ANALYSIS OF THE POSSIBILITIES OF MITIGATING THE EFFECTS OF HEAD-ON COLLISIONS ON CHILDREN TRANSPORTED IN CAR SAFETY SEATS FIXED ROTATIONALLY RELATIVE TO THE CAR CABIN

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INTRODUCTION
The basic means of protecting the children transported in cars are special car safety seats introduced in the USA in 1970s. It has been established that effective protection in case of a car crash can be achieved by fastening the child to the cabin frame as its deformation can partially absorb the impact energy. Along with the efforts to improve the construction of traditional car safety seats, works are continued to find new solutions based on the concept of the seat and the child rotation relative to the car cabin in case of traffic collision. The concept is to mitigate the collision impact on the child by converting a portion of kinetic energy into rotational motion [1-3].

The study provides a comparative analysis of the possibility of mitigating the effects of head-on collisions on children transported in passenger cars in special safety seats fixed rotationally (Figure 1) relative to the car cabin PCSS (Pivoted Child Seats System) as compared to traditional safety seats fixed as stiffly as possible to the cabin frame – e.g. the system ISOFIX equipped with a device counteracting the rotation (support leg) – FCSS (Fixed Child Seats System). In the present case the seat movement has been limited to swivelling on one axis perpendicular to the car symmetry plane.

METHODS
The basic testing method adopted was a computer simulation based on the MADYMO system [4] – universally used software for researching passive safety systems in cars. The child was modelled with the use of an “ellipsoid” dummy available in the MADYMO system base: Hybrid III 3-year-old Child Dummy fastened to the car safety seat with a five-point harness. The seat harness belts were modelled using shell type elements. The seat geometry was recreated by 3D scanning of the commercial version of the safety seat type GO/1 ISOFIX and modelled with elements of the “facet surface” type. In the simulation model special constructional elements were included, which were indispensable for the practical execution of a controlled rotational motion of the safety seat relative to the rear car seat. The safety seat motion during the collision is controlled due to the application of a specific braking torque $T_b$ in the revolute joint.

RESULTS AND DISCUSSION
Simulation tests were carried out for a scenario relevant for head-on collisions of typical passenger cars, with a rigid obstacle, at the speed of 50 km/h. For this purpose the time span of acceleration impulse was applied (fulfilling the requirements of the ECE R44.03 [8]), that was measured during one of the sled-test-type experimental tests [5] which had been carried out earlier.

To assess the injury risk for a child a special synthetic index of injury risk $Snr$ [9] was applied. $Snr$ was defined as a sum of twelve selected standardized biomechanical injury criteria calculated based on collision simulation results in the MADYMO program.

Reference values of individual criteria, considered as critical for a three-year old child, were adopted based on literature data [4, 6, 7].

With the use of the $Snr$ index, a percentage index for safety improvement was defined – $SFI$ (Safety Factor Improvement), which makes it handy to compare the benefits of using a PCSS safety seat – fixed rotationally – and a fixed seat (FCSS), as follows:

$$SFI=\frac{100\%}{\frac{Snr_{Fix}}{Snr_{Fix}}-Snr}$$

where: $Snr_{Fix}$ stands for the value of the $Snr$ for a fixed seat.

Possible practical limitations of the PCSS solution were examined by analyzing the sizes of the motion zones PLR (Plane Motion Range) by projecting the trace of the movement of the seat with the child in it onto the longitudinal car symmetry plane. The comparison of motion zones of the FCSS and PCSS models (for a selected point of placement of the joint) are shown in Figure 1. Maximal transfers of child’s head $L_{max}$ in the XZ plane were analyzed with special attention to conformity with [8]. The size of this transfer can be treated both as a factor in injury risk assessment and as a hint for designing the seat fixing in a particular model of a car.

Based on the results of the collision simulation tests achieved for the FCSS model (index value $Snr=Snr_{FCSS}=6.5$, and motion zone $PLR_{FCSS}$) levels of reference for the comparative analysis were determined. Parametric research of the PCSS model was carried out for 18 locations of joint
pivot axis against the seat main body (Figure 1) and a dozen or so (for each of the pivot axis locations) values of the braking torque (friction) $T_b$ in the joint. As a result of the simulation for each of the 18 locations of the joint the best solution was determined $S_i = \{T_b, \alpha_{\text{max}}, \text{Snr}, \text{SFI}, \text{PLR}, L_{\text{hx}}\}$.

This analysis made it possible to narrow down the choice to two locations of the pivot point, which – with the preservation of the safety improvement index (SFI) at about 50%, a limited size of the motion zone and a reduction of all the relevant partial criteria – do not pose constructional problems (points P$_{10}$ and P$_{17}$). Visible here is the major reduction of all the partial criteria, except C$_1$ (the 3ms criterion of acceleration for the thorax), which reaches small values in comparison to the critical values both in the case of the pivotal seat and the fixed seat, so its minor increase does not pose a problem.

For thus selected points (P$_{10}$ and P$_{17}$) experimental research shall be carried out, that will make it possible to formulate final conclusions on the potential effectiveness of the proposed solution.

CONCLUSIONS
Simulation tests demonstrated significant possibilities of child injury reduction as a result of the application of the pivotal seat (SFT index value at about 50%). Should the first sled-test-type experimental research confirm these very optimistic results, it will be possible to progress into the next phase – designing and constructing a “technology demonstrator” in the form of a pivotal seat placed in a selected, mass-produced passenger car and carrying out a full-scale crash test.

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