MODEL-BASED ENGINEERING - SIMULATIONS BASED DESIGN OF THE SUSPENSION OF CITY BUS

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Abstract

Process of designing of vehicle suspension as a combination of springs and dampers is a very complicated task. In general it requires designing system respecting good ride comfort and good handling at the same time. It is obvious that these two aspects are dependent also of the type of the road on which vehicle is riding. Especially it is important in city buses which are workplaces for bus drivers and each day are transporting thousands of people. Bus suspension system is quite different from car suspension. Because of the mass and size instead of traditional springs, pneumatics springs are used. In some cases, values of damping and stiffness of the spring are adjusted to the proper road in a real bus while driving. It is necessary nowadays to have a virtual assessment that can simulate"bus suspension behaviour" to abstracted suspension parameters such as springs and dampers characteristics. In this paper a multibody model of city bus suspension has been presented. Multibody models are the best way of simulation of dynamic behaviour of the vehicle. Simulations showing how different types of the road affect the structure of the vehicle have been performed. Such prepared model can be then use as an input for optimization of the bus suspension in terms of ride comfort, handling, or even passengers' safety.

Keywords: *transport, road transport, simulation, vehicle modelling, vehicle suspension*

1. Introduction

Nowadays design of automotive structures should fulfil many different criteria which arise from customer needs and global competition in a free market. The scheme of problems which are main design tasks in personal car and buss is shown in Fig. 1 [7].

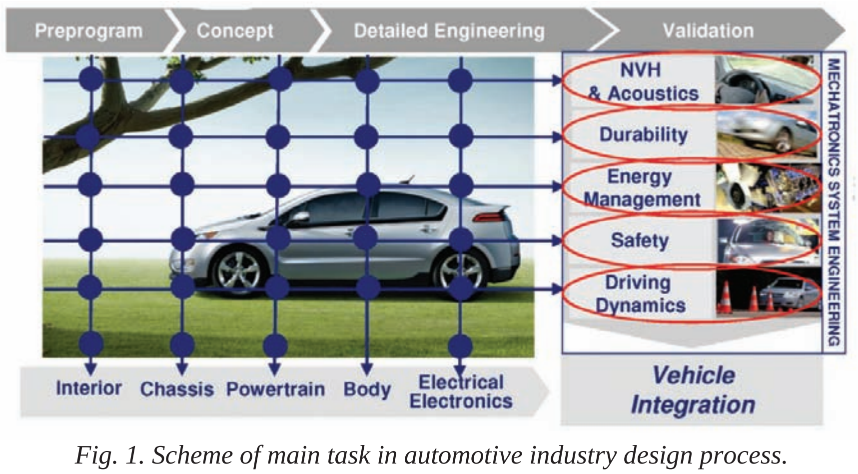

Fig. 1. Scheme of main task in automotive industry design process.

These tasks should be consider during all design phases; conceptual design, detail design and design validation. The second issue which could be considered during design process is multidisciplinary nature of current automotive products which creates necessity to use multidomain approach to design. In practical implementation such approach requires to consider structure as a whole (full equipped bus) including all board electronic systems but not only mechanical parts. It's a reason that automotive structure design process is very complex and time consuming.

The usage of virtual assessments for designing (Model Based Engineering) a new vehicle speeds up a time to market because this method needs fewer prototypes to be made and tested. It can reduce the costs of production due to fact that some changes can be done in the concept phase of vehicle design. One of the most powerful types of such a virtual assessment is multibody simulation which can simulate dynamic behaviour of the vehicle. Multibody simulations are not only use in vehicle modelling but also in a lot of other fields for different mechanisms where the dynamics is important to be simulated [3].

Very often multibody simulation is use in the automotive field to simulate suspensions of the vehicles [2]. The vehicle suspension can be shortly characterize as a construction with springs and dumpers which should isolates people inside from uneven terrain leaving the driver the possibility of driving safety, providing comfort ride and long lifetime of the elements [5]. Especially in the public transport where the bus is a workplace for the driver it is important to provide comfort ride and good handling.

This kind of virtual prototyping lets to find the best dynamic behaviour of the bus without necessity of many tests of real structure.

In this article the multibody model of the city bus is presented. This model can be use to the virtual tests the bus suspension in terms of damping and stiffness of the springs and bushing elements while riding on the different type of the roads profiles.

Nowadays spring-damper structural parameters characteristics of the bus suspension are adjusted to the road where the bus will be riding by assembling special test shock absorbers to the real bus and performing real tests trying to find the best values for comfort ride and good handling. However this type of performance takes a lot of time and it costs. Multibody model can be use as an input for automatic optimization of suspension parameters instead of traditional tests with the real bus. Similar solution has been introduces for another city trolleybus [4].

2. The fully equipped city bus model

The multibody model has been created in ADAMS/Car simulation tool [1]. The same tool has been used to simulate the bus suspension behaviour and to investigate an influence between different types of the road, suspension and structure.

Fig. 2. The multibody model of the city bus

The multibody model is divided into the structure and chassis. Structure is built from the rigid elements as a one body whereas chassis is built also from rigid elements but with kinematics joints (revolute, spherical joints etc.) between elements which provides movements between different parts. This results in 98 degrees of freedom. All the rigid elements have been characterized with the parameters such as mass, moment of inertia. In the mounting points between the structure and the suspension the rubber bushing has been modelled. The nonlinear force-deformation (axial, radial, Cardanic and torsional) characteristics have been taken from manufacture data sheets. Bus suspension is also divide into front and rear one. Front suspension contains rigid elements connected by kinematic joints two air springs and two shock absorbers. This suspension is mounted to the frame (also with rubber bushing). As in this type of suspension air springs are used instead of normal springs, non linear force- height characteristics depends on different level of pressure have been taken from manufacture data sheets. Shock absorbers also have been modelled in terms of dependence the damping force on the relative velocity of compression and rebound given by manufacture data sheets. Rear suspension contains four air springs and the same number of shock absorbers (two on the left side and two on the right). The force-height and force-velocity characteristics are the have been given by producer [8]. To the front suspension anti-roll bar has been mounted with ball joints. This bar is connected to the frame by rubber bushings. For both front and rear suspension are connected with the tires which have been chosen as a standard bus tires from ADAMS/Car 275/70R22.5 (twins for rear suspension). Such prepared model is robustness enough to perform ride simulations.

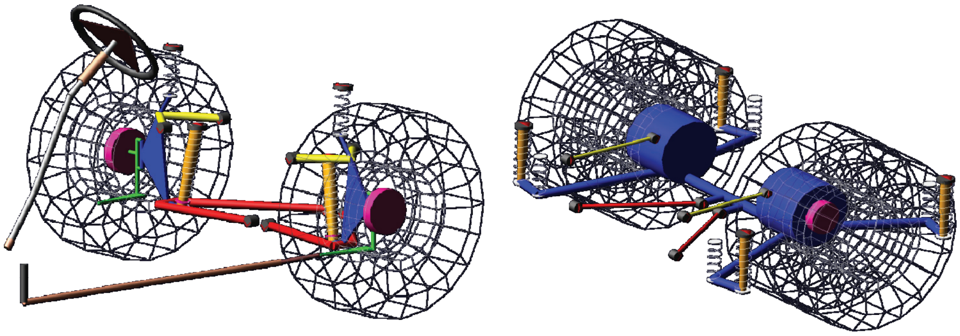

Fig. 3. Front and rear suspension models of the city bus

In the simulation process all intelligent systems which are installed in the bus should be considered because of their interaction with mechanical structure of the bus including chassis and suspension.

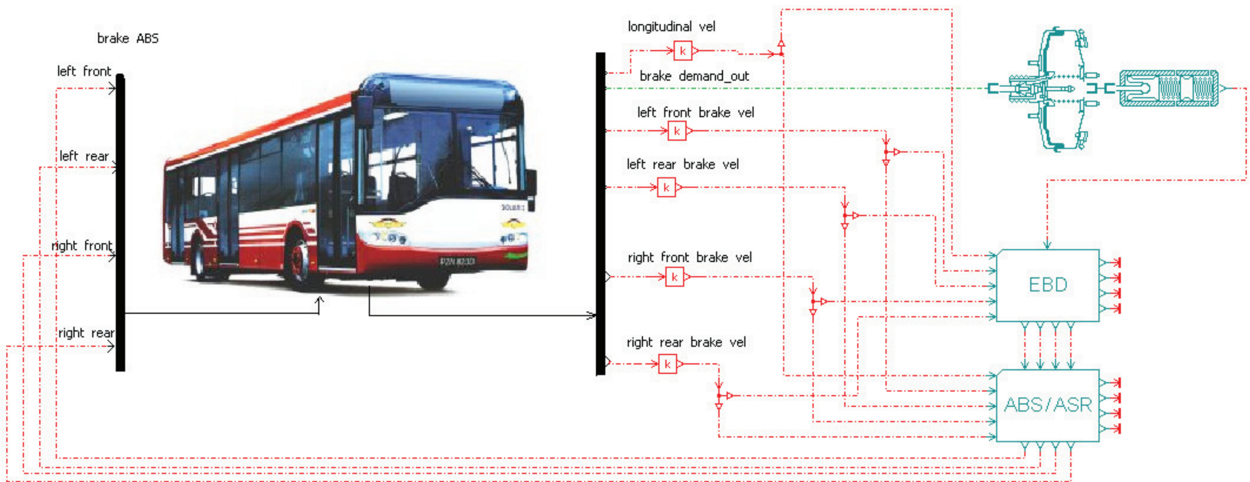

Fig. 4. Schema of fully equipped city bus with intelligent systems

3. Results of simulations

The simulations have been performed for one velocity 50 km/h with two different types of the road profile (crown road and polyline- cubic spline description of the road profile for left and right wheel track. selected from ADAMS/Car [1]) changing the damping value of front shock absorbers by changing the force-velocity characteristics according to the formula (1) [6] (respecting the relation between rebound and compression force).

$$F_d = k_d \cdot v^i, \tag{1}$$

where:
F_d - force of shock absorber,
k_d - coefficient of damping of shock absorber,
v - velocity of the body vibrations relative to the tires,
i - exponent characterizing the damping force of the shock absorber depending on the velocity v.

As an output acceleration of the vibrations of the frame and roll angle have been measured. Also anti-roll bar bushing forces have been observed. Fig. 5-7 show the time responds of observed parameters while bus ride on two different road profiles (crown road upper fig. and polyline lower fig.) with tree different front shock absorbers characteristics (red line for a average force- velocity characteristic from manufacturing data sheets, green line for a maximum values of damping force and black for minimum values).

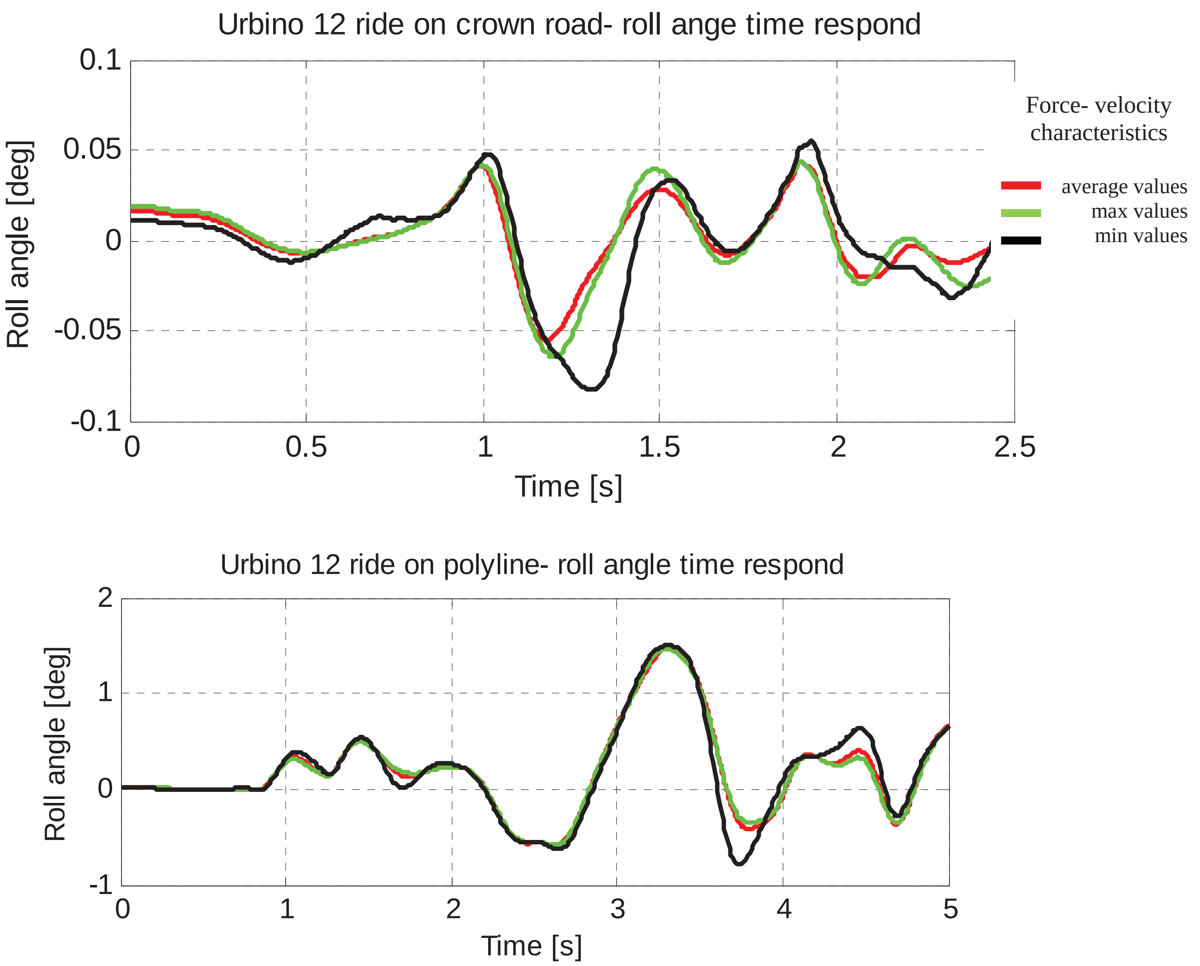

Fig. 5. Roll angle time respond with tree different force-velocity characteristics of damper element while riding on two different road profiles (crown upper one and polyline lower one)

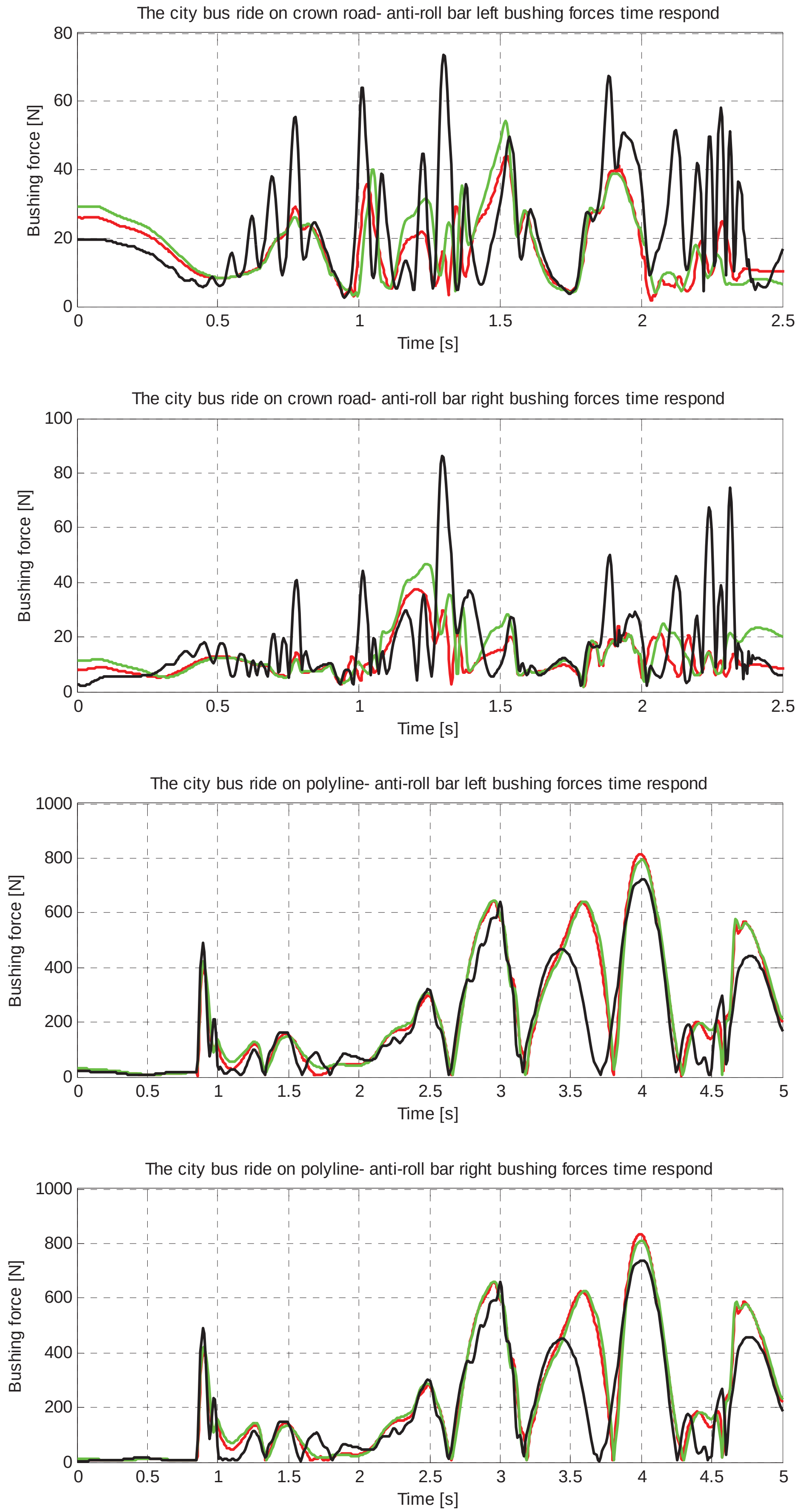

Fig. 6. Anti-roll bar bushing force time respond with tree different force-velocity characteristics of damper element while riding on two different road profiles (crown upper one and polyline lower one)

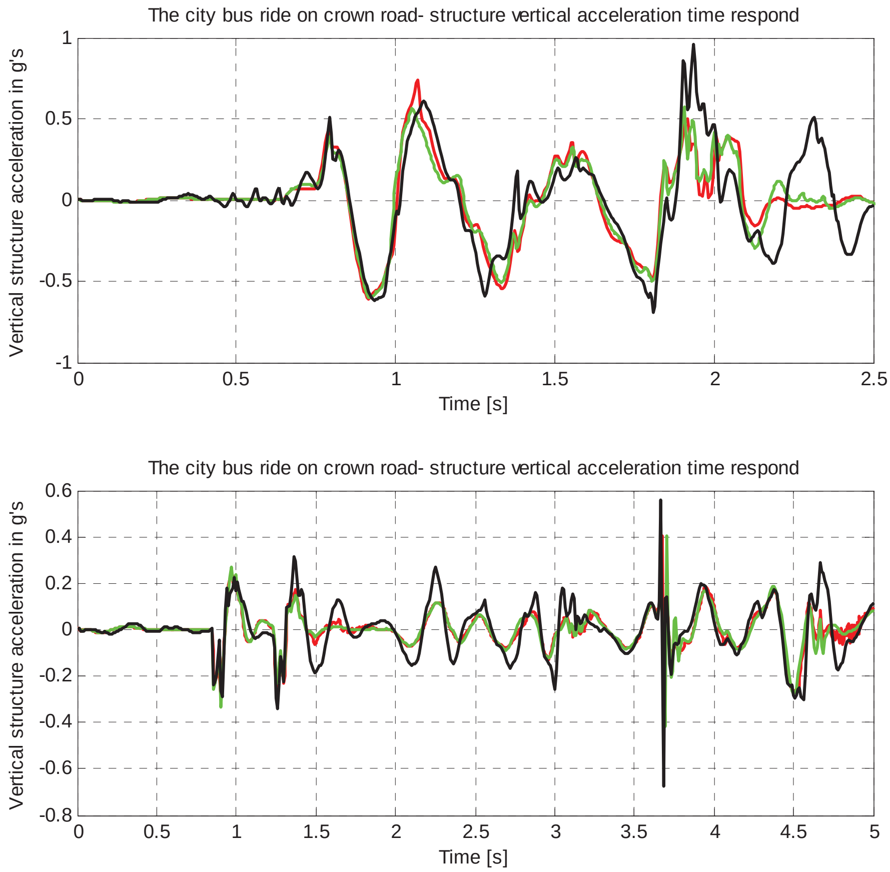

Fig. 7. Structure vibration accelerations time respond with tree different force-velocity characteristics of damper element while riding on two different road profiles (crown upper one and polyline lower one)

Tab. 1. Comparison of RMS value of observed variables in terms of different type of the road profile and force-velocity characteristics of front shock absorbers

RMS value of	The city bus ride on crown road			The city bus ride on polyline		
	Force-velocity characteristics of front shock absorbers					
	Minimum	Producer normal	Maximum	Minimum	Producer normal	Maximum
Roll angle [deg]	0.029	0.018	0.023	0.528	0.497	0,490
Anti-roll bar left bushing force [N]	26.686	18.389	21.115	271.410	315.519	316.020
Anti-roll bar right bushing force [N]	22.018	13.226	17.027	274.789	318.043	318.457
Vertical structure acceleration in g's	0.283	0.208	0.240	0.115	0.079	0.078

Graphs and a tab. 1 show that parameters such as roll angle, bushing forces or structure vibrations depends on type of the road where the bus rides and damping force- velocity structural elements characteristics. They also show that characteristics given by producer are good respecting its minimum and maximum value while riding on crown profile road however none good enough for polyline road. That is why it is important to take into account also type of the road to adjust spring- damper structural elements characteristics.

4. The idea of the multi-optimization approach using multibody model

As it has been said at the beginning, nowadays characteristics of the spring-damper structural elements of the bus suspension are adjusted during tests with real bus what takes time. To reduce a time to market a new bus it is to find optimal values of the spring-damper elements in earlier phase of design. Using fully equipped model and simulations it is possible. The idea of a multi-objective optimization approach is to use the city bus fully equipped model (more precise, spring-damper structural elements characteristics) as an input variables for optimization. As an optimization criteria ride comfort and handling will be taken. Also the road specification will be defined for ride simulation (Fig. 8). Such prepared approach can give us characteristics of air-springs and shock absorbers already in vehicle concept phase.

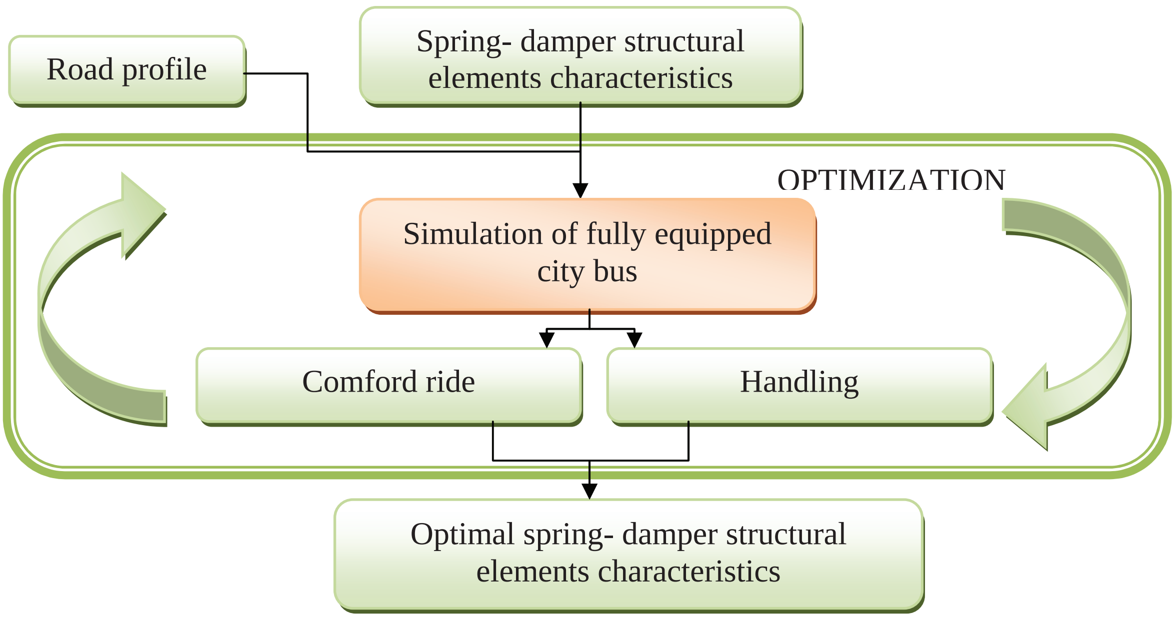

Fig. 8. Schema of multi-objective optimization process using multibody model and simulations

5. Conclusions and future work

As simulations have shown there is a big influence of the damper structural elements characteristics on comfort ride and handling. This issue became to be an idea for multi-objective optimization approach which will adjust characteristics of shock absorbers but also air springs in terms of different type of the road on which bus will be driven. As a criteria ride comfort and good handling performance will be taken. Benefits that can be obtained with this solution is decreasing time to market a new bus and decreasing the number of tests with real bus.

Future work should include sensitivity analysis of spring-damper elements characteristics for better evaluation an influence on the ride comfort and handling. Because handling can be represented by roll angle, optimization of handling can be performed changing the geometry of the anti-roll bar. This can be achieved with morphing technologies.

Acknowledgements

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