DEVELOPMENT OF A METRIC SYSTEM TO EVALUATE THE PERFORMANCE OF PASSENGER CARS IN FRONTAL CRASH TESTS

ÖNDEN ÇARPMA TESTLERİNDE BİNEK ARAÇLARIN PERFORMANSLARININ DEĞERLENDİRİLMESİNE YÖNELİK BİR ÖLÇÜM SİSTEMİNİN GELİŞTİRİLMESİ

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ABSTRACT

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Passenger safety during a collision is a criterion taken into account in automobile designs. For this reason, it is aimed to design the vehicles in such a way that the people inside the vehicle, especially the driver and passengers, are least damaged in the collision. Some autonomous organizations subject new vehicles to tests to examine how well they meet criteria such as passenger and pedestrian safety before they are put on the market. The National Highway Traffic Safety Administration (NHTSA) is one of these organizations. It evaluates vehicle safety from different aspects since 1979 under a program called the New Car Assessment Program (NCAP) [1] and then scores vehicle safety with a "5 Star" metric evaluation together with a detailed report. Crash tests are basically created by crashing the vehicle into a determined type of obstacle at a specified speed. Mannequins equipped with sensors called dummy are placed at various points in the vehicle that will carry out the collision. The scoring system, on the other hand, is created by scaling the sensor data levels of vehicle crash performance equivalent to serious injury in dummies.

In the thesis, the crash tests made in NCAP will be done by comparing the sensor data taken from different points on the vehicle and from the dummies. After this comparison, instead of a metric system that gives a single total result corresponding to vehicle crash performance, it is aimed to evaluate vehicle crash performance with two different metric systems which are vehicle structural performance and restraint system performance. In the collision scenario, full-width rigid barrier collisions, defined as "full-width rigid barrier (FWRB)" will be examined. While the structural performance of the vehicle is defined as the concepts that absorb the vehicle kinetic energy with factors such as plastic deformation, vibration and sound during the collision, restraint systems will be defined as the factors that ensure the safety of the occupant with the aid of seat belt and airbag in the collision. While aiming to create a new crash performance score based on these two separate factors, new parameters related to acceleration and speed, which have not yet been defined for vehicle safety, are determined.

Key Words:

Crash Safety, Crash Safety Scoring. Structural Systems’ Performance, Restraint Systems’ Performance, FWRB

ÖZET

ÖNDEN ÇARPMA TESTLERİNDE BİNEK ARAÇLARIN PERFORMANSLARININ DEĞERLENDİRİLMESİNE YÖNELİK BİR ÖLÇÜM SİSTEMİNİN GELİŞTİRİLMESİ

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Otomobil tasarımlarında çarpışma sırasındaki yolcu güvenliği göz önünde bulundurulan bir kriterdir. Bu sebepten araçlar şoför ve yolcular başta olmak üzere, araç içindeki kişilerin çarpışmada en az zarar göreceği şekilde tasarlanması hedeflenmektedir. Bazı özerk kuruluşlar piyasaya sunulmasından önce yeni araçları yolcu, yaya güvenliği gibi kriterleri ne kadar sağladığını incelemek için testlere tabi tutarlar. The National Highway Traffic Safety Administration (NHTSA) ise bu kuruluşlardan birisidir. New Car Assessment Program (NCAP) isimli bir program dahilinde 1979'dan beri araç güvenliğini farklı yönlerden değerlendirir [1] ve sonrasında detaylı bir raporla beraber "5 Yıldız" metrik değerlendirmesi ile araç güvenliğini puanlar. Çarpışma testleri temel olarak aracın belirlenen bir hızda belirlenen tipte engellere çarptırılması ile oluşturulmuştur. Çarpışmayı gerçekleştirecek araç içine dummy adı verilen sensörlerle donatılmış mankenler çeşitli noktalara yerleştirilir. Puanlama sistemi ise araç çarpışma performansının mankenlerdeki ciddi yaralanmaya eşdeğer sensor veri seviyelerinin ölçeklendirilmesi ile oluşturulmaktadır.

Tezde NCAP'te yapılmış çarpışma testlerinin araç üzerindeki farklı noktalardan ve mankenlerden alınan sensor verilerinin kıyaslanması ile yapılacaktır. Bu kıyaslama sonrasında araç çarpışma performansının tek bir toplam sonuç veren metrik sistem yerine; araç yapısal performansı ve pasif güvenlik sistemleri olarak iki ayrı ölçeklendirilmiş sistemle değerlendirilmesi hedeflenmektedir. Çarpışma senaryosunda "full-width rigid barrier (FWRB)" olarak tanımlanan tam genişlikte sert bariyer çarpışmaları incelenecektir. Aracın yapısal performansı çarpışma esnasında plastik deformasyon, titreşim ve ses gibi etkenlerle araç kinetik enerjisini emen kavramlar olarak tanımlanırken, restraint sistemleri ise emniyet kemeri ve hava yastığının çarpışmada yolcu güvenliğini sağlayan etkenler olarak tanımlanacaktır. Bu iki ayrı etmen üzerinden yeni bir çarpışma performansı puanlaması oluşturulması hedeflenirken, araç güvenliği ile ilgili henüz tanımlanmamış ivme, hız ile ilişkili yeni parametreler belirlenmektedir.

Anahtar Kelimeler: Araç Çarpışma Güvenliği, Çarpışma Güvenliği Puanlaması, Yapısal Sistem Perfomansları, Emniyet Sistemleri Performansı

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1 INTRODUCTION

Automobile manufacturers can produce vehicles by adhering to regulations. These regulations limit the physical and technological aspects of the vehicles. One of these regulations is the issue of passenger and pedestrian safety. Manufacturers sometimes design new cars or update existing models to adapt to regulations and sometimes to catch up with the changing consumer trend. When a newly designed or updated car is to be produced from scratch; along with the drivers and passengers in the vehicle, the safety of pedestrians who may be involved in an accident in traffic should also be considered. Some independent organizations subject new vehicles to tests to examine how well they meet criteria such as passenger and pedestrian safety before they are put on the market. The National Highway Traffic Safety Administration (NHTSA), which works in the United States of America, is one of these organizations. It has been evaluating vehicle safety with tests from different aspects since 1979 under a program called New Car Assessment Program (NCAP) [2].

In many parts of the vehicles used in these tests, sensors are placed to examine the results of the collision. The crash safety performance of the vehicles is examined by examining and processing the data received from these sensors, and then the vehicle safety is scored with a "5 Star" metric evaluation together with a detailed report. In the vehicle crash performance report, it shows how the passengers and the driver in the vehicle may be harmed during the accident. Crash tests are basically created by crashing the vehicle into a determined type of obstacle at a specified speed. Mannequins equipped with sensors called “Dummy” are placed at various points in the vehicle that will carry out the collision. The scoring system is created by scaling the sensor data levels of vehicle crash performance equivalent to serious injury in dummies. Thanks to the data received from the sensors, the physical damages that may be incurred by the person during the collision are calculated and reported.

In addition to the sensors placed on the vehicles in vehicle crash tests; sensors are placed on the obstacle that the vehicle hits. At the same time, markers are placed at some points on the vehicle. In addition to all these, the moment of collision is recorded from multiple angles with high-speed cameras. The data and images taken from all these equipment are published by NHTSA on the institution's website. Along with these data, it is also possible to access a detailed report showing the crash safety performance of the vehicle. Thanks to the processing and analysis of these data, new associations can be established about the performance of the vehicles by using different methods. In this way, it can find new approaches to the strengths and weaknesses of vehicles in crash safety.

When designing a car to define a newly designed vehicle as showing good crash performance; For design parameters related to crash resistance, cabin structure, nominal values such as the deceleration performance of the car, the deformation during the collision and the stiffness of the vehicle should be known [3]. The study in this thesis is about establishing new associations for vehicle safety by processing data to the sensor outputs used by the institution. The factors affecting the crash safety in the vehicle will be evaluated by dividing them into two basic elements. The first of these will be the structural shock absorption performance of the vehicle. The reflection of the kinetic energy absorption performance of the vehicle caused by the speed of the vehicle through plastic deformations, sound and vibration by the structural elements after the collision is evaluated as the structural crash performance. On the other hand, the effects of airbag and seat belt, which are other occupant protective safety measures in the vehicle, on the crash performance is evaluated as the crash performance of the restraint systems.

By examining the sensor data taken from the vehicle and the dummy movements, the relationship between two separate performance criteria on passenger safety has been reached. The associated and graphically verified data created in this context helped to determine new design criteria to ensure vehicle safety. The new (proposed) design criteria have been validated with data from many instruments. With the establishment of similar data relations in all vehicles, the performances of the vehicles were re-examined on the criteria that should affect the vehicle design. By checking the compatibility of the 5-Star system with the proposed criteria, a second verification opportunity has arisen. A new vehicle crash scoring system is created using these criteria by analyzing vehicles defined as safe by NHTSA. This scoring system scores the structural and restraint performance measures separately and provides preliminary information to the manufacturers and the end user.

In crash tests, vehicles have a certain kinetic energy due to their speed. The greatest part of this kinetic energy transforms into sound and vibration, deformation of structural parts during collision. For example, in the tests of frontal crash with a rigid barrier, the speed of the vehicles drops to zero for a moment during the collision and then the vehicles bounce back from the wall at a lower speed. The variation of the acceleration experienced by the vehicle from the moment of first contact in the collision to the moment when the contact is lost from the barrier is called the crash pulse. Acceleration-based injury risk parameters and passive safety system performance criteria are defined [3][4].

The deceleration of the vehicle is reflected to the passengers as acceleration inside the vehicle. Reducing this acceleration can only be managed to a certain level due to other economic and design constraints in vehicle design such as the length of the vehicle. Structural factors and passive safety systems (i.e. restraint systems) in the vehicle are the two main factors that affect the crash safety performance of the vehicle. The most basic restraint systems are the airbags and seat belts. Since structural factors alone cannot ensure crash safety, these factors come into play and occupant protection systems such as airbags and seat belts are used to reduce injuries in the event of an accident [2].

The kinetic energy of the vehicles while going at a certain speed is transformed into deformation energy during the crash. The system that absorbs the deformation energy is the structural systems of the vehicle consisting of metal, composite and plastic materials. Structural systems are the bodies that form the appearance of the vehicle and allow all necessary systems to be placed on it. In the frontal crash tests, which are the subject of the thesis, more than one point of the vehicle, especially the front part of the vehicle, is deformed. This deformation can be either in the form of rupture or in the form of deformation. It is difficult to examine individually how much shock absorbs each region in the vehicle structural system, which is a complex structure, in crash tests. Finite element analysis (FEA) can be used to analyze how much shock is absorbed by which part of the vehicle's body during a collision, which takes place in a very short time. Detailed calculation of the shock absorbency of the vehicle structure is possible with FEA analysis methods or component test methods. By using the data to be used in this thesis, the performance of the structural parts of the vehicles that affect the safety during a frontal crash can also be evaluated by using the test method. This independent evaluation of structural performance will help vehicle manufacturers to improve their designs. Formulas that can indicate the necessity of increasing the structural crash safety performance of the vehicles have been suggested.

In line with the study and the results obtained, the structural and restraint performance of vehicles have been investigated. This will be beneficial for companies that will produce new vehicles, or for manufacturers who are considering changing their existing vehicles by using research and development processes. By examining the results, new vehicle manufacturers will be able to examine the crash safety performance of structural or restraint systems they will supply from different companies. On the other hand, manufacturers aiming to improve their vehicles will be able to identify areas that are open to improvement in their vehicles with less effort, by taking this study, which examines more local areas, instead of the general work that needs to be done to increase the safety elements in their vehicles.

1.1 FWRB Frontal Impact Tests and Test Data

In the FWRB Frontal Impact test, the vehicle to be tested impacts a rigid barrier at 56 km/h. The overlap between the vehicle and the wall in a collision is 100%. During this collision, data is received from the sensors on the vehicle, on the dummies and on the wall. Simultaneously, the collision is monitored by high-speed cameras. The sensors on the dummies are usually tri-axial accelerometers, potentiometers and load cells. Dummies are placed on the vehicle seats and the test begins with the seat belts on. In addition, there are accelerometer sensors in the vehicle under test. These sensors are integrated into the vehicle's structural system: the rear sills, rear seats and engine.

The vehicle is accelerated and hit perpendicular to the wall. In the meantime, deformation occurs in the vehicle. For this reason and due to their inertia, dummies inside the vehicle are exposed to forces during the collision. The forces that occur on the dummy can be at levels that do not harm, or they can be at levels of injury. After the measurements made by the sensors used during the test, the limit values that were confirmed by the previous cadaver tests, are used. In line with these limit values, the crash safety performance of the vehicle can be examined by comparing the test data.

In the study conducted in this thesis, the vehicle performances were evaluated separately as structural and restraint systems by taking the limit values used by NHTSA and the average of the crash safety performance of the vehicles used in this study. The criteria (metrics) used in the study are shown in Table 1 with their explanations.

Figure 1: FWRB Frontal Crash Test, Pre-Test Right View of Test Vehicle [5]

Figure 2: FWRB Frontal Crash Test, Pre-Test Right View of Test Vehicle [5]

Table 1 List of Test Injury Criteria

Criteria (Metrics)	**Systems that perform**
HIC15	Structural and Restraint Systems
Left Femur Force	Structural and Restraint Systems
Right Femur Force	Structural and Restraint Systems
Nij	Structural and Restraint Systems
Neck Compression Force	Structural and Restraint Systems
Neck Tension Force	Structural and Restraint Systems
Largest Neck Shear Force	Structural and Restraint Systems
Head Resultant Acceleration 3ms Exc,	Structural and Restraint Systems
Relative Velocity Coefficient	Structural and Restraint Systems
Relative Displacement Coefficient	Structural and Restraint Systems
Chest Compression Force	Structural and Restraint Systems
Max, V.C.	Structural and Restraint Systems
CTI	Structural and Restraint Systems
The Mean Acceleration of The Occupant Compartment	Structural System
The Maximum Moving Average (50ms) Acceleration of The Occupant Compartment	Structural System
The Adjusted Crash Severity (50ms)	Structural System
Chest Acceleration Factor	Restraint System
Head Acceleration Factor	Restraint System

More than 12000 data packages from 33 passenger cars were used to establish the criteria given in Table 1. These data packages contain time-dependent data from the sensors used in the vehicle crash test. By using the data, the values constituting the vehicle performance criteria could be found. These data were examined by finding the average values of the vehicles within themselves or by comparing them with the established maximum and minimum values. The driver dummy data is selected and analyzed in this study.

The separation of occupant protection performance in vehicle crashes used in the thesis as restraint and structural systems is a unique method. In line with this method, elements that contribute to the protection of the passenger at the time of crash were determined by region. These elements are directly or indirectly associated with the vehicle's structural and restraint systems.

2 LITERATURE SURVEY

The performances of restraint and structural systems are not evaluated separately from each other after the current tests. The post-accident passenger safety performance of the vehicle is evaluated after these two elements act together. In this thesis, the frontal collisions against full width barrier will be examined and scoring will be realized by taking a separate approach to the structural performance and passive safety restraint) systems in the vehicle.

In Himmetoglu et al. [3] study, 10 passenger car groups with different masses and brands were examined. Values for design criteria are obtained by processing data not found in crash test reports of cars selected from the crash test database of the US National Highway Traffic Safety Administration (NHTSA). It is critical to obtain a car with good impact resistance in frontal impacts; There are statistical analysis of the values of design parameters such as maximum deformation, mean acceleration, between loading phase duration and mean acceleration, and suggestions for related design criteria [3].

In Himmetoglu et al. [6] study, 8 minibus groups were selected from the National Highway Traffic Safety (NHTSA) crash test database of different masses and brands. These vans, produced between 2012 and 2017. are among the winners of a four or five star rating. In full-width rigid barrier (FWRB) front impact test; estimated crash-pulse duration, duration of the loading phase, mean acceleration of the occupant compartment occupant compartment, mean acceleration of the occupant compartment during the loading phase, mean acceleration of the occupant compartment, mean acceleration of the occupant compartment, peak moving average (Statistical analysis of the values of design parameters such as 25ms) acceleration of the occupant compartment, peak moving average (50ms), acceleration of the occupant compartment, peak acceleration of the occupant compartment, maximum head resultant acceleration of the driver are presented and suggestions are given for the relevant design criteria [6].

Douglas J. Gabauer et al. [2] examine the effect of changes in vehicle speed and passenger type on the level of protection, while occupant protection systems such as airbags and seat belts are used to reduce injuries in the event of an accident. In this study, two parameters are proposed to measure the performance of passive security systems. It has been stated that one of these two parameters shows the risk of head and chest injury better than the other [2].

Venkatesh Agaram et al. [7], examine full front rigid barrier engineering with vehicle-to-vehicle crash tests. Vehicles are examined by their heights with the acceleration stroke. In addition, pulse phase cross-correlation and pulse shape, which are used in different tests, are also examined. The collision is equivalent to a collision with a 41 mph vehicle with a fully rigid barrier at 30mph. [7].

Wu et al. [8] examine an energy relationship between restraint systems and vehicle impact pulses. In addition, the different vehicle impact pulses effect on the occupant with nonlinear restraints [8].

The Euro NCAP frontal crash test has main five criteria and limits for the driver. These are generally Head, Neck, Chest, Knee-Femur and Pelvis, Lower Leg.

For the head criteria, HIC15 and Resultant Acc 3 msec exceedance criteria have been determined and evaluation is made over the limit values of these criteria. The crash test performance of the vehicle is measured by considering the shear, tension force and extension limits for the neck. Injury evaluation in the chest region is made with the limit values of compression and viscous criterion. Only one criterion is evaluated for knee, femur and pelvis: femur compression. The Lower Legs performance criteria is measured for monitoring purpose only [9].

On the other hand, NCAP uses HIC15, Maximum Chest Compression, Nij, Neck Tension, Neck Compression, Left Femur Force and Right Femur Force criteria for frontal crash testing [5].

2.1.1 HIC15

HIC, the head injury criterion is coming from the center of gravity of the head and its maximum value's resultant acceleration is recorded.

The maximum HIC value recorded in NCAP FWRB tests is calculated over a time interval of 15 ms hence it is also denoted by HIC15.

$$HIC = max_{T0 \leq t_1 \leq t_2 \leq TE}\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} R(t)dt\right]^{2.5} * (t_2 - t_1)$$

T0 is the time zero, TE is the final time, R(t) is the resultant acceleration of head in G's, t_1 and t_2 are the start and final times [10].

2.1.2 Left Femur Force

It is the axial force value on the left femur bone of the dummy in the driver's seat during the vehicle crash test.

2.1.3 Right Femur Force

It is the axial force value on the right femoral bone region of the dummy in the driver's seat during the vehicle crash test.

2.1.4 Nij - Biomechanical Neck Injury Criteria

Nij is a predictor that shows injuries that may occur due to applying a longitudinal load. It can be calculated by including the force applied in the z direction and the moment around the y axis in the formula.

$M_y = M'_y - e \cdot F_x$

N_{ij}:

$N_{ij} = \frac{Fz}{Fzc} + \frac{My}{Myc}$

F_{zc} and M_{yc} are constants are coming from the dummy's property and the neck loading condition [10].

2.1.5 Neck Compression Force

The pressing force on the driver's neck at the time of crash can cause fatal injuries.

2.1.6 Neck Tension Force

The magnitude of the pulling force on the neck of the occupant in a vehicle collision can lead to fatal causes, as in the Neck Compression Force. The structural safety performance of the vehicle plays a major role in this small value.

2.1.7 The Mean Acceleration of the Occupant Compartment

Occupant compartment is the name given to the cabin of the vehicle. The mean acceleration of the occupant compartment is directly related to the injury of people during the crash. For this reason, the change in the acceleration of this region is directly related to the injuries.

2.1.8 The Maximum Moving Average (50ms) Acceleration of The Occupant Compartment

Calculating the moving average acceleration means the average value of the acceleration over the time interval. This time interval is 25 ms or 50 ms. For a given crash impact, the highest value of the moving average accelerations for the entire duration of the crash impact is reported [11].

2.1.9 The Adjusted Crash Severity (50ms)

The change in vehicle velocity during a collision is called delta-v. This is a suggested measure in this thesis. It takes into account both delta-v and average acceleration. Cars can have the same delta-v but different mean accelerations and vice versa.

Adjusted Crash Severity = (Delta-V ÷ Impact Velocity) * (Maximum Moving Average Acceleration of the Occupant Compartment)

2.1.10 Largest Neck Shear Force

Exposure of passengers or drivers to high neck shear force in vehicle frontal crashes can cause paralysis or fatal results. For this reason, the less the Neck Shear Force, the lower the risk of injury. Whether this value will be high or not is the main determinant of the vehicle's structural and restraint system performance.

2.1.11 Head Resultant Acceleration 3ms

In written sources, the 3 ms head acceleration value is vaguely defined as the highest amplitude of the head acceleration signal that lasts 3 ms. However, since a largest value is not sustained for 3 ms in this present study, the acceleration signal is traced by using a moving window of 3 ms and if in this moving window, the change in the acceleration signal is less than 5 g, then the largest acceleration value in that 3 ms window is chosen as the 3 ms acceleration value. The largest of the 3 ms head resultant acceleration values throughout whole crash is chosen as the final and the single value for the 3 ms head resultant acceleration value [12].

2.1.12 Head Acceleration Factor

The Head Acceleration Factor is a factor that defines how much acceleration the driver's head area has during a crash. As a result of the acceleration of the head region, the contact of the vehicle with any rigid point may cause injuries such as cerebral hemorrhage or external hemorrhage. The lower the acceleration of the driver's head in the vehicle, the lower the risk of injury. This is a suggested measure for restraint performance in this thesis.

Head Acceleration Factor = Maximum Head Resultant Acceleration ÷ Mean Acceleration of the Car

2.1.13 Relative Velocity Coefficient

Prior to impact, the occupant and the cabin (i.e. occupant compartment) have the same velocity which is the impact velocity of the car. As a result of the impact, the cabin decelerates and the relative velocity of the head with respect to the cabin increases hence the relative velocity coefficient indicates the amount of head's relative velocity in relation to the speed of the car.

Larger values of this coefficient signals higher injury risk. This is a suggested measure in this thesis.

Relative Velocity Coefficient = (Largest Relative X-Velocity of The Head (Relative To The Cabin)) ÷ (Impact Speed of The Car)

The x-velocity in the formula corresponds to the relative velocity of the head along the x-axis of the global coordinate system which is attached to the ground.

2.1.14 Relative Displacement Coefficient

For a given chest to dash (i.e. dashboard) distance, if the maximum relative displacement of the head with respect to the cabin is higher, then the energy absorption of the occupant by the restraint systems is not effective enough hence the injury risk can also be higher. This is a suggested measure in this thesis.

Relative Displacement Coefficient = (Maximum Relative x-Displacement of The Head (Relative to The Cabin)) ÷ (Chest to Dash Distance).

The x-displacement in the formula corresponds to the relative displacement of the head along the x-axis of the global coordinate system which is attached to the ground.

2.1.15 Maximum Chest Compression

It is a phenomenon that specifies the compression in mm resulting from the pressure applied to the chest area during the crash. Due to the presence of vital organs such as lungs and heart, the injury to the chest can leave permanent damage and cause death. For this reason, it is vital for the driver that this value is small. The main sources of force applied to the chest area are the seat belt and the airbag system.

2.1.16 Chest Acceleration Factor

The ribs are located in the chest area and protect vital organs such as the lungs and heart. Despite the ribs in the chest, which has high acceleration during the collision, physical damage may occur in the internal organs. In order to prevent this situation, the chest should not hit something hard and experience high acceleration. The belt forces on the chest should also be limited. This is a suggested measure for restraint performance in this thesis and this parameter is referred as Dynamic Amplification Factor in reference [13].

Chest Acceleration Factor = Max Chest Resultant Acceleration ÷ Mean Acceleration of The Car

2.1.17 Maximum V.C. (Viscous Injury Response)

The chest; It consists of soft tissues such as blood vessels, heart and lungs, as well as hard tissues such as spinal cord and ribs. These organs are often vital organs and are therefore critical to the protection of the chest area. The instantaneous compression function's symbol is (C), deformation velocity symbol is (V). The deflection is D, in addition SZ is a prescribed size. SF is coming from Dummy's property. SF is 0.229 and SZ is 1.3 for a Hybrid-III 50th percentile dummy [10].

$$V.C. = SF * max \frac{dD(t)}{dt} + \frac{D(t)}{SZ}$$

2.1.18 CTI (Combined Thoracic Index)

This criterion is combined from the maximum chest deflection Dmax, the resultant upper spline acceleration’s maximum value at 3ms: Amax.

$$CTI = (A_{max} / A_{int}) + (D_{max} / D_{int})$$

A_{int} and D_{int} are constants. For the dummy Aint is 850 m/s^2 and Dint is 0.102 m [10]

3 METHODS

Crash test data from previous years are used in the thesis. The outputs obtained after the measurements on the computer aided image were also supported by the sensor data. After the frontal crash model analysis, which is the subject of the thesis, a new scoring system was created in terms of innovation in automobile design criteria and vehicle crash safety.

- Measurements were made from the collision images of vehicles of various brands and models,

• Collision sensor data has been examined and sorted,

• Establishing a relationship and approximation between the collision sensor data through the MATLAB program,

• The results were verified by examining the compatibility with the tools defined as safe and unsafe,

• The crash performance of the vehicle structure and the passive safety (restraint) systems are scored independently of each other.

If the comparison of the criteria used to determine vehicle performances is specified as maximum or minimum in the NHTSA system, this method is used. The comparison of the vehicles whose maximum or minimum values are not found in the literature was created by proportioning the values of 33 vehicles.

The systems that prevent the damage to the passengers during the crash of the vehicles are evaluated in two main branches as structural and restraint systems. The data outputs associated with these two systems show the approach of the thesis. Thanks to this method, which is used as an original value, it is aimed to determine the aspects of the tools that are open to development.

While conducting the studies, the sensor data used in the test by the NHTSA institution, which conducts the frontal crash safety tests, were used in the MATLAB program. The number of these data can be between 132 and 634 per vehicle. These data are processed with the written code. After processing, the values determined as structural and restraint system performance criteria were reached. There may not be some sensor data due to system errors in the data of NHTSA. The reason for this is that there is no data flow from the relevant sensor during the test. The data of vehicles in these and similar situations have not been calculated. All performance criteria of all vehicles whose crash performance was examined were calculated. Vehicles with missing data were not included in the study.

The study was performed one by one for the criteria in Table 1 in all vehicles. The results obtained after the work done on the MATLAB program are listed. If the maximum value of the selected criterion, which will not cause a safety problem during a vehicle collision, is obtained from the literature, the number found is subtracted from this value and divided by the maximum value by taking it into the absolute value. Similarly, if the minimum value for the relevant criterion was obtained from the literature; The minimum value is subtracted from the number in the absolute value and again divided by the minimum value. In this way, performance values specific to each vehicle and for each criterion were found separately.

In the method used by NCAP in scoring, injury risk calculations are made. This method’s name is Relative Risk Scores. A large number of traffic accident data are analyzed for this method. In addition, it evaluates a lot of hospital data. For this reason, injury risk calculation methods and analysis of risks are very difficult. On the other hand, Euro NCAP sliding scale system is used. In this method, two limits are determined for each parameter. While one of these limits determines the higher performance, the other determines the lower limit. In frontal impacts, the maximum score for tests region is four points; for rear impact protection, it is three points. If a value is between the two limits, linear interpolation is used for the score [9][1].

The formulas used to find the values of each vehicle of the relevant criteria and their vehicle performance scoring formulas are as follows:

3.1 SCORING FACTORS

Various factors have been created in order to examine the performance of vehicle crash tests in detail and to simplify and classify big data. The factors are compared with the injury criteria to assess whether the occupant's injury is high. As a result of the comparison of the values obtained with the factors, it can be accessed how successful the test tool gave in terms of the factor. In this way, the crash performance of the vehicles was analyzed and as a result of the whole analysis, the vehicle crash performance was divided into two as structural and restraint systems and performance scoring was made.

3.1.1 HIC15 Factor

Head injury criteria value is shared by NHTSA in vehicle crash reports.

HIC15 evaluation score for the vehicle (N_{HIC15}):

$$N_{HIC15} = (\text{HIC15 Value}) \div (HIC15\ max.value)$$

3.1.2 Left Femur Force Factor

The maximum value that the dummy can be exposed to during the collision is 10008 Newton [5]. Left Femur Force Factor (N_{LFF}) is:

$$N_{LFF} = (\text{LFF Value}) \div (LFF\ max.value)$$

3.1.3 Right Femur Force Factor

The maximum value that the dummy can be exposed to during the collision is 10008 Newton [5]. Right Femur Force Factor for crash performance (N_{RFF}):

$$N_{RFF} = (\text{RFF Value}) \div (RFF\ max.value)$$

3.1.4 Nij - Biomechanical Neck Injury Criteria Factor

The maximum Nij value is 1 in the literature [5]. Vehicle crash performances are also evaluated with this number. The closer it is to 1. the lower the vehicle's neck protection performance.

$$N_{Nij} = (\text{Nij Value}) \div (Nij\ max.value)$$

3.1.5 Neck Compression Force Factor

The critical value for neck injury during a collision is 4000 Newton [5].

$$N_{NCF} = (\text{NCF Value}) \div (NCF\ max.value)$$

3.1.6 Neck Tension Force Factor

The critical value for neck injury during a collision is 4170 Newton [5].

$$N_{NTF} = (\text{NTF Value}) \div (NTF\ max.value)$$

3.1.7 The Mean Acceleration of the Occupant Compartment Factor

The arithmetic average has been taken for the vehicles with all The Mean Acceleration of the Occupant Compartment values in the test data found in the reports published as a result of the collisions. This average was 15.451 g.

$$N_{MAOC} = (\text{MAOC Value}) \div (MAOC\ average\ value)$$

3.1.8 The Maximum Moving Average (50ms) Acceleration of The Occupant Compartment Factor

Vehicles with acceptable crash performance have MMA values between 26.2 g and 31.7 g. The closer the number is to 26.2. the better it performs.

$$N_{MMA} = (\text{MMA Value}) \div (NCF\ min.value)$$

Moving average acceleration of the crash pulse has been shown to be a better crash-severity measure in comparison to the mean acceleration of the crash pulse [14]. In moving average acceleration calculations, the mean value of the acceleration in a specified moving time interval is calculated. This moving time interval is typically selected as 25 ms or 50 ms [11]. Throughout the crash, moving average accelerations are calculated for all moving time intervals and the maximum of these is selected as the maximum moving average acceleration (MMA) value. This value of this parameter depends on the structural properties of the vehicle hence showing the severity of the crash pulse. Crash pulse is the acceleration versus time history of the occupant compartment.

In full-width rigid barrier impact tests (NCAP) performed at 56 km/h impact speed, vehicles with acceptable crash performance have maximum dynamic deformations between 0.550 m and 0.800 m on average. This approximately corresponds to 26.2 g and 31.7 g of MMA (50 ms) for the occupant compartment [15]. The closer the number is to 26.2. the better it performs.

3.1.9 The Adjusted Crash Severity (50ms) Factor

A value of 32.226 g was obtained as a result of calculating The Adjusted Crash Severity (50 ms) values of the vehicles studied and calculating the arithmetic average of the vehicles included in the study.

$$N_{ACS} = (\text{ACS Value}) \div (ACS\ avarage\ value)$$

3.1.10 Largest Neck Shear Force Factor

The maximum injury criteria to which the neck will be exposed is determined as 1000 Newton[5].

$$N_{NSF} = (\text{NSF Value}) \div (NSF\ max.value)$$

3.1.11 Head Resultant Acceleration Factor (3 ms)

The acceleration average in the 3 ms intervals of the collision of the dummy in the vehicles is 48.786 g for all vehicles.

$$N_{HRA} = (\text{HRA Value}) \div (HRA\ avarage\ value)$$

3.1.12 Head Acceleration Factor

The average head acceleration factor obtained from the dummy in the vehicles at the time of collision is 3.234 in all vehicles.

$$N_{HA} = (\text{HA Value}) \div (HA\ avarage\ value)$$

3.1.13 Relative Velocity Coefficient Factor

The average of the Relative Velocity Coefficient obtained as a result of the calculation of the data received in the collision of the vehicles is 0.603.

$$N_{RVC} = (\text{RVC Value}) \div (RVC\ avarage\ value)$$

3.1.14 Relative Displacement Coefficient Factor

The average of the Relative Displacement Coefficient obtained as a result of calculating the data received in the collision of the vehicles is 0.88.

$$N_{RDC} = (\text{RDC Value}) \div (RDC\ avarage\ value)$$

3.1.15 Maximum Chest Compression Factor

Maximum Chest Compression to be applied on the dummy can be 63 mm[5].

$$N_{CC} = (\text{CC Value}) \div (CC\ avarage\ value)$$

3.1.16 Chest Acceleration Factor

The average of the values obtained by measuring the acceleration in the dummy chest during the collision within the vehicles is 3.019.

$$N_{CA} = (\text{CA Value}) \div (CA\ avarage\ value)$$

3.1.17 Maximum V.C. (Viscous Injury Response) Factor

The VC could be less / equal to 1 [16].

$$N_{VC} = (\text{VC Value}) \div (1)$$

3.1.18 CTI (Combined Thoracic Index) Factor

The CTI value is unitless. The maximum value of CTI could be 1 [16].

$$N_{CTI} = (\text{CTI Value}) \div (1)$$

3.2 DETERMINATION OF DUMMY HEAD ANGLES

The calculation of relative velocity and relative displacement coefficients involve the motion of the head relative to the cabin. There are accelerometers attached to the cabin (i.e. occupant compartment) at around the rear seat and in the crash test data the acceleration of the cabin is expressed in the global coordinate system attached to the ground as shown in Fig. 3. The x_0 axis of the global coordinate system is horizontal to the ground and in the moving direction of the vehicle before the crash whereas the z_0 axis downward. On the other hand, dummy head accelerations are measured in the local coordinate system attached to the head as shown in Fig.

3. In order to quantify the motion of the head relative to the cabin, the measured head accelerations must be expressed in the global coordinate system. By using video frames captured by the high speed cameras, the angles (θ) of the dummy head with respect to the ground (on the $x_0 - z_0$ plane) are measured at selected time instants assuming negligible parallax errors. Considering that the dummy head makes a planar motion approximately on the $x_0 - z_0$ plane, the measured head acceleration $\vec{a}_h$ is expressed by Eqn.1 where $\vec{u}_1^{(h)}$ and $\vec{u}_3^{(h)}$ are the unit basis vectors along the x_h and z_h axes, respectively. The unit basis vectors $\vec{u}_1^{(0)}$ and $\vec{u}_3^{(0)}$ are along the x_0 and z_0 axes of the global coordinate system. It is desired to find the components of $\vec{a}_h$ in the global coordinate system as indicated in Eqn.1. The required component transformation is given by Eqn. 2.

$$\vec{a}_h = a_x\, \vec{u}_1^{(h)} + a_z\, \vec{u}_3^{(h)} = a_{x0}\, \vec{u}_1^{(0)} + a_{z0}\, \vec{u}_3^{(0)} \qquad Eqn.(1)$$

$$\begin{bmatrix} a_{x0} \\ 0 \\ a_{z0} \end{bmatrix} = \begin{bmatrix} cos\theta & 0 & -sin\theta \\ 0 & 1 & 0 \\ sin\theta & 0 & cos\theta \end{bmatrix} \begin{bmatrix} a_x \\ 0 \\ a_z \end{bmatrix} \qquad Eqn.(2)$$

Once the components of dummy head acceleration in the global axes are determined, numerical integration is performed to calculate the velocity and displacement of the dummy head. It should be noted that an interpolating curve is fitted to dummy head (θ) versus time history so as to obtain head angles at all time instants.

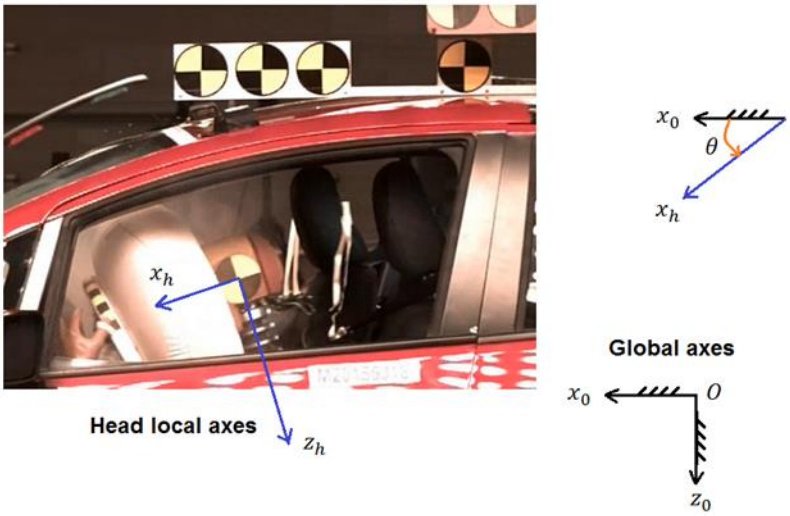

Figure 3: Head Angle

3.3 EVALUATION OF CRASH PERFORMANCE OF VEHICLES

Eighteen evaluation metrics were determined by processing the data obtained from the vehicle crash test in the MATLAB program. HIC15. Left Femur Force, Right Femur Force, Nij, Neck Compression Force, Neck Tension Force, Largest Neck Shear Force, Head Resultant Acceleration, Relative Velocity Coefficient, Relative Displacement Coefficient, Maximum Chest Compression, Maximum VC, CTI are both structural and restraint performance metrics of the vehicle.

In addition, Head Acceleration and Chest Acceleration factors are the metrics that directly serve to evaluate the crash safety performance of the restraint systems in the vehicle.

The Mean Acceleration of the Occupant Compartment, The Maximum Moving Average (50ms) Acceleration of The Occupant Compartment, The Adjusted Crash Severity (50ms) values are the criteria that show only the structural safety performance of the vehicle.

The data obtained as a result of the study were compared between the tools. By comparing these data, the structural and restraint system performance of the vehicles were examined against the scores they received in the NCAP star system. In this way, it has been observed that there are vehicles with better crash safety performance among vehicles that have received the same score from the 5-star system.

In addition to the comparison of the structural and restraint system safety performances of the vehicles, the total vehicle score was calculated by using the values obtained from the metrics applied in this thesis. With this method, it can be concluded which of the structural or restraint system metrics of vehicles with low crash safety performance is more unsuccessful. Thanks to the study, it can be seen what systems the manufacturer companies need to develop in the vehicle are. In addition, it has been observed that some vehicles have better performance despite having the same score in the NCAP star scale. This led to a more enlightening scoring system for vehicle customers.

3.4 CODE

The sensors used in the FWRB crash tests are identified by numbers. During the collision, data can be received from more than 600 sensors. NHTSA describes all the sensor codes it uses, along with the areas of use. While the tests are applied to different vehicles, measurements are made from the same sensors in each test. The code written in the MATLAB program used in the study calculated the scoring metrics by automatically accessing the data it needed from the folder containing all the sensor data while making the calculations.

The make and model of the vehicles are hidden. Instead of brands and models, codes are given in alphabetical order. The aim here is to create a new scoring system, instead of re-evaluating the measured crash safety performance of the vehicles, to enable comparisons with the measured crash safety performances of the vehicles.

The crash speed of the vehicle, the unique number containing the code given to the vehicle by NHTSA (For example V08495), Barrier Force vs Time, Deformation vs Time, Acceleration vs Time codes, chest to dash distance, driver head resultant acceleration, driver chest resultant acceleration are the elements that create the entries in the code. These values are entered for each vehicle. Other functions and sensor data are automatically drawn from the code. The sensor data is available in folders for various vehicles on the website where NHTSA shares its data. The study can be repeated for different vehicles with this code. Vehicle performance information can be accessed by comparing the outputs obtained as a result of the calculations of the code.

The values obtained after running the code are tabulated. All tools and program outputs are included in the table.

A filter was applied to the data used while the code was running. SAE J211-1 standards [17] are taken as reference while doing this. With this filter, the magnitudes of high frequency signals from the accelerometers and load cells are reduced. Sample figures from the Matlab code were given for a selected vehicle in the following pages.

The filters available in SAE J211-1 are applied to Vehicle structural acceleration, Barrier face force, Belt restraint system loads, Anthromorphic Test Device, Sled acceleration, Steering column loads, Headform acceleration data. Separate filters are made for Neck, Thorax, Lumvar, Pelvis and Femur/Knee/Tibia/Ankle in Anthromorphic Test Device. The filter values used in the thesis are shown in the Table 2:

Table 2 List of Test Filters [17]

Test Measurements	**Channel Frequency Class**
Vehicle Structural Acceleration:	
Total vehicle comprasion	60
Collision simulation input	60
Integration for velocity or displacement	180
Barrirer Face Force	60
Belt Restraint System Loads	60
Anthromorphic Test Device:	
Head accelerations	1000
Neck Forces	1000
Neck Moments	600
Thorax spine accelerations	180
Thorax rib accelerations	1000
Thorax sternum accelerations	1000
Thorax deflections	600
Lumbar forces	1000
Lumbar moments	1000
Pelvis accelerations	1000
Pelvis forces	1000
Pelvis moments	1000
Femur/Knee/Tibia/Ankle forces	600
Femur/Knee/Tibia/Ankle moments	600
Femur/Knee/Tibia/Ankle displacements	180
Sled Accelerations	60
Steering Column Loads	600
Headform Acceleration	1000

As can be seen in Figure 4, it is not possible to use unfiltered data. Due to environmental effects, errors that may occur in test equipment and the inability to create an absolutely correct test environment in the real world; There may be false data and noise. These values are very different from the usual results. By eliminating these values, real data can be reached. The purpose of the studies can be achieved by filtering these unrealistic data. Otherwise, erroneous results will be obtained after the procedures.

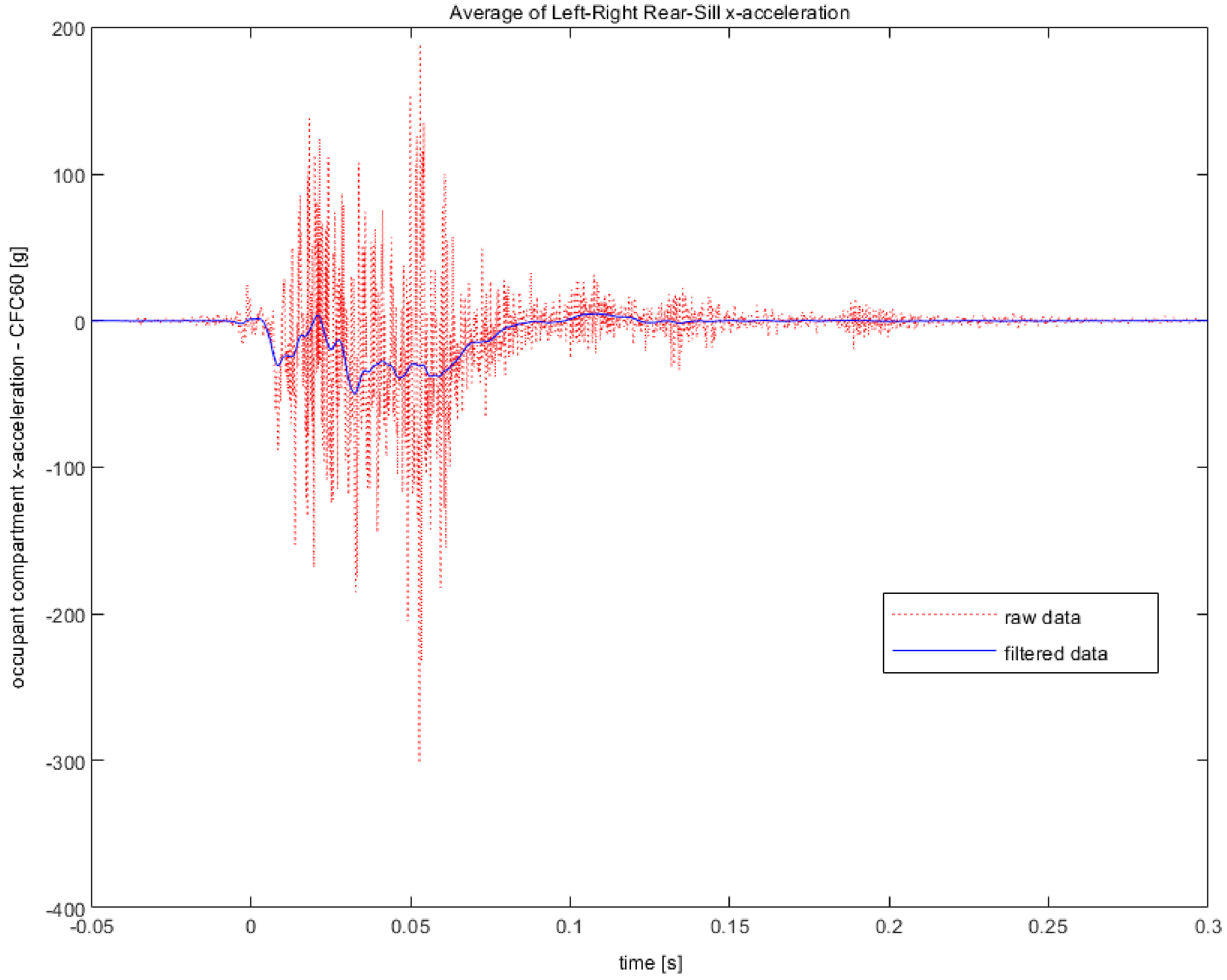

Figure 4: Filtered and Raw Data Graphic

Code structure: Initially, input data is defined in the code. Time increment for head center of gravity data, driver head center of gravity local accelerations, driver chest local accelerations, vehicle impact velocity, chest to vehicle dash distance, driver head resultant accelerations, head of angle with respect to global x-axis in degrees and time instants corresponding to head angle in ms are some inputs of the code.

Calculations are made by using the sensor data in the code along with these inputs. While the code is running, results are obtained by combining the sensor data with the inputs with formulas. Here are some outputs used to get the results:

Maximum deformation of car occurs, resultant barrier force from time=0 to the time of max. deformation, occupant compartment acceleration, the indices in xi vector where deformation, the latest instant of time where deformation, Estimated rebound velocity, mean acceleration of the occupant compartment, Extract head local accelerations from time=0 to 0.15 s, head local accelerations to global accelerations, head acceleration factor, maximum head resultant acceleration over mean acceleration of the car, chest acceleration factor, maximum chest resultant acceleration over mean acceleration of the car, head center of gravity global velocities, the pre-crash head center of gravity velocities, head center of gravity velocities relative to occupant compartment, head center of gravity x & z velocities relative to occupant compartment, head center of gravity resultant relative velocity, max. head displacement relative to occupant compartment, the global position of the head, the global position of the occupant compartment, head x-displacement relative to occupant compartment, the maximum relative x-displacement of the head. max relative x-displacement over chest-to-dash distance, Chest local x-accelerations.

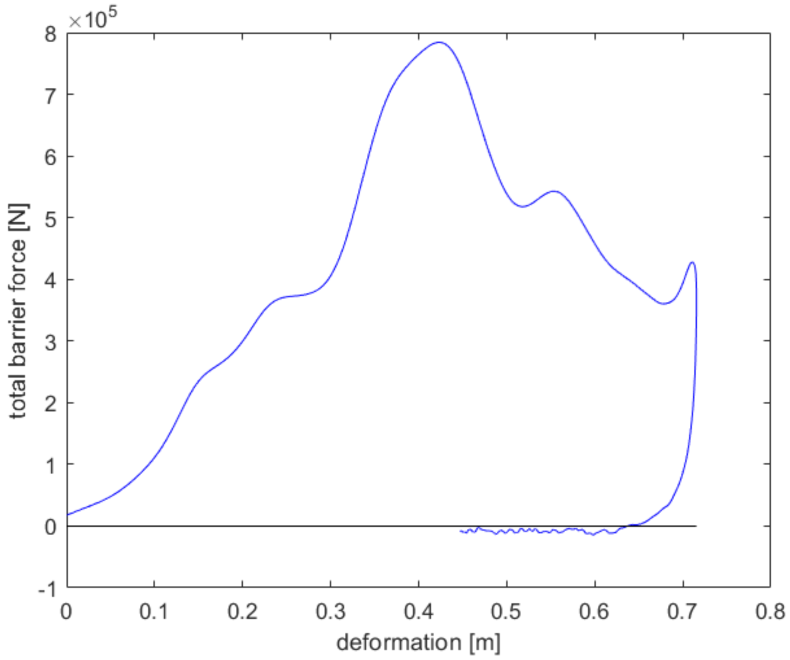

Figure 5: Total Barrier Force – Deformation

In figure 5 shows the force applied to the vehicle by the barrier. With this graph, the deformation of loss of contact from the wall in a collision can be found.

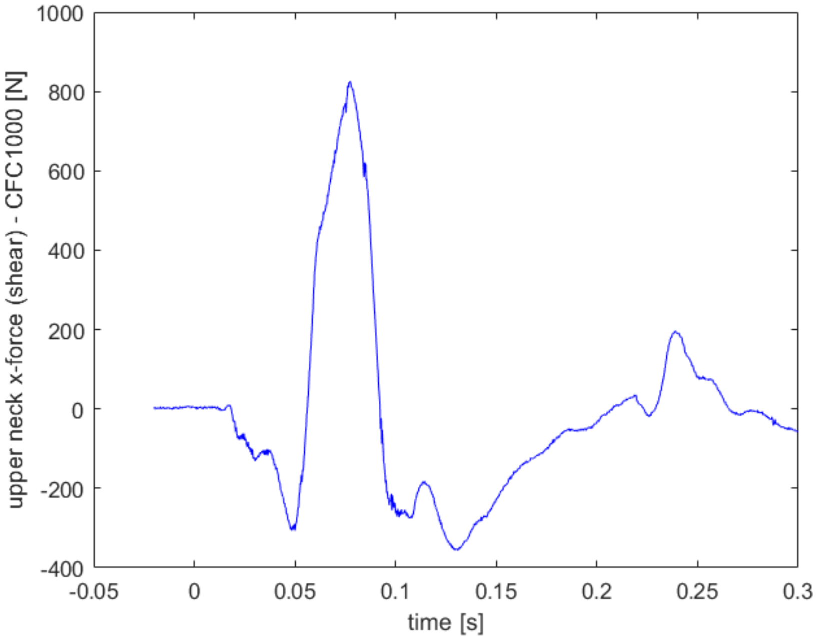

Figure 6: Upper Neck Shear Force - Time

In figure 6, neck injuries data are obtained by examining the amount of shear force applied to the neck depending on time.

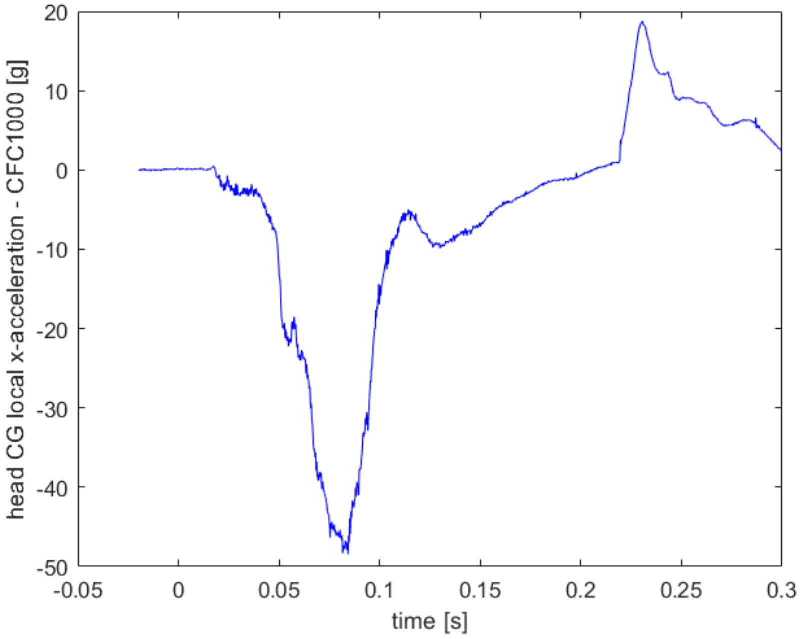

Figure 7: Head Center of Gravity X Acceleration– Time

In figure 7, the movement of the head at the time of the collision can be observed. This movement is quite effective in neck injuries.

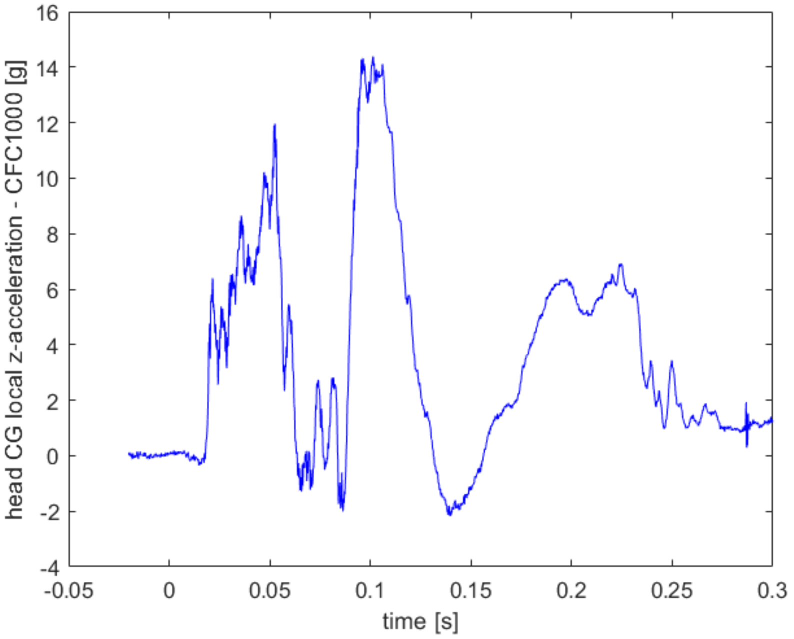

Figure 8: Head Center of Gravity Z Acceleration – Time

In figure 8, the movement of the head at the time of the crash can be observed. This movement is quite effective in neck injuries, just like figure 6.

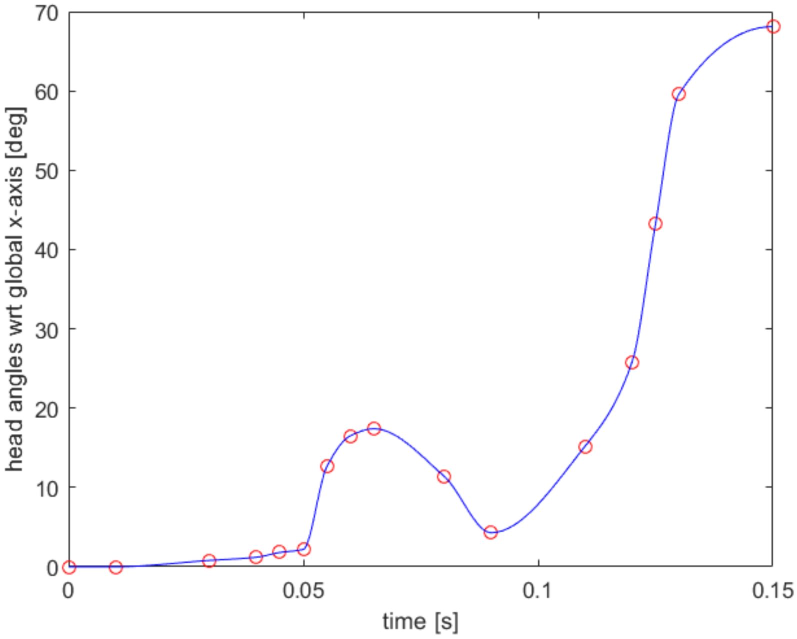

Figure 9: Head Angle with respect to Global X Axis - Time

In figure 9, by examining the head angle change, restraint system performance can be found indirectly.

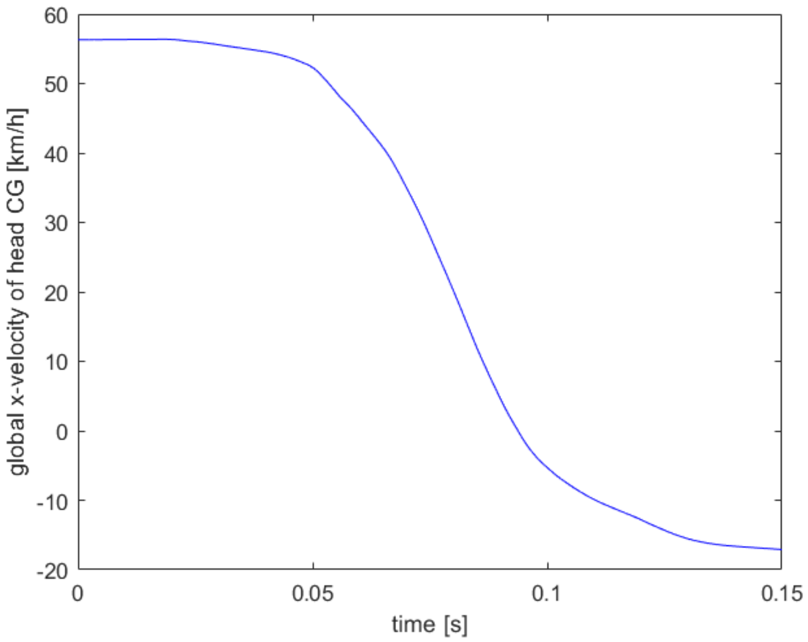

Figure 10: Global X Velocity of Head Center of Gravity - Time

In figure 10, Following the general speed of the head is important in calculating the longitudinal load. It can be observed that the head is exposed to extreme accelerations.

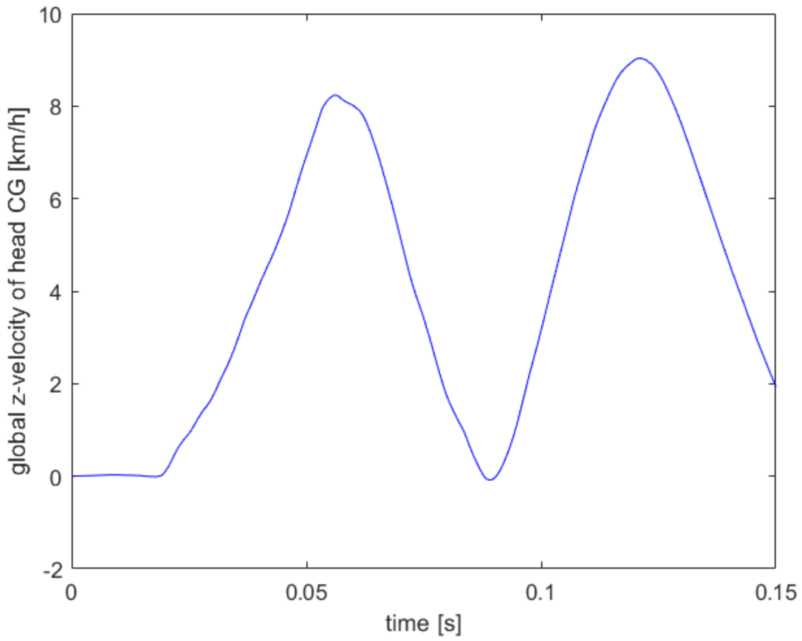

Figure 11: Global Z Velocity of Head Center of Gravity - Time

In figure 11, the applied acceleration can be calculated by observing the velocities of the head in the z-axis.

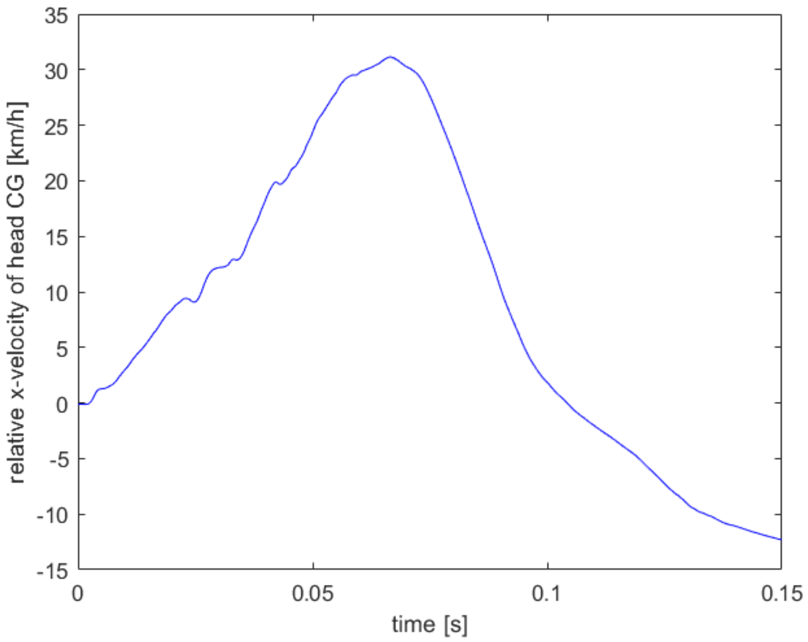

Figure 12: Relative X Velocity of Head Center of Gravity - Time

In figure 12, the applied acceleration can be calculated by observing the velocities of the head in the x-axis.

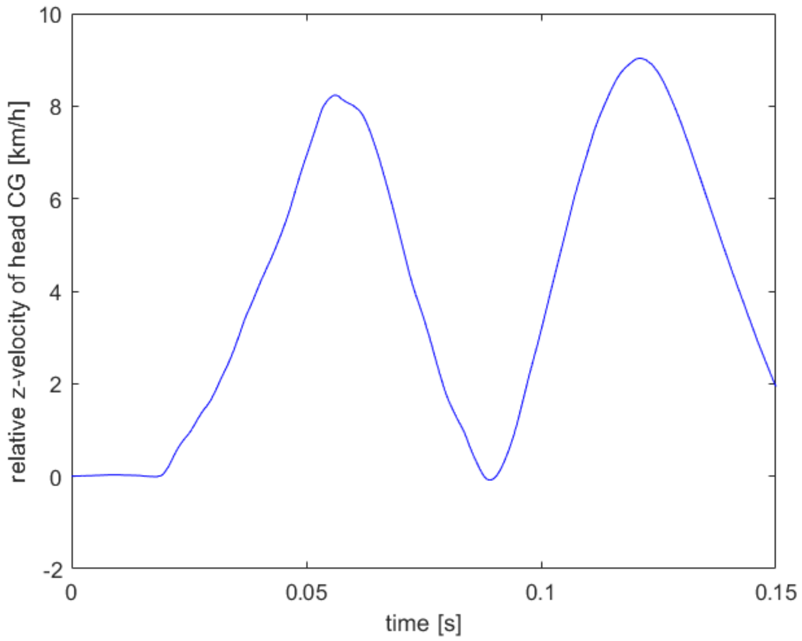

Figure 13: Relative Z Velocity of Head Center of Gravity – Time

In figure 13, the applied acceleration can be calculated with the velocities of the head in the z-axis. Since the value is taken relative, it is used to observe vehicle safety performance.

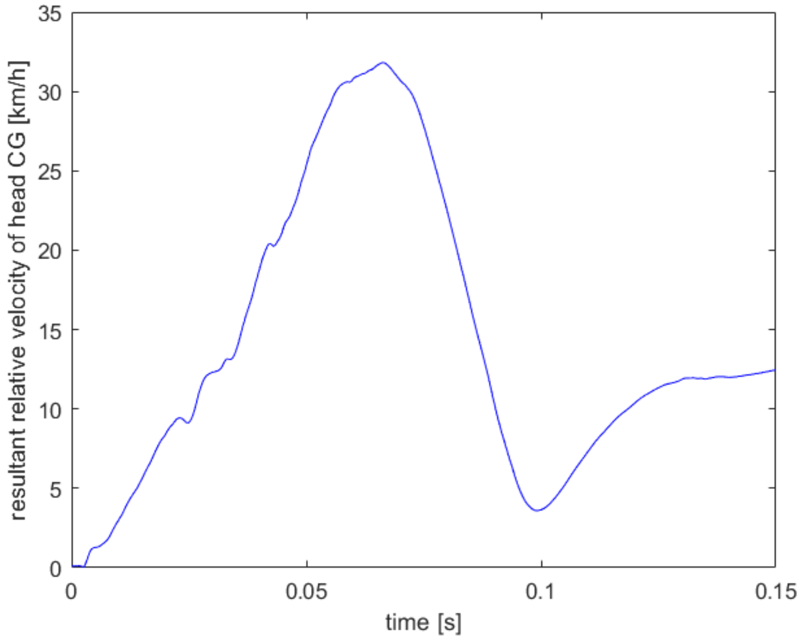

Figure 14: Resultant Relative Velocity of Head Center of Gravity - Time

Figure 14 in which the total acceleration of the head during the crash is observed thanks to the combination of the velocities of the head in the z and x directions.

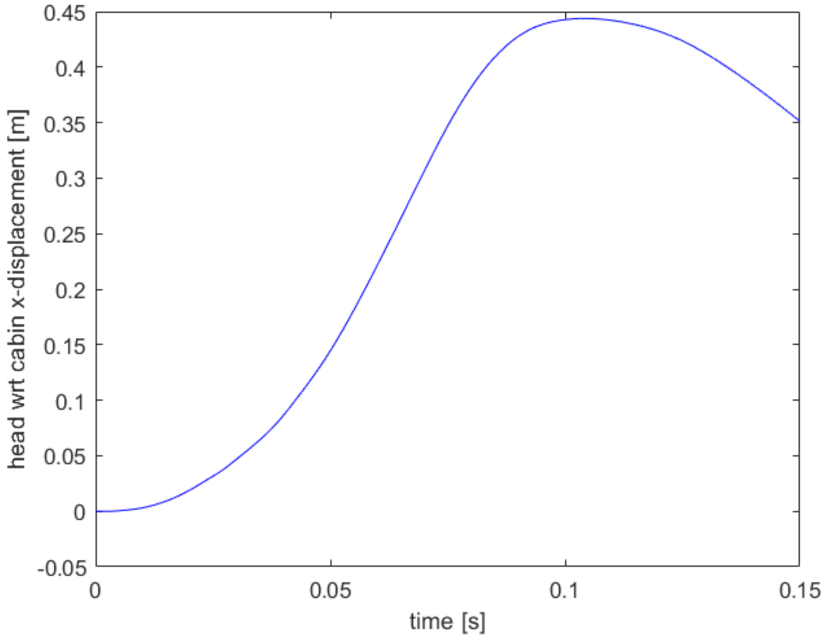

Figure 15: Head with respect to Cabin X Displacement - Time

In figure 15, the movement of the head inside the vehicle during the accident is observed. Its protection by restraint systems depends on this displacement.

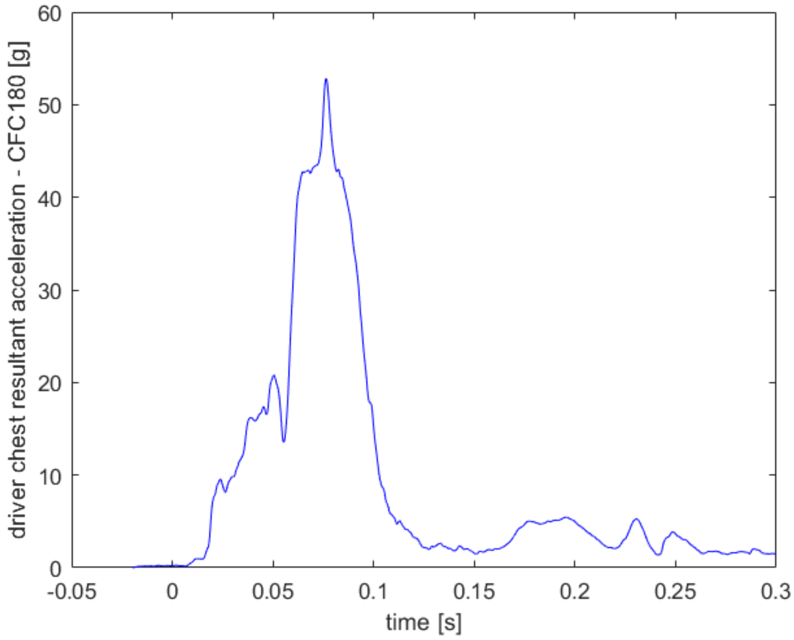

Figure 16: Driver Chest Resultant Acceleration – Time

In fügure 16, the acceleration of the chest area, which has vital organs and must be protected during a crash, has been associated with the performance of the restraint system.

4 SCORING AND RESULTS

Scoring in the study is formed as a result of processing the values received from the sensors. These sensors are on the vehicle and on the dummy. The perfect value is when no force other than gravity is applied to the vehicle or dummy. The most ideal situation is when the vehicle does not have any collisions. In terms of structural and restraint systems, getting zero points in scoring is the most ideal situation in terms of vehicle performance. In this scale, the closer the value of vehicles in crash safety performance is to zero, the more successful they are.

In the study, all criteria score for 33 vehicles were made completely. The number of stars in the NCAP star performance evaluation system of the 33 selected vehicles is either 4 or 5. It has been revealed that the vehicles rated with 4 and 5 stars have more successful and unsuccessful aspects compared to each other in structural or restraint systems.

Table 3 HIC15 Factor

Vehicle Code	HIC15 Value	HIC15 Factor	NCAP Star
A	130.2	0.186	4
B	209.0	0.299	4
C	222.5	0.318	5
D	275.2	0.393	4
E	196.4	00.281	4
F	183	0.261	4
G	217.4	0.311	4
H	152.5	0.218	5
I	152	0.217	5
J	143	0.204	5
K	335.0	0.479	4
L	144.0	0.206	5
M	125.0	0.179	5
N	146.1	0.209	4
O	230.4	0.329	4
P	144.3	0.206	4
Q	129.2	0.185	5
R	134	0.191	5
S	225.2	0.322	4
T	191.7	0.274	5
U	269.7	0.385	4
V	230.0	0.329	4
W	225.2	0.322	4
X	95.0	0.136	4
Y	251.4	0.359	5
Z	267.4	0.382	4
AA	197.0	0.281	4
AB	218.7	0.312	5
AC	454.0	0.649	4
AD	124.0	0.177	5
AE	204.0	0.291	5
AF	150.4	0.215	4
AG	260.7	0.372	4
AH	236.2	0.337	4
Maximum	454.00	0.65	
Minimum	95.00	0.14	
Avarage	208.59	0.29	
Standart Deviation	71.61	0.10	

Table 4 Left Femur Force Factor

Vehicle Code	**Left Femur Fırce**	**Left Femur Force Factor**	**NCAP Star**
A	1899.60	0.190	4
B	4324.00	0.432	4
C	254.90	0.025	5
D	2014.94	0.201	4
E	1341.48	0.134	4
F	3059.00	0.306	4
G	2592.60	0.259	4
H	598.10	0.060	5
I	1458.00	0.146	5
J	926.00	0.093	5
K	1804.60	0.180	4
L	1823.00	0.182	5
M	1344.00	0.134	5
N	709.76	0.071	4
O	2812.97	0.281	4
P	411.00	0.041	4
Q	2078.30	0.208	5
R	138.00	0.014	5
S	821.10	0.082	4
T	473.77	0.047	5
U	2359.40	0.236	4
V	3266.00	0.326	4
W	821.10	0.082	4
X	2588.00	0.259	4
Y	231.75	0.023	5
Z	1378.80	0.138	4
AA	3620.00	0.362	4
AB	1838.70	0.184	5
AC	479.00	0.048	4
AD	1227.00	0.123	5
AE	1233.00	0.123	5
AF	842.56	0.084	4
AG	1552.96	0.155	4
AH	2132.72	0.213	4
Maximum	4324.00	0.43	
Minimum	138.00	0.01	
Avarage	1601.65	0.16	
Standart Deviation	1023.40	0.10	

Table 5 Right Femur Force Factor

Vehicle Code	Right Femur Force	Right Femur Force Factor	NCAP Star
A	2420.50	0.242	4
B	2935.00	0.293	4
C	2363.40	0.236	5
D	2175.99	0.217	4
E	3929.24	0.393	4
F	3670.00	0.367	4
G	4458.70	0.446	4
H	785.90	0.079	5
I	1807.00	0.181	5
J	1462.00	0.146	5
K	2474.10	0.247	4
L	2020.00	0.202	5
M	377.00	0.038	5
N	1845.44	0.184	4
O	3170.50	0.317	4
P	2022.90	0.202	4
Q	1846.10	0.184	5
R	1741.00	0.174	5
S	1387.20	0.139	4
T	1114.69	0.111	5
U	2409.30	0.241	4
V	2843.00	0.284	4
W	1387.20	0.139	4
X	1959.00	0.196	4
Y	241.96	0.024	5
Z	2229.12	0.223	4
AA	4467.00	0.446	4
AB	1929.60	0.193	5
AC	453.00	0.045	4
AD	2078.00	0.208	5
AE	2027.00	0.203	5
AF	1366.90	0.137	4
AG	2141.78	0.214	4
AH	2425.57	0.242	4
Maximum	4467.00	0.45	
Minimum	241.96	0.02	
Avarage	2116.62	0.21	
Standart Deviation	1001.53	0.10	

Table 6 Nij Factor

Vehicle Code	Nij	Nij Factor	NCAP Star
A	0.290	0.290	4
B	0.330	0.330	4
C	0.200	0.200	5
D	0.340	0.340	4
E	0.390	0.390	4
F	0.400	0.400	4
G	0.320	0.320	4
H	0.240	0.240	5
I	0.310	0.310	5
J	0.260	0.260	5
K	0.230	0.230	4
L	0.300	0.300	5
M	1.000	1.000	5
N	0.270	0.270	4
O	0.230	0.230	4
P	0.300	0.300	4
Q	0.300	0.300	5
R	0.290	0.290	5
S	0.240	0.240	4
T	0.200	0.200	5
U	0.460	0.460	4
V	0.320	0.320	4
W	0.240	0.240	4
X	0.260	0.260	4
Y	0.278	0.278	5
Z	0.300	0.300	4
AA	0.250	0.250	4
AB	0.310	0.310	5
AC	0.330	0.330	4
AD	0.210	0.210	5
AE	0.250	0.250	5
AF	0.263	0.263	4
AG	0.305	0.305	4
AH	0.330	0.330	4
Maximum	1.00	1.00	
Minimum	0.20	0.20	
Avarage	0.31	0.31	
Standart Deviation	0.13	0.13	

Table 7 Neck Compression Force Factor

Vehicle Code	Neck Compression Force	Neck Compression Force Factor	NCAP Star
A	1040.80	0.250	4
B	959.00	0.230	4
C	841.80	0.202	5
D	1425.25	0.342	4
E	1736.43	0.416	4
F	1537	0.369	4
G	1223.80	0.293	4
H	1193	0.286	5
I	1165	0.279	5
J	904	0.217	5
K	1047.90	0.251	4
L	1121.00	0.269	5
M	2620.00	0.628	5
N	800.46	0.192	4
O	921.36	0.221	4
P	1049.70	0.252	4
Q	1099.00	0.264	5
R	1220	0.293	5
S	993.70	0.238	4
T	1031.88	0.247	5
U	1853.10	0.444	4
V	1522	0.365	4
W	993.70	0.238	4
X	1022.00	0.245	4
Y	184.00	0.044	5
Z	1474.87	0.354	4
AA	1169.00	0.280	4
AB	1515.70	0.363	5
AC	1566.00	0.376	4
AD	744	0.178	5
AE	773	0.185	5
AF	1022.04	0.245	4
AG	383.60	0.092	4
AH	2.056.36	0.493	4
Maximum	2620.00	0.63	
Minimum	184.00	0.04	
Avarage	1198.17	0.28	
Standart Deviation	488.80	0.11	

Table 8 Neck Tension Force Factor

Vehicle Code	Neck Compression Force	Neck Compression Force Factor	NCAP Star
A	1040.80	0.250	4
B	959.00	0.230	4
C	841.80	0.202	5
D	1425.25	0.342	4
E	1736.43	0.416	4
F	1537	0.369	4
G	1223.80	0.293	4
H	1193	0.286	5
I	1165	0.279	5
J	904	0.217	5
K	1047.90	0.251	4
L	1121.00	0.269	5
M	2620.00	0.628	5
N	800.46	0.192	4
O	921.36	0.221	4
P	1049.70	0.252	4
Q	1099.00	0.264	5
R	1220	0.293	5
S	993.70	0.238	4
T	1031.88	0.247	5
U	1853.10	0.444	4
V	1522	0.365	4
W	993.70	0.238	4
X	1022.00	0.245	4
Y	184.00	0.044	5
Z	1474.87	0.354	4
AA	1169.00	0.280	4
AB	1515.70	0.363	5
AC	1566.00	0.376	4
AD	744	0.178	5
AE	773	0.185	5
AF	1022.04	0.245	4
AG	383.60	0.092	4
AH	2056.36	0.493	4
Maximum	2620.00	0.63	
Minimum	184.00	0.04	
Avarage	1198.17	0.28	
Standart Deviation	488.80	0.11	

Table 9 The Mean Acceleration of The Occupant Compartment Factor

Vehicle Code	The Mean Acceleration of The Occupant Compartment	The Mean Acceleration of The Occupant Compartment Factor	NCAP Star
A	17.40	1.126	4
B	14.76	0.955	4
C	16.53	1.070	5
D	15.00	0.971	4
E	12.31	0.797	4
F	17.35	1.123	4
G	15.07	0.975	4
H	14.84	0.960	5
I	19.47	1.260	5
J	14.73	0.953	5
K	14.96	0.968	4
L	12.99	0.841	5
M	15.15	0.981	5
N	15.31	0.991	4
O	15.77	1.021	4
P	16.85	1.091	4
Q	16.85	1.091	5
R	16.41	1.062	5
S	14.46	0.936	4
T	13.27	0.859	5
U	18.09	1.171	4
V	14.33	0.927	4
W	14.41	0.933	4
X	13.74	0.889	4
Y	15.29	0.990	5
Z	13.55	0.877	4
AA	17.18	1.112	4
AB	17.86	1.156	5
AC	17.43	1.128	4
AD	14.02	0.907	5
AE	13.96	0.904	5
AF	18.06	1.169	4
AG	16.99	1.100	4
AH	13.91	0.900	4
Maximum	19.47	1.26	
Minimum	12.31	0.80	
Avarage	15.54	1.01	
Standart Deviation	1.69	0.11	

Table 10 The Maximum Moving Average (50ms) Acc. of The Occ. Compartment Factor

Vehicle Code	**The Maximum Moving Average (50ms) Acc. of The Oc.Compartment**	**The Maximum Moving Average (50ms) Acc. of The Oc. Compartment Factor**	**NCAP Star**
A	29.25	1.116	4
B	26.16	0.998	4
C	29.08	1.110	5
D	28.81	1.100	4
E	27.82	1.062	4
F	31.01	1.184	4
G	30.22	1.153	4
H	28.18	1.076	5
I	30.02	1.146	5
J	25.29	0.965	5
K	24.27	0.926	4
L	26.03	0.994	5
M	25.90	0.989	5
N	28.62	1.092	4
O	27.33	1.043	4
P	28.74	1.097	4
Q	28.01	1.069	5
R	26.19	1.000	5
S	29.38	1.121	4
T	26.41	1.008	5
U	29.67	1.132	4
V	27.27	1.041	4
W	29.38	1.121	4
X	29.25	1.116	4
Y	28.16	1.075	5
Z	29.20	1.115	4
AA	28.62	1.092	4
AB	32.69	1.248	5
AC	31.28	1.194	4
AD	26.82	1.024	5
AE	27.14	1.036	5
AF	29.94	1.143	4
AG	28.81	1.100	4
AH	28.34	1.082	4
Maximum	32.69	1.25	
Minimum	24.27	0.93	
Avarage	28.33	1.08	
Standart Deviation	1.78	0.07	

Table 11 The Adjusted Crash Severity (50ms) Factor

Vehicle Code	The Adjusted Crash Severity (50ms)	The Adjusted Crash Severity (50ms) Factor	NCAP Star
A	33.28	1.033	4
B	29.60	0.919	4
C	33.39	1.036	5
D	32.96	1.023	4
E	31.53	0.978	4
F	35.06	1.088	4
G	34.08	1.058	4
H	32.00	0.993	5
I	35.88	1.113	5
J	28.53	0.885	5
K	27.86	0.865	4
L	29.24	0.907	5
M	29.46	0.914	5
N	31.53	0.978	4
O	32.19	0.999	4
P	35.42	1.099	4
Q	31.54	0.979	5
R	28.12	0.873	5
S	33.45	1.038	4
T	30.32	0.941	5
U	33.03	1.025	4
V	29.91	0.928	4
W	33.46	1.038	4
X	34.75	1.078	4
Y	32.73	1.016	5
Z	32.37	1.004	4
AA	32.73	1.016	4
AB	37.69	1.170	5
AC	31.28	0.971	4
AD	31.47	0.977	5
AE	29.85	0.926	5
AF	34.57	1.073	4
AG	32.76	1.017	4
AH	31.22	0.969	4
Maximum	37.69	1.17	
Minimum	27.86	0.86	
Avarage	32.15	1.00	
Standart Deviation	2.27	0.07	

Table 12 Largest Neck Shear Force Factor

Vehicle Code	Largest Neck Shear Force	Largest Neck Shear Force Factor	NCAP Star
A	851.56	0.852	4
B	825.72	0.826	4
C	588.59	0.589	5
D	918.26	0.918	4
E	1085.05	1.085	4
F	437.96	0.438	4
G	513.35	0.513	4
H	829.69	0.830	5
I	1075.33	1.075	5
J	912.10	0.912	5
K	501.99	0.502	4
L	878.95	0.879	5
M	1212.67	1.213	5
N	1039.90	1.040	4
O	897.20	0.897	4
P	487.64	0.488	4
Q	1060.66	1.061	5
R	981.46	0.981	5
S	819.91	0.820	4
T	464.71	0.465	5
U	721.01	0.721	4
V	475.14	0.475	4
W	819.91	0.820	4
X	899.68	0.900	4
Y	628.71	0.629	5
Z	849.82	0.850	4
AA	564.68	0.565	4
AB	552.67	0.553	5
AC	962.86	0.963	4
AD	864.00	0.864	5
AE	722.53	0.723	5
AF	1079.80	1.080	4
AG	585.01	0.585	4
AH	628.62	0.629	4
Maximum	1212.67	1.21	
Minimum	437.96	0.44	
Avarage	786.39	0.79	
Standart Deviation	213.10	0.21	

Table 13 Head Resultant Acceleration Factor (3 ms)

Vehicle Code	**Head Resultant Acceleration (3 ms)**	**Head Resultant Acceleration Factor (3 ms)**	**NCAP Star**
A	41.72	0.855	4
B	49.08	1.006	4
C	51.28	1.051	5
D	54.66	1.120	4
E	51.42	1.054	4
F	45.95	0.942	4
G	51.52	1.056	4
H	43.29	0.887	5
I	41.80	0.857	5
J	43.09	0.883	5
K	61.81	1.267	4
L	44.34	0.909	5
M	40.01	0.820	5
N	42.83	0.878	4
O	54.58	1.119	4
P	42.58	0.873	4
Q	41.73	0.855	5
R	47.94	0.983	5
S	50.84	1.042	4
T	46.14	0.946	5
U	56.96	1.168	4
V	50.52	1.036	4
W	49.98	1.024	4
X	36.56	0.749	4
Y	52.81	1.082	5
Z	55.33	1.134	4
AA	47.87	0.981	4
AB	50.42	1.033	5
AC	67.23	1.378	4
AD	38.34	0.786	5
AE	48.59	0.996	5
AF	46.16	0.946	4
AG	53.94	1.106	4
AH	50.81	1.041	4
Maximum	67.23	1.38	
Minimum	36.56	0.75	
Avarage	48.59	1.00	
Standart Deviation	6.48	0.13	

Table 14 Head Acceleration Factor

Vehicle Code	Head Acceleration	Head Acceleration Factor	NCAP Star
A	2.448	0.757	4
B	3.326	1.028	4
C	4.101	1.268	5
D	3.644	1.127	4
E	4.177	1.292	4
F	2.645	0.818	4
G	3.417	1.057	4
H	2.918	0.902	5
I	2.147	0.664	5
J	2.926	0.905	5
K	4.130	1.277	4
L	3.411	1.055	5
M	2.660	0.823	5
N	2.792	0.863	4
O	3.461	1.070	4
P	2.541	0.786	4
Q	2.469	0.763	5
R	2.918	0.902	5
S	3.458	1.069	4
T	3.471	1.073	5
U	3.146	0.973	4
V	3.538	1.094	4
W	3.469	1.073	4
X	2.801	0.866	4
Y	3.270	1.011	5
Z	3.784	1.170	4
AA	2.787	0.862	4
AB	2.822	0.873	5
AC	3.868	1.196	4
AD	2.753	0.851	5
AE	3.517	1.088	5
AF	2.510	0.776	4
AG	3.172	0.981	4
AH	3.720	1.150	4
Maximum	4.18	1.29	
Minimum	2.15	0.66	
Avarage	3.18	0.98	
Standart Deviation	0.52	0.16	

Table 15 Relative Velocity Coefficient Factor

Vehicle Code	Relative Velocity Coefficient	Relative Velocity Coefficient Factor	NCAP Star
A	0.530	0.879	4
B	0.553	0.917	4
C	0.674	1.118	5
D	0.594	0.985	4
E	0.478	0.793	4
F	0.698	1.158	4
G	0.744	1.234	4
H	0.519	0.861	5
I	0.739	1.226	5
J	0.424	0.703	5
K	0.331	0.549	4
L	0.436	0.723	5
M	0.610	1.012	5
N	0.629	1.043	4
O	0.519	0.861	4
P	0.488	0.809	4
Q	0.498	0.826	5
R	0.603	1.000	5
S	0.627	1.040	4
T	0.596	0.988	5
U	0.724	1.201	4
V	0.628	1.041	4
W	0.626	1.038	4
X	0.574	0.952	4
Y	0.474	0.786	5
Z	0.697	1.156	4
AA	0.536	0.889	4
AB	0.804	1.333	5
AC	0.783	1.299	4
AD	0.547	0.907	5
AE	0.599	0.993	5
AF	0.695	1.153	4
AG	0.665	1.103	4
AH	0.637	1.056	4
Maximum	0.80	1.33	
Minimum	0.33	0.55	
Avarage	0.60	0.99	
Standart Deviation	0.11	0.18	

Table 16 Relative Displacement Coefficient Factor

Vehicle Code	Relative Displacement Coefficient	Relative Displacement Coefficient Factor	NCAP Star
A	0.852	0.968	4
B	0.817	0.928	4
C	0.984	1.118	5
D	0.795	0.903	4
E	0.719	0.817	4
F	1.036	1.177	4
G	1.058	1.202	4
H	0.749	0.851	5
I	1.214	1.380	5
J	0.678	0.770	5
K	0.421	0.478	4
L	0.824	0.936	5
M	0.938	1.066	5
N	1.043	1.185	4
O	0.729	0.828	4
P	0.804	0.914	4
Q	0.866	0.984	5
R	0.851	0.967	5
S	0.798	0.907	4
T	0.986	1.120	5
U	0.595	0.676	4
V	0.981	1.115	4
W	0.804	0.914	4
X	0.990	1.125	4
Y	0.713	0.810	5
Z	0.915	1.040	4
AA	0.850	0.966	4
AB	1.113	1.265	5
AC	0.876	0.995	4
AD	0.899	1.022	5
AE	0.954	1.084	5
AF	1.031	1.172	4
AG	0.923	1.049	4
AH	0.918	1.043	4
Maximum	1.21	1.38	
Minimum	0.42	0.48	
Avarage	0.87	0.99	
Standart Deviation	0.15	0.17	

Table 17 Maximum Chest Compression Factor

Vehicle Code	Maximum Chest Compression	Maximum Chest Compression Factor	NCAP Star
A	32.000	0.508	4
B	22.000	0.349	4
C	23.000	0.365	5
D	28.520	0.453	4
E	28.980	0.460	4
F	24.000	0.381	4
G	25.000	0.397	4
H	23.000	0.365	5
I	18.000	0.286	5
J	13.000	0.206	5
K	30.000	0.476	4
L	23.000	0.365	5
M	16.000	0.254	5
N	33.857	0.537	4
O	26.320	0.418	4
P	28.000	0.444	4
Q	23.000	0.365	5
R	19.000	0.302	5
S	29.000	0.460	4
T	24.660	0.391	5
U	19.000	0.302	4
V	21.000	0.333	4
W	29.000	0.460	4
X	35.000	0.556	4
Y	23.771	0.377	5
Z	29.930	0.475	4
AA	19	0.302	4
AB	24.000	0.381	5
AC	22	0.349	4
AD	17	0.270	5
AE	19	0.302	5
AF	31.665	0.503	4
AG	23.041	0.366	4
AH	26.320	0.418	4
Maximum	35.00	0.56	
Minimum	13.00	0.21	
Avarage	25.10	0.39	
Standart Deviation	5.13	0.08	

Table 18 Chest Acceleration Factor

Vehicle Code	Chest Acceleration	Chest Acceleration Factor	NCAP Star
A	2.559	0.848	4
B	3.590	1.189	4
C	2.695	0.893	5
D	2.945	0.975	4
E	3.444	1.141	4
F	2.536	0.840	4
G	3.742	1.239	4
H	2.837	0.940	5
I	2.229	0.738	5
J	2.729	0.904	5
K	2.834	0.939	4
L	2.795	0.926	5
M	2.918	0.967	5
N	2.924	0.969	4
O	2.500	0.828	4
P	2.772	0.918	4
Q	2.890	0.957	5
R	2.486	0.823	5
S	3.417	1.132	4
T	2.993	0.991	5
U	2.908	0.963	4
V	3.280	1.086	4
W	3.428	1.135	4
X	2.707	0.897	4
Y	3.231	1.070	5
Z	3.923	1.299	4
AA	3.224	1.068	4
AB	2.430	0.805	5
AC	3.208	1.063	4
AD	2.895	0.959	5
AE	3.001	0.994	5
AF	3.137	1.039	4
AG	2.773	0.919	4
AH	3.109	1.030	4
Maximum	3.92	1.30	
Minimum	2.23	0.74	
Avarage	2.97	0.98	
Standart Deviation	0.38	0.13	

Table 19 Maximum V.C (Viscous Injury Response) Factor

Vehicle Code	Maximum V.C.	Maximum V.C. Factor	NCAP Star
A	0.28	0.28	4
B	0.12	0.12	4
C	0.09	0.09	5
D	0.16	0.16	4
E	0.18	0.18	4
F	0.16	0.16	4
G	0.17	0.17	4
H	0.14	0.14	5
I	0.11	0.11	5
J	0.07	0.07	5
K	0.19	0.19	4
L	0.15	0.15	5
M	0.15	0.15	5
N	0.25	0.25	4
O	0.17	0.17	4
P	0.13	0.13	4
Q	0.11	0.11	5
R	0.08	0.08	5
S	0.12	0.12	4
T	0.12	0.12	5
U	0.06	0.06	4
V	0.10	0.10	4
W	0.12	0.12	4
X	0.19	0.19	4
Y	0.15	0.15	5
Z	0.48	0.48	4
AA	0.10	0.10	4
AB	0.10	0.10	5
AC	0.11	0.11	4
AD	0.08	0.08	5
AE	0.09	0.09	5
AF	0.22	0.22	4
AG	0.12	0.12	4
AH	0.12	0.12	4
Maximum	0.48	0.48	
Minimum	0.06	0.06	
Avarage	0.15	0.15	
Standart Deviation	0.08	0.08	

Table 20 CTI (Combined Thoracic Index) Factor

Vehicle Code	**C.T.I.**	**C.T.I. Factor**	**NCAP Star**
A	0.82	0.82	4
B	0.83	0.83	4
C	0.72	0.72	5
D	0.80	0.80	4
E	0.78	0.78	4
F	0.70	0.70	4
G	0.83	0.83	4
H	0.71	0.71	5
I	0.69	0.69	5
J	0.58	0.58	5
K	0.79	0.79	4
L	0.63	0.63	5
M	0.68	0.68	5
N	0.86	0.86	4
O	0.71	0.71	4
P	0.83	0.83	4
Q	0.80	0.80	5
R	0.66	0.66	5
S	0.89	0.89	4
T	0.70	0.70	5
U	0.77	0.77	4
V	0.71	0.71	4
W	0.86	0.86	4
X	0.78	0.78	4
Y	0.74	0.74	5
Z	0.79	0.79	4
AA	0.81	0.81	4
AB	0.72	0.72	5
AC	0.88	0.88	4
AD	0.66	0.66	5
AE	0.67	0.67	5
AF	0.89	0.89	4
AG	0.76	0.76	4
AH	0.76	0.76	4
Maximum	0.89	0.89	
Minimum	0.58	0.58	
Avarage	0.76	0.76	
Standart Deviation	0.08	0.08	

The scores they got from these factors and the scores of the 5-Star system they got from the tests conducted by NHTSA can be observed in the tables. In addition to these tables, three tables were created. These tables were created by using more than one factor. General Structural Factor, General Restraint Factor and Total System Factor, which show structural performance, are named.

General Structural Factor is a score obtained by multiplying the arithmetic mean of the values showing only structural performance by 100. If this score is closer to zero, it also means that the vehicle crash safety performance is high.

Similarly, General Restraint Factor is a score obtained by multiplying the arithmetic average of the values showing only restraint system performance by 100. If this score is closer to zero, it also means that the vehicle crash safety performance is high.

Total System Factor is a score created by taking into account all the metrics used in this study. It thoroughly examines the performance of the vehicle in the crash test, as in the 5-Star system. Unlike the 5-Star system, it has more detailed scoring. In this scoring system, the driver in the vehicle with the lowest score experienced a safer crash.

Table 21 General Structural System Factor

Vehicle Code	General Structural Factor	NCAP Star
A	109.18	4
B	95.74	4
C	107.20	5
D	103.11	4
E	94.56	4
F	113.15	4
G	106.21	4
H	100.97	5
I	117.31	5
J	93.46	5
K	91.97	4
L	91.39	5
M	96.11	5
N	102.05	4
O	102.09	4
P	109.55	4
Q	104.61	5
R	97.81	5
S	103.17	4
T	93.59	5
U	110.94	4
V	96.55	4
W	103.08	4
X	102.80	4
Y	102.67	5
Z	99.86	4
AA	107.33	4
AB	119.11	5
AC	109.75	4
AD	96.92	5
AE	95.52	5
AF	112.81	4
AG	107.19	4
AH	98.36	4
Maximum	119.11	
Minimum	91.39	
Avarage	102.83	
Standart Deviation	7.12	

Table 22 General Restraint System Factor

Vehicle Code	General Restraint Factor	NCAP Star
A	80.23	4
B	110.88	4
C	108.04	5
D	105.11	4
E	121.62	4
F	82.89	4
G	114.80	4
H	92.10	5
I	70.11	5
J	90.44	5
K	110.79	4
L	99.03	5
M	89.45	5
N	91.59	4
O	94.91	4
P	85.19	4
Q	86.04	5
R	86.29	5
S	110.05	4
T	103.23	5
U	96.80	4
V	109.02	4
W	110.41	4
X	88.14	4
Y	104.07	5
Z	123.48	4
AA	96.48	4
AB	83.88	5
AC	112.93	4
AD	90.51	5
AE	104.08	5
AF	90.76	4
AG	94.97	4
AH	109.00	4
Maximum	123.48	
Minimum	70.11	
Avarage	98.45	
Standart Deviation	12.40	

Table 23 Total System Factor

Vehicle Code	Total System Factor	NCAP Star
A	72.72	4
B	70.10	4
C	68.04	5
D	73.47	4
E	74.45	4
F	71.60	4
G	76.73	4
H	63.83	5
I	69.92	5
J	57.08	5
K	66.95	4
L	64.19	5
M	71.85	5
N	74.12	4
O	69.86	4
P	64.32	4
Q	66.13	5
R	62.56	5
S	70.02	4
T	63.70	5
U	69.72	4
V	68.87	4
W	69.76	4
X	69.88	4
Y	64.32	5
Z	89.58	4
AA	67.94	4
AB	71.38	5
AC	77.37	4
AD	60.45	5
AE	64.35	5
AF	76.26	4
AG	68.66	4
AH	71.33	4
Maximum	89.58	
Minimum	57.08	
Avarage	69.46	
Standart Deviation	5.78	

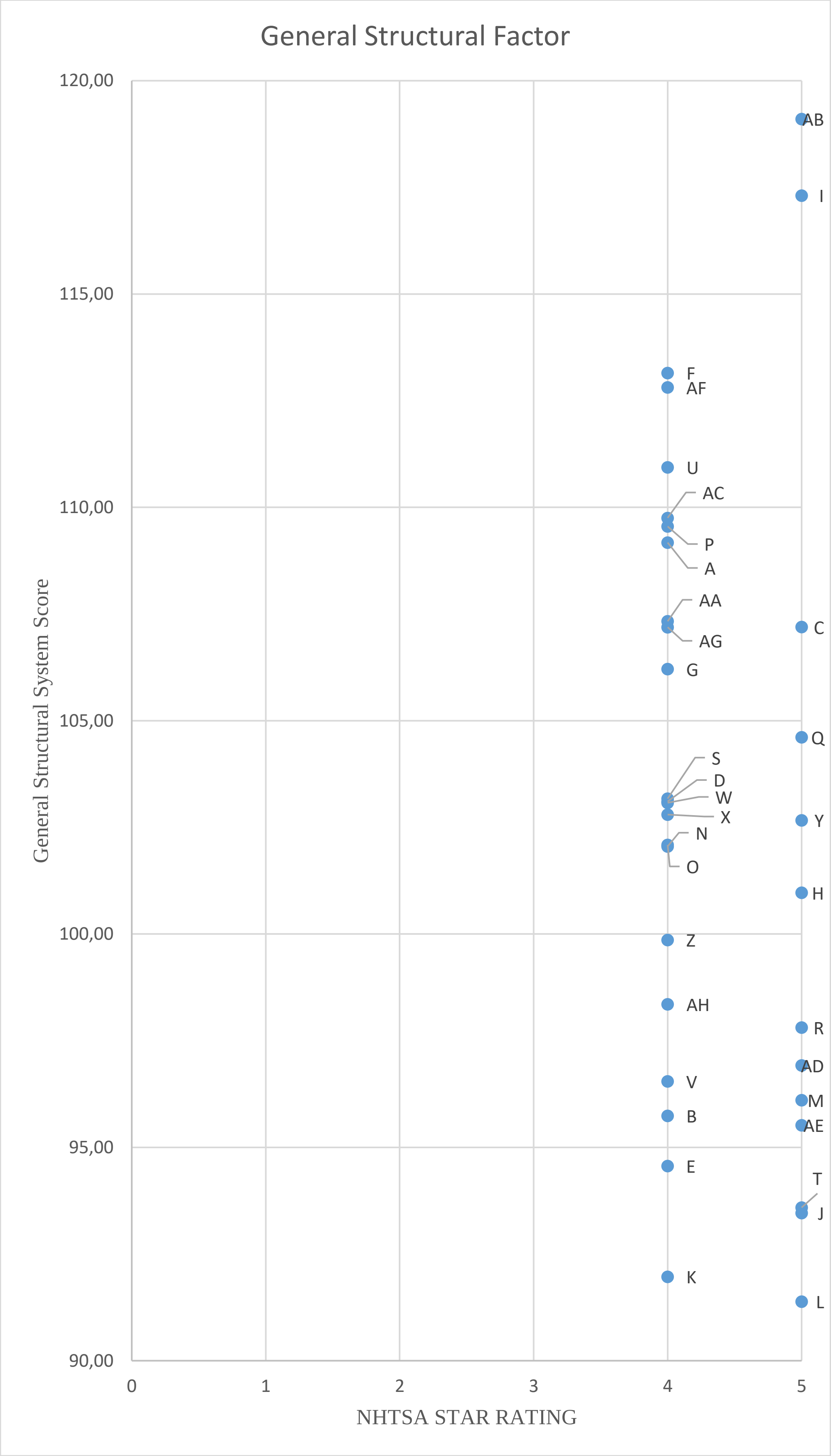

Figure 17: General Structure Factor – NHTSA Star Rates

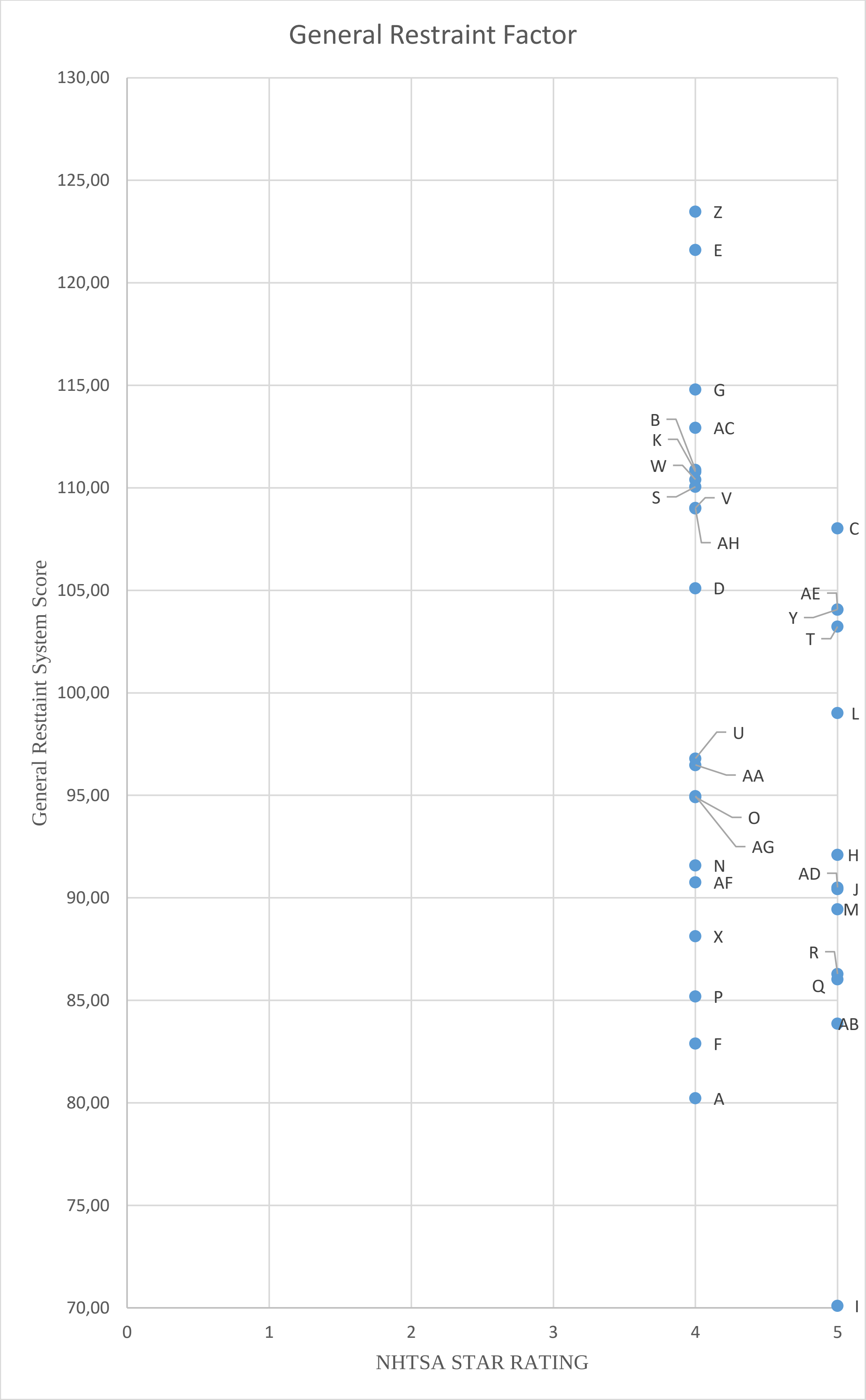

Figure 18: General Restraint Factor – NHTSA Star Rates

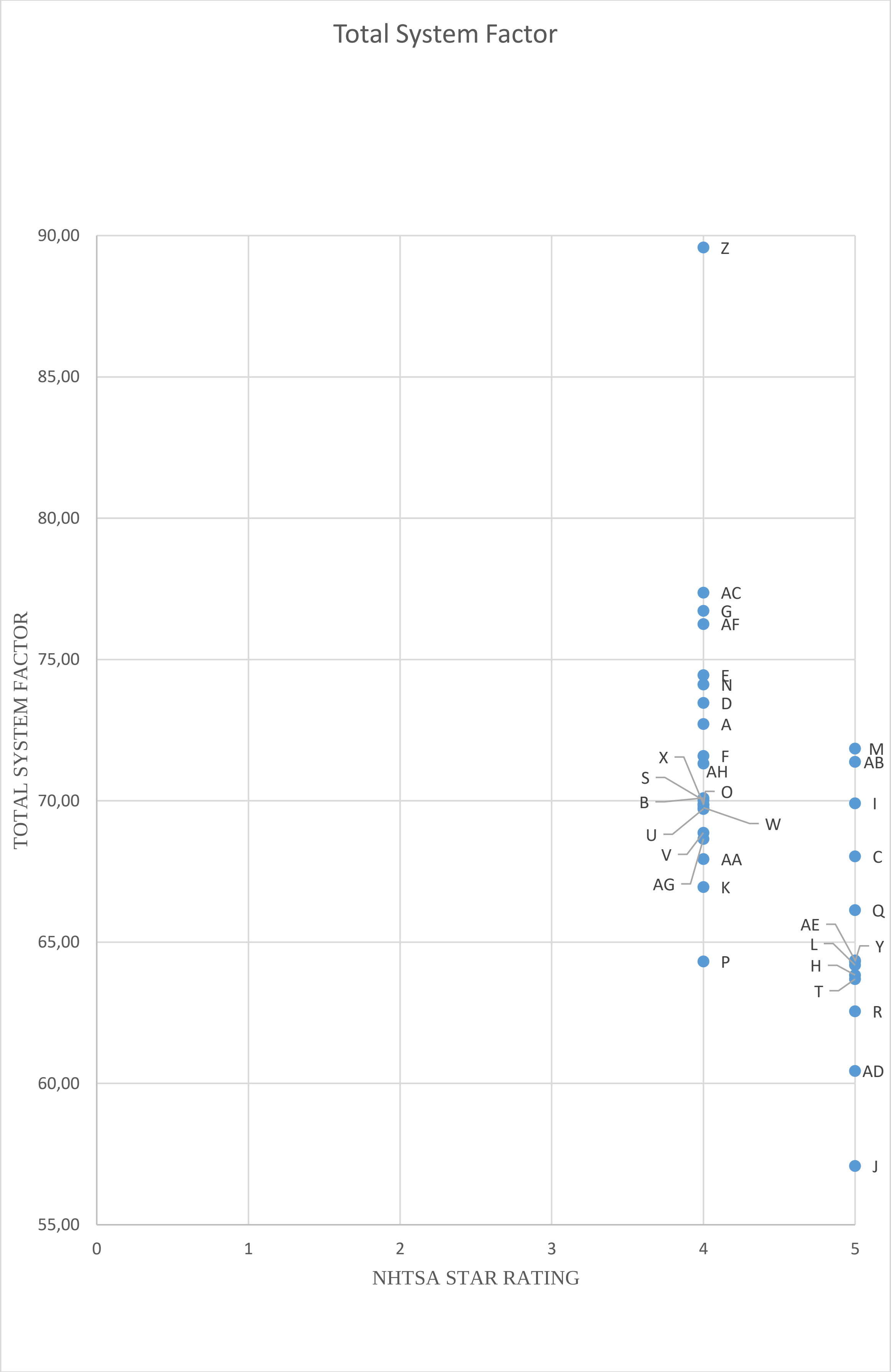

Figure 19: Total System Factor – NHTSA Star Rates

The graphics seen in Figures 16-18 are the proofs of the studies in the thesis. Structural System Factor, Restraint System Factor and General System Factor were created by using all the relevant criteria that were examined separately.

As seen in Figure 16; The location with the highest number of 4-star vehicles is 100-115. General Structure Factor values of vehicles with 5 stars are in the range of 94 - 107.

As seen in Figure 17; The location with the highest number of 4-star vehicles is 90 - 115. Vehicles with 5 stars are in the range of General Restraint Factor 85 - 105.

As seen in Figure 18; The location with the highest number of 4-star vehicles is 67 - 75. Vehicles with 5 stars are in the range of Total System Factor 60 - 67.

5 CONCLUSION

The results obtained as a result of all studies are listed below:

In the light of the data obtained by examining the FWRB crash test results, the scoring system applied by NCAP was developed. When the vehicles with the same star score are compared, it has been proven that there are vehicles that exert less force on the driver in the event of an accident. The 5-star scoring system has been detailed. In this way, a more detailed analysis of crash safety has been made for vehicle manufacturers and customers who will buy cars. As a result of the crash tests, it was revealed that the vehicles with a performance rating between 4 and 5 stars, when evaluated with the performance system in the thesis, although they had the same score, they could not get the same score.

A model has been created that can be used for the necessary studies to increase the crash safety performance of the cars. Thanks to this model, a system has been developed that can be used to increase the performance of vehicles with lower crash safety performance.

The data obtained after the studies carried out in the thesis examines vehicle performances in more detail compared to the current scoring system. With this detailed examination, the components that successfully fulfill their duties for the crash safety of the vehicles and those that do not can be determined easily. The data obtained after the studies carried out in the thesis examines vehicle performances in more detail compared to the current scoring system. With this detailed examination, the components that successfully fulfill their duties for the crash safety of the vehicles and those that do not can be determined easily. Safety is an important criterion for customers purchasing vehicles. Crash safety will be able to examine its performance in more detail with this study. It will allow him to observe the differences between vehicles with similar star ratings. It can easily be seen how the design and restraint system SAE elements, which manufacturers and automobile designers take as an example, provide the expected performance. Manufacturers considering using similar external geometric elements or materials in their vehicle designs will be able to observe the crash safety performance of the existing tested elements.

In addition to these, there are cases where the study has some disadvantages compared to the NCAP star system. For example, the NCAP Star Rating System is simple and simple for customers to understand. The system in the study in the thesis contains complex data for the end user. Due to this complex structure, it may not be possible for the system in the thesis to become widespread. In addition, the criteria used have not been compared with actual tests. The accuracy of the measurements in the tests was accepted and the study was completed. These measurements, which are the subject of the thesis, may need to be verified by tests.

It can be clearly seen that, based on this study, each car exerts different forces on the driver during the crash. Injury levels of these forces were used as performance criteria (metrics) in the thesis. While creating the performance criteria, it was focused on three different forms as structural, restraint and total performance. As a result of the study using 33 vehicle data, the structural and restraint system performances of the vehicles were examined separately. While the prominent feature of some cars for crash safety is their structural systems, it has been concluded that some cars can get high scores thanks to their restraint systems.

For example, when we examine the B coded vehicle, it can be observed that the structural safety performance score is close to the vehicles with 5 stars, while the restraint system total score has a worse score. For this vehicle, it is understood that with the development of the restraint crash safety systems in the vehicle, this vehicle can easily reach the status of 5 stars.

In order to use the systems in existing vehicles directly in new vehicle designs, it is provided to obtain information about the restraint and structural systems in the vehicle separately. Through this study, it can be understood which features of a vehicle with high crash safety are stronger.

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