ = 74 km/h with time t_{AB} = 7.7 s, Fig. 4d).

High adequacy of "miMa" model can be confirmed by evaluation of the considered Lada VFTS motion states (Fig. 4) and the obtained trajectory (Fig. 3).

Tab. 1. Description of „miMa" model components for dynamic analysis of Lada VFTS

Model parts	**Generalized coordinates (q)**	**Description**
Car body	6 (x, y, z, φ, θ, ψ)	Position and orientation of rigid body
wheels	4 (φ_1, φ_2, φ_3, φ_4)	Rotation about wheel bearings
suspensions	4 (z_1, … z_4)	Bounce motion
tires	4+4 ($s_{x1}\ldots s_{x4}$, $\alpha_1\ldots\alpha_4$)	Dynamics of tire horizontal forces
Steering sys.	1 (φ_k)	Compliance of steering shaft
Powertrain	1+1+1 (M_s, φ_m, φ_w)	Engine torque + differential + compliance of shafts
SUM	**26**	

3. Optimization of driver actions for RH corner

The described above closed-loop maneuver with RH corner will be evaluated with respect to a sport performance by using two criteria: section time (t_{AB}) and exit velocity (v_{B}). Driver actions (δ_h-steering wheel, δ_b -brake pedal, δ_a –accelerator, Fig. 4) were parameterized by piece-wise functions and included with 14 components to the optimization decision variables (***d***). The rest of the model parameters are kept constant.

Optimization algorithm for the considered maneuver is defined as follows:

- minimize the car performance criteria

  $\boldsymbol{w} = [w_1\ w_2]_{1\mathrm{x}2}$ (where: $w_1 = t_{\mathrm{AB}}$, $w_2 = -v_{\mathrm{B}}$);

- through decision variables

  $\boldsymbol{d} = [\boldsymbol{\delta}]_{1\mathrm{x}14}$, (where: $\boldsymbol{\delta} = [\boldsymbol{\delta}_{\mathrm{h}}\ \boldsymbol{\delta}_{\mathrm{b}}\ \boldsymbol{\delta}_{\mathrm{a}}]$ driver actions);

- under constraints

  $\boldsymbol{d}_{min} < \boldsymbol{d} < \boldsymbol{d}_{max;}$
  trajectory reference points and track boundaries;
  braking without full lock;
  braking with right foot;
  vehicle spin rejection.

This multi-criteria optimization has been solved by using Genetic Algorithms with nondominated sorting [3], which is effective in finding of global optima of discontinues objective spaces. Simulation of a single road scenario of 8s duration time takes about 3s on PC with 3GHz processor and 2GB RAM. About 30000 evaluations (ca. 20 hrs) of the objective function (2) are needed to terminate with satisfying results.

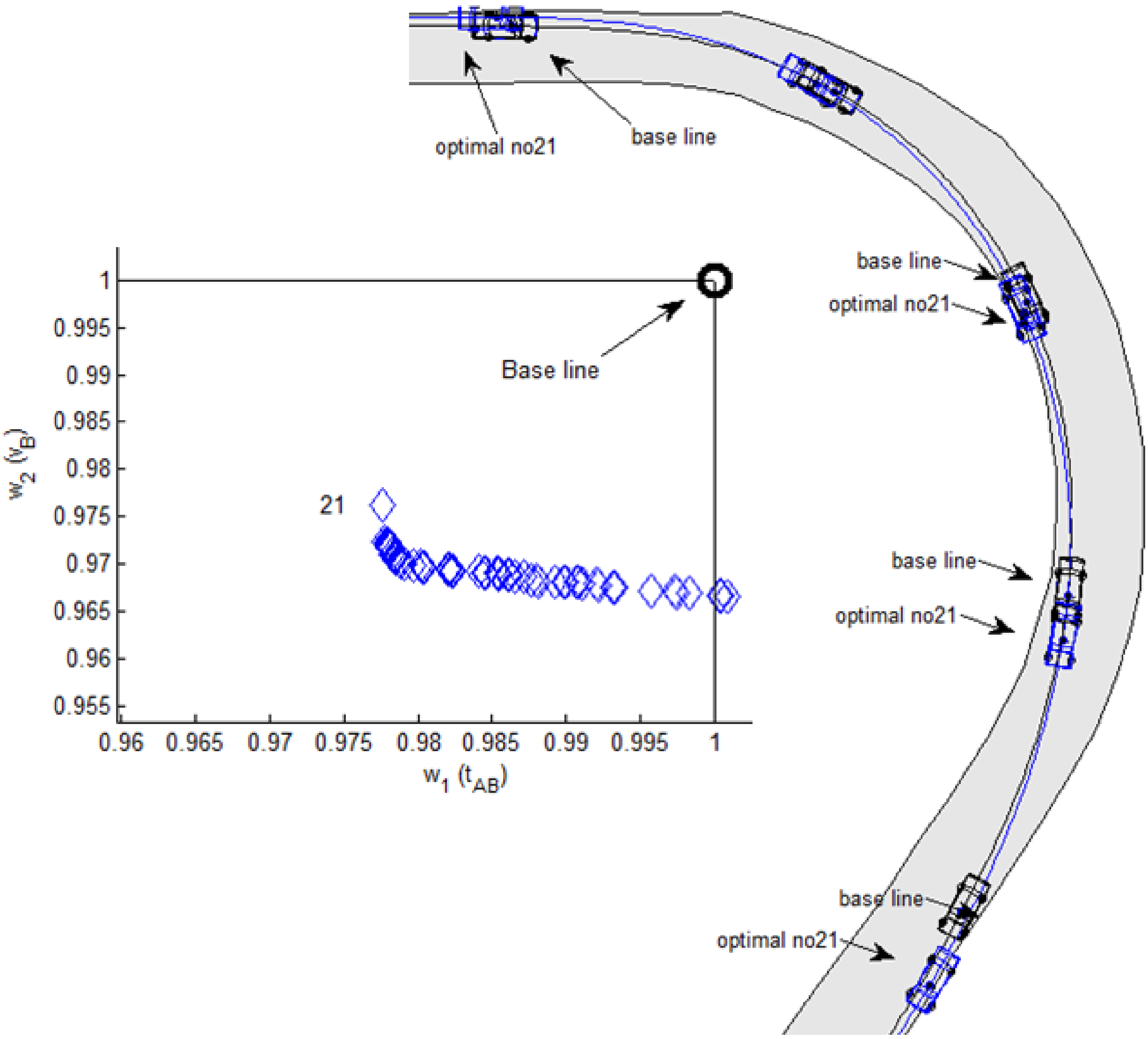

Fig. 5. Pareto-optimal results (left) and (right) comparison of base line and optimal no21 trajectories of Lada VFTS

Obtained Pareto-optimal solutions, utilizing genetic algorithms for driver actions optimization, are presented in Fig. 5 on normalized w_1-w_2 plane. Base line car-driver setup is scored by w_1= 1 and w_2= 1. Any improvement can be expected from a solution with lower criterion number.

Convex front of Pareto-optimal results (Fig. 5) means contradictory relation between the criteria, i.e. the driver can decrease time of passing this section or increase the exit velocity of the car. In dependence on the driver preferences and a type of following part of the racing track, different solution can be chosen.

For example, choosing optimal solution no21 (Fig. 5) the driver by applying the corresponding driving strategy can achieve decrease of the section time (t_{AB}) by 2.4% and increase of the exit velocity (v_B) by 2.5%. Comparison of time profiles of RH corner maneuver with LADA VFTS for base line setup and optimal solution no21, is presented in Fig.6. Corresponding trajectories of the vehicle in both cases are presented in Fig. 5. The vehicle with optimal driver actions is faster than the base line driver only in the second phase of the maneuver. This is sufficient to approach the section end (B) with reduced time by 0.3 s and increased exit velocity by 4 km/h (Fig. 6d). The goal was obtained mainly by shorter (but harder) braking (Fig. 6d) inducing greater velocity through the corner. In the well balanced car the driver could apply the accelerator much earlier what translates in further increase of the vehicle exit velocity.

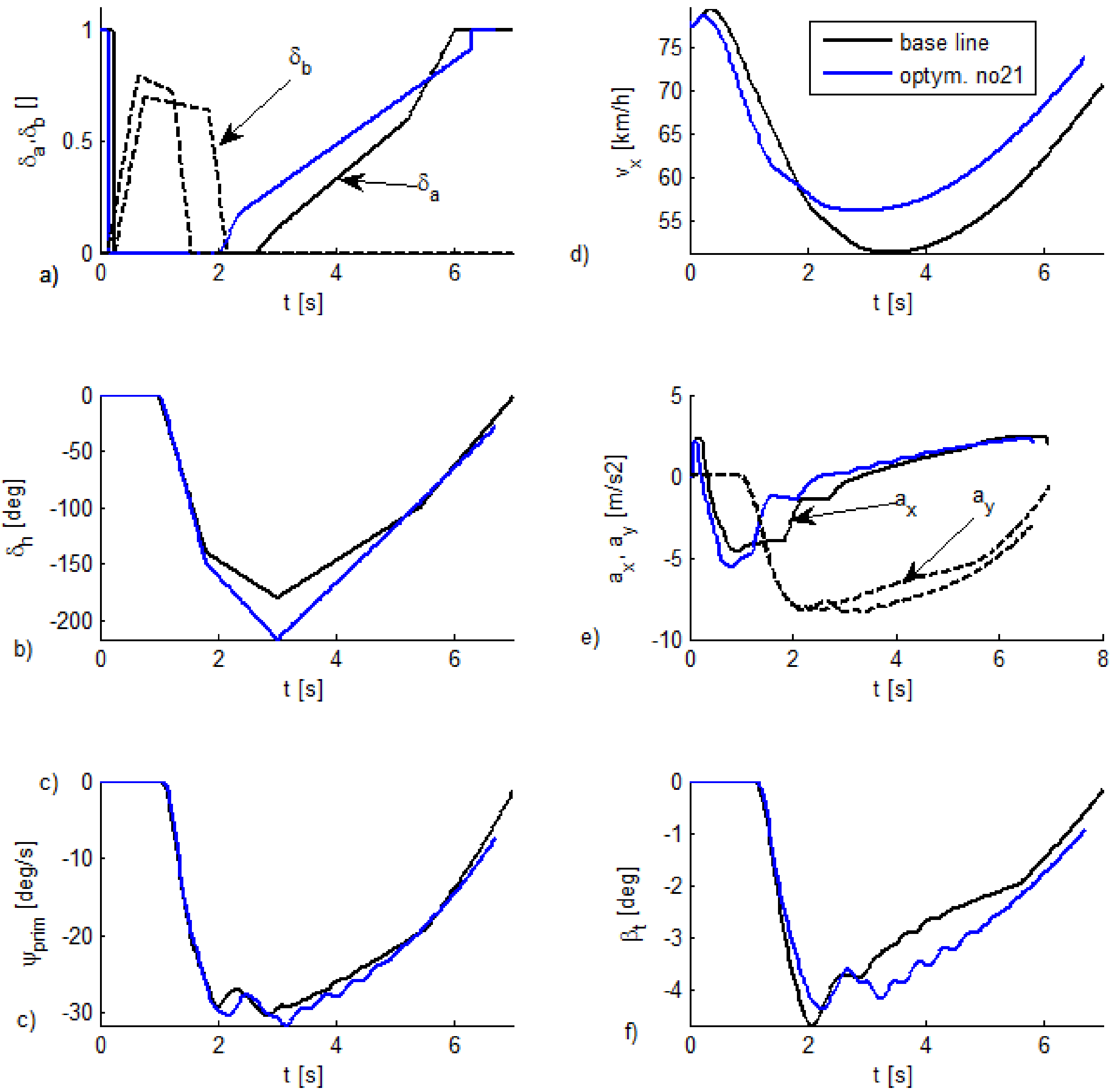

Fig. 6. Comparison of time profiles of RH corner maneuver with LADA VFTS for base line setup and optimal (no21) driver actions

4. Conclusions

The paper presents optimization results of driver actions considering extreme negotiation of a RH corner with LADA 2105 VFTS (RWD, 106HP) prepared for road racing. Decision variables were defined with 14 components describing application of steering wheel, brake and accelerator pedals by the driver during this closed-loop maneuver. "miMa" model of the vehicle with 26 state variables and 420 parameters was formulated and verified on the basis of road tests. The optimization goal function includes two criteria, i.e. section time and exit velocity of the vehicle. The optimization constraints included fixed trajectory of motion and boundaries of the racing track section.

Changing the driving strategy, according to the obtained optimization results (no. 21) utilizing genetic algorithms, the section time (t_{AB}) can be reduced by 2.5% and the exit velocity (v_B) can increased by 3.5%, what in a competition reality gives a tremendous progress.

Formulated “miMA” soft enables also combined optimization of driver actions, vehicle chassis parameters and motion trajectory.

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