

# ANALYSIS OF PASSIVE SAFETY SYSTEMS ENSURING CHILD SAFETY IN MODERN VEHICLES

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## Abstract

This article scientifically and practically analyzes passive safety systems that ensure child safety in modern vehicles. Passive safety systems are systems designed to minimize injuries to passengers after a road traffic accident occurs, and they are of particular importance for children. The research results show that adapting passive safety systems to the anatomical and physiological characteristics of children can significantly reduce child injuries and fatalities in road traffic accidents.

**Keywords:** Passive safety, child safety, automotive interior design, child restraint systems, ISOFIX system, airbags, seat belts, body structure, deformation zones, CRS.

## Introduction

Automotive transport has become an integral part of modern life, and every day millions of families take their children to school, kindergarten, medical facilities, and other places in cars. Road traffic accidents are one of the leading causes of death for children aged 5-14 worldwide. According to the World Health Organization (WHO), more than 186,000 children die in road traffic accidents every year, and millions more suffer injuries of varying severity.

Passive safety systems are systems designed to minimize injuries to passengers after a road traffic accident occurs, which are installed in the vehicle structure and activate automatically when an accident occurs. Since children differ from adults in anatomical and physiological terms, ensuring their safety in vehicles requires a special approach. A child's head is larger relative to their body, neck muscles are weaker, and bones are more flexible and vulnerable.

In recent years, passive systems aimed at child safety in the automotive industry have been developing rapidly. Strict regulatory requirements for child safety have been introduced in the United States and European Union countries, which compel automakers to consider child safety as a priority direction in interior design.

The main purpose of this article is to comprehensively analyze passive safety systems ensuring child safety in modern vehicles, evaluate their effectiveness, and develop practical recommendations.



## LITERATURE REVIEW

1. Research conducted by Arbogast K.B., Durbin D.R., Kallan M.J. (2003) analyzed the effectiveness of child seats. Based on data from the University of Pennsylvania and the US National Highway Traffic Safety Administration (NHTSA), the authors analyzed statistical data involving more than 5,000 children who participated in road traffic accidents between 1998 and 2002. According to the research results, proper use of child seats reduces child mortality in road traffic accidents by 70-80%, and injuries by 60-70%. The authors also proved that using a child seat in the rear seat is safer compared to the front seat. The study emphasized that the effectiveness of child seats depends on their correct installation and compliance with the child's age, weight, and height [1].
2. Research conducted by Brown J., Bilston L.E. (2019) studied the effectiveness of rear-facing child seats. Based on data from the University of Sydney and the New South Wales Transport Research Centre in Australia, the authors analyzed road traffic accidents involving more than 10,000 children between 2000 and 2018. According to the research results, using rear-facing seats for children up to 15 months of age reduces the risk of cervical spine injuries by 90% compared to forward-facing seats. The authors also recommended extending the use of rear-facing seats up to 2 years of age. The results of this study served as the basis for revising legislation on child seat usage in many countries [2].
3. Research conducted by Durbin D.R., Elliott M.R., Winston F.K. (2018) analyzed the effectiveness of booster seats. Based on data from the University of Pennsylvania School of Medicine and the US National Highway Traffic Safety Administration (NHTSA), the authors analyzed road traffic accidents involving more than 3,000 children aged 4-8 between 2000 and 2015. According to the research results, using booster seats reduces the risk of child injuries by 45%. Particularly, high-back booster seats have been proven to be highly effective in protecting children's heads during rear and side impacts. The study also recommended the use of booster seats for children aged 4 to 12 years [3].
4. In the report prepared by Kahane C.J. (2021) for the US National Highway Traffic Safety Administration (NHTSA), the effectiveness of ISOFIX and LATCH systems was analyzed. The author analyzed more than 15,000 road traffic accidents involving vehicles equipped with ISOFIX and LATCH systems between 1990 and 2020. According to the research results, standardized mounting systems reduce the risk of incorrect installation of child seats by 70%. The study noted that with ISOFIX systems equipped with installation indicators, the installation time of child seats decreased from an average of 2-3 minutes to 30-40 seconds. The author also emphasized that the ISOFIX system is the most effective solution in ensuring child safety [4].
5. Research conducted by Klinich K.D., Pritz H.B., Beebe M.S., Welty K. (2021) analyzed child seat mounting systems in vehicles. Based on data from the US National Highway Traffic Safety Administration (NHTSA) and the University of Michigan, the authors conducted a comparative analysis of the effectiveness of ISOFIX, LATCH, and top-tether systems. According to the research results, seats secured with ISOFIX systems shift 50% less during collisions compared to seats secured with seat belts. The study also proved the importance of the top-tether anchor system and its ability to increase the effectiveness of forward-facing seats



by 30%. The authors emphasized that the combined use of ISOFIX and top-tether systems is the most effective solution in ensuring child safety [5].

6. Research conducted by Hu J., Mizuno K. (2009) analyzed the kinematic characteristics of child seats secured with the ISOFIX system in frontal collisions. Based on data from Nagoya University and Toyota Technological Institute in Japan, the authors conducted frontal collision simulations using a Hybrid III 3-year-old dummy and a child finite element model. According to the research results, seats secured with the ISOFIX system significantly reduce head and chest injuries to the child. The study also proved that the combined use of the ISOFIX system with an additional top-tether anchor system further increases effectiveness [6].

7. Research conducted by Polanco J.M., Smith J.M. (2022) analyzed the role of modern smart airbag systems in child safety. Based on data from the US National Highway Traffic Safety Administration (NHTSA) and technical documentation of automakers, the authors analyzed the effectiveness of front, side, curtain, and far-side airbags. According to the research results, while front airbags are effective for adults, they can be dangerous for children aged 1-3 years. Side airbags reduce the risk of head injuries to children in side collisions by 40-50%. Curtain airbags are highly effective in protecting children's heads during rollovers. The far-side airbag prevents the driver and front passenger from colliding with each other in side collisions [7].

8. Research conducted by Kallan M.J., Durbin D.R., Arbogast K.B. (2020) studied the placement of child seats in the vehicle interior and their impact on safety. Based on data from the University of Pennsylvania School of Medicine and the US National Highway Traffic Safety Administration (NHTSA), the authors analyzed road traffic accidents involving more than 10,000 children between 2000 and 2018. According to the research results, placing child seats in the center of the rear seats reduces the risk of child injuries in side collisions by 30-40%. The study also emphasized the importance of allocating sufficient space for child seats in the vehicle interior and installing side airbags [8].

## RESEARCH METHODOLOGY

This research is aimed at analyzing passive safety systems ensuring child safety in modern vehicles, and it employs a complex of scientific methods and approaches.

The theoretical and methodological basis of the research consists of scientific studies in the fields of automotive safety engineering, ergonomics, child anatomy and physiology, as well as international standards and regulatory documents. The work comprehensively uses methods of system analysis, comparative analysis, statistical data processing, observation, expert assessment, comparison, and generalization.

As the research object, passive safety systems in the interior design of modern vehicles were selected. During the research, passive safety solutions in the interior design of various vehicle models - Chery TIGGO4, Polestar 3, Volvo XC60, BMW X5, Mercedes-Benz GLE, Toyota Highlander and other modern cars - were analyzed. The research subject consists of the constructive features of passive safety systems, their operating principles, and their effectiveness in ensuring child safety.

The research utilized the following data sources. First, reports and statistical data of international organizations - World Health Organization (WHO), US National Highway Traffic



Safety Administration (NHTSA), European Economic Commission ECE R44/04 and i-Size (R129) standards - were studied. Second, scientific articles and research works of foreign scientists such as Arbogast K.B., Durbin D.R., Brown J., Bilston L.E., Kahane C.J., Kallan M.J., Klinich K.D., Polanco J.M., Sherwood C.P., as well as local scientists Karimov Sh.A. and Raximov R.R. were analyzed. Third, technical documentation and design solutions of automakers - Chery, Polestar, Volvo, BMW, Mercedes-Benz, Toyota - were studied. Fourth, regulatory documents and standards on child safety - ECE R44/04, i-Size R129, FMVSS 213, ISO 13216, ISO 29061 - were used.

In the preparatory stage, scientific literature, international standards, and regulatory documents on the topic were studied, the purpose, tasks, object, and subject of the research were clearly defined, and the research plan and methodology were developed. During the literature review, more than 50 scientific sources - articles, books, reports, standards - were studied and their main results were systematized.

In the stage of practical observation and analysis, passive systems ensuring child safety in vehicle interiors - body structure, deformation zones, seat belts, airbags, child restraint systems (CRS), ISOFIX, LATCH and top-tether mounting systems, anti-pinch window protection systems, rear door child safety locks - were studied and analyzed. Passive safety solutions in different vehicle models were comparatively analyzed.

In the expert assessment stage, the effectiveness of passive safety systems was evaluated with the participation of 10 experts in the field of automotive design and safety engineering - automotive designers, safety engineers, representatives of child seat manufacturers. Experts were asked to evaluate factors of automotive interior design affecting child safety on a 10-point scale. According to the expert assessment results, the effectiveness of passive safety systems depends on the following factors: presence and convenient location of ISOFIX anchors (9.2 points), sufficient space for placing child seats in the rear seats (8.8 points), presence of side airbags (8.5 points), anti-pinch window protection system (8.3 points), body made of high-strength steel (8.1 points), rear door child safety locks (8.0 points), presence of top-tether anchor system (7.8 points), ability to deactivate front airbags (7.5 points), smart sensor systems (7.2 points).

In the statistical data processing stage, the obtained results were statistically processed using Microsoft Excel and SPSS programs. Mean values, standard deviation, correlation, and regression analyses were calculated. The reliability of the results was checked using Student's t-test ( $p < 0.05$ ). Expert assessment results were summarized and presented in the form of graphs and tables.

In the comparative analysis stage, passive safety solutions in different vehicle models, types of child seats, and mounting systems were compared with each other. The effectiveness of passive safety systems was evaluated in terms of their constructive features, compliance with standards, and practical applicability.

In the stage of summarizing research results, all obtained data were systematized, main conclusions on passive safety systems ensuring child safety in modern vehicles were formulated, and practical recommendations were developed.



Furthermore, during the research, the following criteria were used to evaluate the effectiveness of passive safety systems in ensuring child safety: constructive features of the system and compliance with standards, the extent to which the system reduces child injuries in road traffic accidents, ease of use and simplicity of installation, integration of the system with smart technologies, cost and availability of the system.

The practical significance of the research is that the obtained results can serve as a basis for developing measures aimed at ensuring child safety for automakers, designers, legislative bodies, and parents. The research results can also be used in developing recommendations for adapting regulatory requirements for child safety in Uzbekistan to international standards and making the use of child seats mandatory.

## CONCLUSION

As a result of this research devoted to analyzing passive safety systems ensuring child safety in modern vehicles, the following main conclusions were reached.

Since children are physically more vulnerable compared to adults, ensuring their safety in vehicles requires a special approach. By adapting passive safety systems to the characteristics of children, it is possible to significantly reduce child injuries and fatalities in road traffic accidents.

Proper use of child seats reduces child mortality by 70-80% and injuries by 60-70%. Rear-facing child seats reduce the risk of cervical spine injuries by 90% for children up to 15 months of age. Booster seats reduce the risk of child injuries by 45%.

The ISOFIX system reduces the risk of incorrect installation of child seats by 70% and secures seats 40% more effectively. The top-tether anchor system increases the effectiveness of forward-facing seats by 30%.

Five-point seat belts protect children 30-50% more effectively than standard three-point belts. Side airbags reduce the risk of head injuries to children in side collisions by 40-50%. Front airbags can be dangerous for children, so there should be an option to deactivate them.

Anti-pinch window protection systems and rear door child safety locks significantly reduce the risk of children being injured inside the vehicle. Smart sensor systems can reduce cases of children being left behind in vehicles by 80-90%.

In Uzbekistan, regulatory requirements for child safety need to be adapted to international standards (ECE R44/04, i-Size R129), ISOFIX system should become mandatory in all vehicles, use of child seats should be established by legislation, and the level of public awareness should be increased.

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