Enhancement on the RUPD system of heavy vehicle by Evaluation of a Head Injury Criteria
Volume 4 NO.1 YEAR 2022
مجلة العلوم والتطــبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

Enhancement on the RUPD system of heavy vehicle by Evaluation of a Head Injury Criteria

Dr . Zeid Fadel Albahash
[a] College of Technical engineering, Department of Refrigeration and Air-Condition Technical Engineering, The Islamic University, Najaf, Iraq.
[b] Ministry of oil , Oil exploration company ,Iraq

Prof .Dr. Ali Abdul Mohsen Alasadi
College of Technical engineering, Department of Refrigeration and Air-Condition Technical Engineering, The Islamic University, Najaf, Iraq.

Recieved 14/1/2022
Accepted 10/2/2022

ABSTRACT
Crashworthiness improvement of under-ride guard system of heavy vehicle design is a highly challenge duty to save passengers life and prevent sever injures of small car in collisions. As a consequence of absence or lack of the powerful under-run guard connected to the rear, side of trucks, trailers and semi-trailers, back under-ride accidents are in charge of a huge death numbers in all the world. This study concentrates on improving Rear Underrun Protection Device (RUPD) structure utilizing Finite Element Analysis apparatus like LS-DYNA. Two designs of under-ride guard devise crushed using Toyota Yaris (2010) with different impact speeds 45km/h and 63km/h. A zero passenger compartment intrusion (PCI) is accomplished with the investment of the recently outlined under-ride guard for rear of trucks. The new under-ride guard model is validated utilizing FMVSS 223/224 regulations. The new design achieved the goal of decreasing the acceleration beyond the limits, which leads to decrease the
head injury criteria (HIC) to (373.250).

Key word: RUPD, LS-DYNA, Head injury criteria (HIC), FMVSS 223/224.

1. Introduction
Nowadays, society has become much more aware of personal and public protection, and has the ability to impose necessary legal sanctions against mechanical faults that threaten public safety. These issues need to design more accurate products to overcome the errors that may appear with increasing vehicles production, as well as develop products to meet the quality standard and high efficiency. With the expansion production of vehicles, the quantity of crashes and fatalities has additionally expanded. This has led to continual exploration in designing effective energy absorbers to disperse energy and protect the passengers of small vehicle in the event of collisions and injury.
An injury index, also known as an injury assessment value, is calculated from measurements such as forces or accelerations taken on human subjects or crash test dummies (Dalong & Wampler, 2009). According to Hutchinson et al.(1998), most popular measures of head injury tolerance to mechanical impact is the Head

مجلة العلوم والتطـبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

Injury Criterion (HIC) where the HIC has been used for more than 20 years in North American motor vehicle safety regulations as a predictor of head injury risk in frontal impacts.

1.1 Head Injury Criterion

As head and thorax are more frequently injured body regions (Yoganandan et al., 2014), the National Highway Traffic Safety Administration proposed the head injury criterion (HIC) in 1972. The HIC is a tool recently used in safety standards for head protection systems (Marjoux et al., 2008). The HIC is used to judge the head injury risk in crush event, where the head load results from too high acceleration or better deceleration values during the crash. The HIC cannot make any statement about severity and type of final injuries but it gives an initial trend for general injury risk assessment (Henn, 1998). The HIC is used to measure the damage from crash pulse on the brain, and it should be less than a certain limit by regulations (Ibrahim, 2009). Head Injury Criterion (HIC) is an integration function of the outcome head acceleration

Presently, collides with head contact (as a matter of fact linear acceleration) and inertial loading of the head (in fact rotational acceleration) have been assumed as the two substantial mechanisms of head damage. Rotational acceleration is assumed to create both focal and diffuse brain wounds, while linear acceleration produces focal brain injuries (King et al., 2003).

The HIC is currently used to evaluate head injury potential in automobile crash test dummies (McHenry et al., 2004). The performance limit for HIC was maintained over a most extreme time period of 36 milliseconds for the 50th percentile male and scaled values for the different dummy sizes. There is a suggestion to limit the HIC evaluation interval to maximum of 15 milliseconds with a performance limit of 700 for the 50th percentile male and scaled limits for the another dummy sizes (Eppinger et al., 1999). The current FMVSS recommends a constant duration of 15 ms of the deceleration pulse (Khattab et al., 2010). The suggested critical HIC standards for the different passenger sizes are explained in Table 1.

Table 1: Head Injury Criterion for Various Dummy Sizes (Thomas et al., 2004)

Dummy Type	Large Male	Mid-sized Male	Small Female	6 Year Old Child	3 Year Old Child	1 Year Old Infant
Existing HIC36 Limit	NA	1000	NA	NA	NA	NA
Proposed HIC15 Limit	700	700	700	700	570	390

To measure the head injury criterion (HIC), the consequent acceleration at the center of gravity of the dummy head should be like that the following equation does not exceed 700. This value represents the threshold for serious internal head injury for impact.

$$\left[\frac{1}{t_2 - t_1} \int_{t1}^{t2} a\,dt \right]^{2.5} \text{HIC} = t_2 - t_1) \qquad (1)$$

where a(t) is the consequent occupant deceleration at the center of mass (cg) of the occupant’s head expressed in g units, and t1 and t2 are every two points in period throughout the collision of the car which

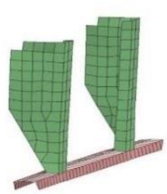
مجلة العلوم والتطـــبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

are within a 15 ms time interval (Chou et al., 2004; Khattab et al., 2010). This expression was first defined in 1971 by Versace (Gabauer et al., 2005).
Head injury criterion is used as part of tear underride protection (RURP) evaluations during crushes, which poses a problem for RURP manufacturers to improve their products. They seek to investigate the differences between crash RURP standards with and without the HIC (Fenner et al., 2005). This study aims to improve Rear Underrun Protection Device (RUPD) structure using Finite Element Analysis apparatus like LS-DYNA. Three designs of RUPD including basic RUPD design and two developed designs were tested at various impact speeds to estimate the Head Injury Criteria.
2. RUPD Design and Modeling

2.1 Model Design and Description

The basic RUPD (Design C), RUPD (Design A) was developed using the nonlinear dynamic analysis software LS-DYNA. The full assembly model of the three designs of RUPD and their components are described in Table 2. RUPD consists of two (2) basic components namely; connecting link, base protection bar which constitutes the basic underride assembly known as control (C) hereafter. Two support bars and many integrated crushing tubes within the base protection bar are included in the new design of the underride to form RUPD design (A) which consists of six components (Zeid et al., 2017).

Table2: Underride Designs

Design ID	Part contains	Cross section	Length Width Height (mm)	Thickness (mm)	Material	Part Weight (kg)	Total weight (kg)
 Desgin C		w h	1550 80.4 36.7	3.5	Mild steel	6.032	18.904
		w h2 h1	562.92 95.37 194 44	5	Mild steel	6.436	
 Design A		rectangular	2000 150 200	1	Mild steel	5.8366	33.726
		circular	150 R25	1	Mild steel	0.1778	
		circular	150 R25		Foam	0.159	
		square	700 100	2	Mild steel	2.1344	
		square	700 100	3.6	Mild steel	5.153	
		rectangular	200 150 100	1	Mild steel	0.622	

مجلة العلوم والتطـــبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

Mild steel is used in designing the RUPD. Steel sheets have been used in vehicle structures for more than 100 years due to its higher energy absorption capacities (Ibrahim et al., 2009, V*a*n Slycken et al., 2006; Peixinho et al., 2007, Zeid et al., 2017). Regarding the cross section area, the circular and the square cross section shows good stable results compare to others shapes, thus they used in most of thin wall structure or tubes in many applications (Jones et al., 1989; Ramakrishna et al., 1998; Guoxing et al., 2003; Chang et al., 2012; Zhou et al., 2011).

2.2 Method

In this study, the rear collision accident is managed utilizing a modeled car (Toyota Yaris model 2010) and truck chassis (Ford Model) as the test FEM model as shown in figure 1. The car model was taken from a standard data base and the RUPD assembly of the truck was modeled using ABACUS software and incorporated on LS-Prepost for critical meshing. Subsequent meshing the system, the pattern was imported in LS-DYNA environment (LS-Prepost) for setting different simulation parameters as appeared in Table 3. The output of Prepost (.k file) was solved in LS-DYNA solver. The truck chassis has a fixed and the premier velocity of car model is presumed two speeds viz. 45 km/hr and 63 km/hr. The simulation is specified a termination time 0.2 sec, which may vary according to material properties of the RUPD bar.

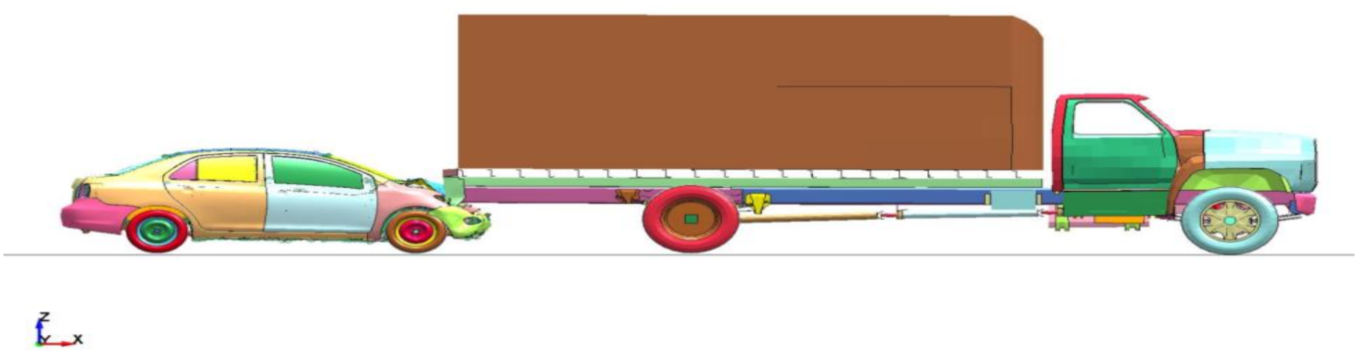


Fig.1: Toyota Yaris Model 2010 and truck Ford Model

Table 3: RUPD design parameters

Test Run	Car Model	Mass of the	Ground Clearance	Underride Design	Impact Speed
1	Toyota Yaris 2010	1300	450	C	45
2				C	64
3				A	45
4				A	64

مجلة العلوم والتطـبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

3. Results and Discussion

3.1 Passenger Car Intrusion

The passenger compartment intrusion is the most important parameter of the standard for RUPD valuation. Even all others parameters meet the requirements, the high PCI means the intrusion of the small car compartment beneath the rear of the truck and may lead to cut the head or cause severe injury for the passengers due to continuity moving of the car beneath the truck. The magnitude of intrusion depends on the length of the bonnet, so longer bonnet is safer than the short one like newest common cars. Figure 2 shows the intrusions of the three designs at 45km/hr speed.

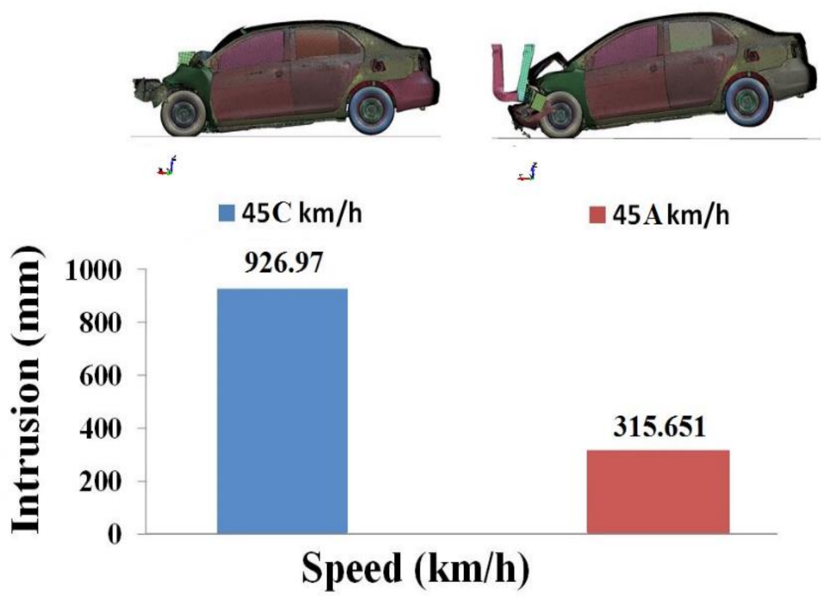


Fig.2: The intrusions for the three designs at 45km/hr

As shown in figure 2, the biggest value of displacement in the RUPD is 926.97mm for design C, which is maximum limiting value around of 900mm. The maximum displacement for the new RUPD design very much lower than design C. Displacement for design A is recorded 314.651mm.

At the second speed 63km/hr as shown in figure 3, the biggest value of displacement in the RUPD is 1091.1 mm for design C, which is extremely maximum limiting value around of 900mm. The maximum displacement for the new design is lower than design C. Displacement for design A recorded 875.37 mm.

Enhancement on the RUPD system of heavy vehicle by
Evaluation of a Head Injury Criteria
Volume 4 NO.1 YEAR 2022
مجلة العلوم والتطـبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

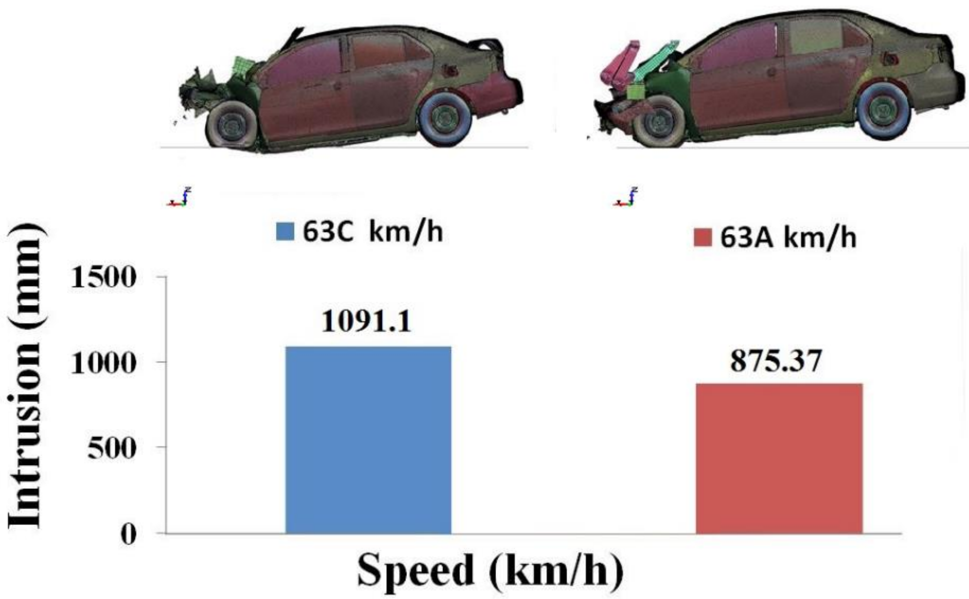


Fig.3: The intrusion for the three designs at 63km/hr

Table 4: Passenger compartment intrusion for three designs

Speed (km/h)	45km/h	54km/h	63km/h
Design A	315.651mm	710.26mm	875.37mm
Design C	926.97mm	1002.4mm	1091.1mm

3.2 Head Injury Criteria (HIC) and Acceleration

The improvement of crashworthiness of the underride guard system of heavy vehicle design is a highly challenge duty to save the passengers life of the small car and prevent sever injures in event of collisions. Three designs of underride guard devise crushed using Toyota Yaris (2010) at different impact speeds 45km/h, 54km/h and 63km/h. A zero passenger compartment intrusion (PCI) is accomplished with the investment of the recently outlined underride guard for rear of trucks. The new underride guard models are validated utilizing FMVSS 223/224 regulations. From table 1 for the large male, the HIC should be less than 700 but the HIC for the 1 year old infant which equal to 390 should be used. So, according to equation (1):

$$A^{2.5}(0.036) = 390$$

Where HIC =390, A=head acceleration and time in millisecond=0.036.

A will equal to 41.1g for the head while the chest should be less, which means that the acceleration should be less than 40g in order to save the life for all passengers including infants.

The head injury criteria, Head acceleration, and Chest acceleration for the three designs are calculated at the three different speeds and introduced in table 5.

Table 5: Head Injury Criterion for three designs at different speeds

RURP Design	Speed	45 km/h	54km/h	63km/h
Design A	HIC	305.000	346.790	373.250
	Head Acceleration	24.8298	25.8998	28.4974
	Chest Acceleration	21.5568	22.3499	22.4181
Design C	HIC	920.500	1005.10	1167.00
	Head Acceleration	68.1990	108.498	137.328
	Chest Acceleration	27.1600	48.5400	65.6400

As shown in table 5, design A records lowest values for HIC for all three speeds and meets the requirements of FMVSS, which state that the HIC value should be below 700. The results indicate a significant difference between the HIC of design A and normal design. Moreover, head and chest acceleration of design A are the lowest and less than 40g, which assist to save infants life in case of sudden accidents. Finally, with normal underride design C for all speeds, the results exceed the limits for HIC and both head and chest acceleration.

4. Research Design Evaluation

In order to approve the good performance of the new design of this research, the new RUPD was tested with Toyota Yaris 2010 and compared with several previous researches in the same field at different speeds which few of them mentioned the value of HIC while the majority gave only the value of acceleration and did not mentioned the HIC value. However, it can provide a general indication on the research design performance. Table 6 illustrate the comparison results with other researches.

Table 6. Comparison between research design and other researches

Design	Speed (km/h)	HIC
This research Using Yaris 2010	63	373.25
Anderson et al, (2003)	64	381
This research Using Yaris 2010	54	346.79
This research Using Yaris 2010	45	305
Henn,(1998)	48.3	307.84

The table 4 shows that the performance of the new RUPD design is better than all researcher in crashworthiness results at different impact speeds, which achieves lower HIC (373.25) at 63 km/h which slightly lower than (Anderson et al, (2003)) at impact speed 64 km/h, also, it records lower HIC (305) at 45 km/h comparing with research design (Henn,(1998))that achieves 307.84 at 48.3 km/h. The higher HIC over 390, will lead fatal injuries especially for the infant.

5. Conclusion

The overall target of the work was to simulate a rear accident analysis and approve the results of the simulations acquired from the accident test. Simulation was performed utilizing the LS-DYNA software. In the simulation, male dummy was used to model the driver and to estimate the Head Injury Criteria (HIC), head resultant deceleration and the chest resultant deceleration. The analysis has well instituted the strategy and parameters of the simulation on modeling and analysis software. It illustrates the energy absorption design in the RUPD assembly during frontal crash of a car with various design parameters of RUPD truck assembly. It can be seen clearly from the findings that the RUPD assembly absorbs large portion of the energy when the car hits the rear side of the truck. Almost half of the energy of the crash is absorbed by the RUPD assembly parts after about 0.6 ms of the crash initiation. It will be conceivable to recommend some pertinent qualities for an energy absorbing rear underrun protection device. The RUPD model A has shown a better energy absorption compared to the basic (control) RUPD C. The car safety effectiveness can act efficiently by giving this RUPD assembly model A to heavy trucks. In many countries, RUPD assembly needs to pass the regulation set by FMVSS 223 to achieve the safety requirement to preserve under running of the passenger car. For model A, the maximum displacement of RUPD assembly was found to be lower than model C. The final design (A) has achieved the goal to meet the requirements of reaction force with a good stability compared to old design. Furthermore, it achieved the goal of decreasing the acceleration beyond the limits which is less than 60g that assists to decrease the head injury criteria (HIC). However, these results may be confirmed by performing a real crash test in the future.

Acknowledgements
The authors were thankful to the Department of Mechanical Engineering and Universiti Tenaga Nasional, Malaysia for providing library resources to complete this review research.

References

Chang,Q., Yang ,S., Dong ,F.; " Crushing analysis and multi-objective crashworthiness optimization of tapered square tubes under oblique impact loading"; (2012), Thin-Walled Structures .59:103–19.

Chou, C.; " Fundamental Principles for Vehicle/Occupant System Analysis"; (2004),Vehicle Crashworthiness and Occupant Protection, P. Prasad and J. Belwafa.

Dalong Gao, and C.W. Wampler. “Head injury criterion.”Robotics & Automation Magazine, IEEE 16.4 (2009): 71-74

Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., Saul, R .; "Development of improved injury criteria for the assessment of advanced automotive restraint systems–II"; (1999), National Highway Traffic Safety Administration, 1-70.

Fenner Jr, H., Thomas, D. J., Gennarelli, T., Pintar, F. A., Becker, E. B., Newman, J. A., & Yoganandan, N. (2005). Final Report of Workshop on Criteria for Head Injury and Helmet Standards. Milwaukee WI: Medical College of Wisconsin and Snell Memorial Foundation.

مجلة العلوم والتطـبيقات الهـندسية
Journal of Science And Engineering Applications
ISSN 2521-3911

Gabauer, D., Thomson, R.; " Correlation of vehicle and roadside crash test injury criteria"; (2005), In 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV)-Washington DC (pp. 6-9).
Guoxing,L., Tongxi,Y.; "Energy absorption of structures and materials";(2003) , England: Woodhead Publishing Limited,1–23.
Henn, H. W. (1998). Crash tests and the head injury criterion. Teaching mathematics and its applications, 17(4), 162-170.
Ramakrishna, S., and Hiroyuki Hamada. "Energy absorption characteristics of crash worthy structural composite materials." Key engineering materials. Vol. 141. Trans Tech Publications, 1998.
Ibrahim, Hesham Kamel. Design optimization of vehicle structures for crashworthiness improvement. Diss. Concordia University Montreal, Quebec, Canada, 2009.
John Hutchinson, Mark J.Kaiser, and Hamid M.Lankarani. “The Head Injury Criterion (HIC) functional” Applied Mathematics and Computation, Volume 96, Issue 1, 1998, Pages 1-16
Jones, N.; " Structural impact";(1989) , Cambridge, UK: Cambridge University Press.
Khattab, A., ElRahman, A.; " Investigation of an adaptable crash energy management system to enhance vehicle crashworthiness";(2010) , Doctoral dissertation, Concordia University, Montreal.
King, A. I., Yang, K. H., Zhang, L., Hardy, W., Viano, D. C.; " Is head injury caused by linear or angular acceleration";(2003) , In IRCOBI conference ,pp. 1-12.
Marjoux, Daniel, et al. "Head injury prediction capability of the HIC, HIP, SIMon and ULP criteria." Accident Analysis & Prevention 40.3 (2008): 1135-1148.
McHenry, B. G.; " Head injury criterion and the ATB";(2004) , ATB Users’ Group, 1-8.
Peixinho, N., and A. Pinho. "Study of viscoplasticity models for the impact behavior of high-strength steels." Journal of Computational and Nonlinear Dynamics 2.2 (2007): 114-123.
Van Slycken, Joost, et al. "Crashworthiness characterization and modelling of high-strength steels for automotive applications." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 220.4 (2006): 391-400.
ZHANGYoganandan, Narayan, et al. "Crash characteristics and injury patterns of restrained front seat occupants in far-side impacts." Traffic injury prevention 15.sup1 (2014): S27-S34.
Zeid Fadel Albahash., M.N.M.Ansari.; “A Review on Rear Under-ride Protection Devices for Trucks”; (2017), International Journal of Crashworthiness, 1-15.
Zeid Fadel Albahash, M. N. M. Ansari, and Qasim H. Shah. "Design and simulation of a rear underride protection device (RUPD) for heavy vehicles”; (2017), International Journal of Crashworthiness, 1-10.
Zhou, Y., Lan, F., Chen, J.; " Crashworthiness research on S-shaped front rails made of steel aluminum hybrid materials";(2011) , Thin-walled Structures ,49:291–7.