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GRNN and MFFNN Models for Energy Equivalent Speed Prediction and Fault Rate Determination of Involvements in Traffic Accidents: A case study in Turkey

by

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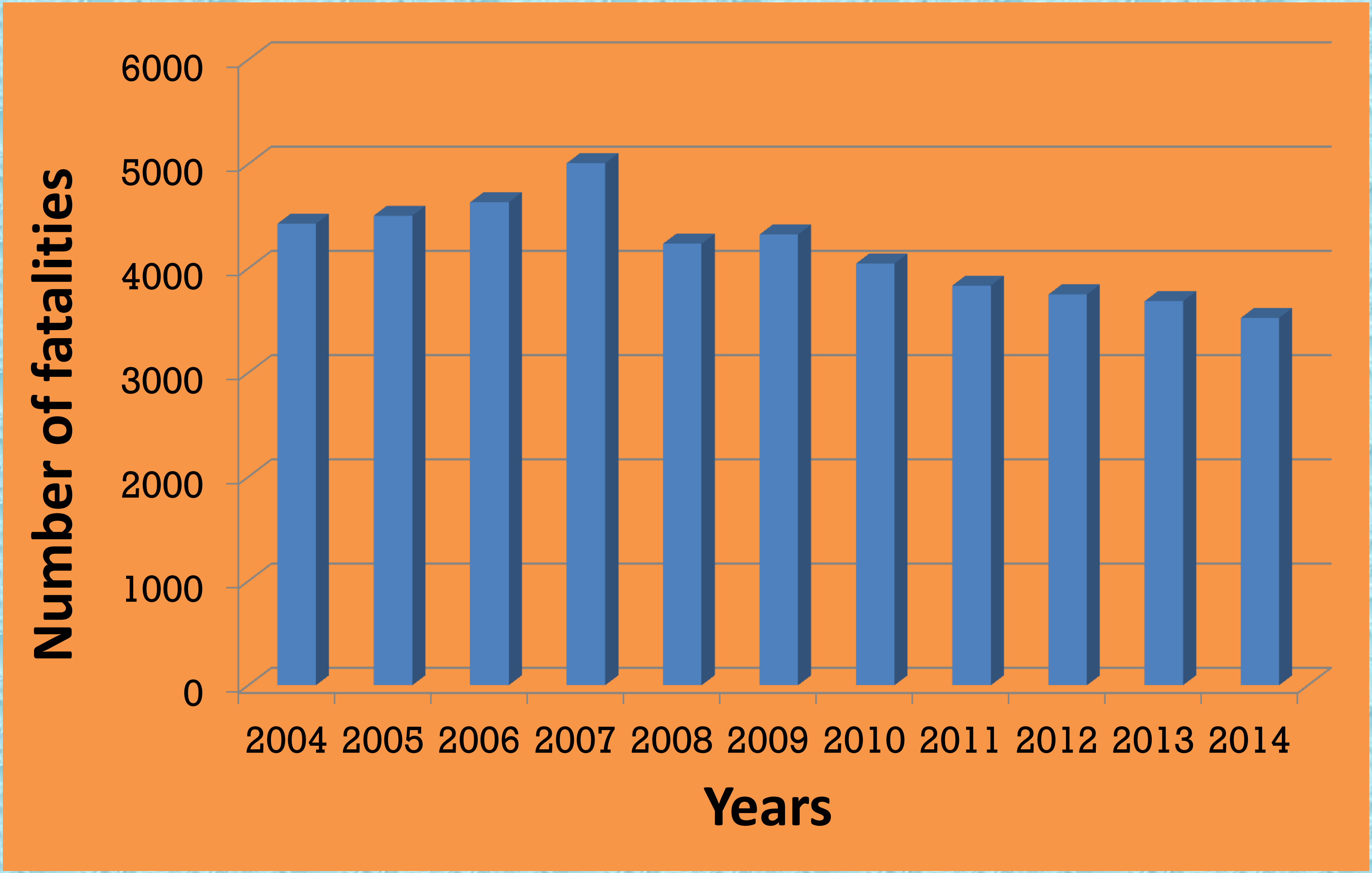
*Highway Fatality Trend in Turkey



*Turkish Statistical Institute, 2015

Vehicular Accident Reconstruction

❖The scientific process of investigating, analyzing and drawing conclusions about the causes and events during a vehicle collision.

Importance and Benefits of Accident Reconstruction

- ✓Identifying the collision causation and contributing factors in different types of collisions including the role of the driver(s), vehicle(s), roadway and the environment and determining precautions to minimize accidents,
- ✓Calculating useful quantities by using softwares based on the laws of physics and engineering principles such as the conservation of linear momentum, work-energy methods, and kinematics,
- ✓Providing analysis of fault rates of involvements in a systematic way in terms of **neutral decisions** especially on events like matter for the courts or forensic investigations.

Energy Equivalent Speed (EES)

❖The equivalent speed at which a particular vehicle would need to contact any fixed rigid object in order to dissipate the deformation energy corresponding to the observed vehicle residual crush.

Energy Equivalent Speed (EES)

The plastic deformation energy of the damaged car is expressed as a kinetic energy of the car with the virtual velocity value EES.

$$\frac{EES_1}{EES_2} = \sqrt{\frac{m_2}{m_1}\frac{s_{Def\,1}}{s_{Def\,2}}} \text{ and } EES_2 = \sqrt{\frac{2.E_D}{m_2\left(\frac{s_{Def\,1}}{s_{Def\,2}}+1\right)}} \text{ (km/h)}$$

where;

m_1, m_2: mass of each vehicle , kg

s_{Def1}, s_{Def2}: crush depth of each vehicle, outer surface to impact point in line with impact force, m

E_D: energy lost by both vehicles in the collision due to damage, J.

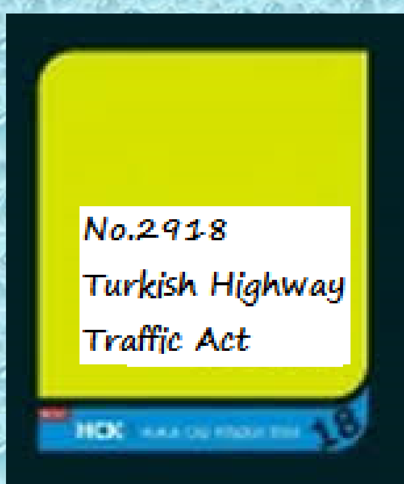
Reconstruction & Analysis of a Sample Traffic Accident

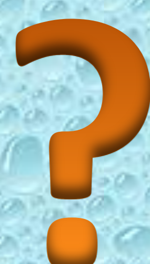
Parameters related to EES calculation are:

- ❖Pre-impact (v_1) & post impact (v_2) velocity, *km/h*
- ❖Deformation (ε), *m*
- ❖Pre-omega (ω_1) & post omega (ω_2), *rad/s*
- ❖Impulse (Imp), *N.s*
- ❖Time (t), *seconds*
- ❖X, y, z coordinates, *m*
- ❖Change in velocity (Δv), *km/h*
- ❖Deformation energy (E), *J*

Current Status in Turkey

❖There are some deficiencies in defining fault rates (FR) in "No.2918 Turkish Highway Traffic Act (THTA)". Currently, in Turkey, fault rates are determined according to initiative of accident experts (sometimes no speed analyses of vehicles, just procession of accident) and there are no specific quantitative instructions on fault rates related to procession of accident in act. Mostly, only consistence situation of accident does not yield adequate data in determining fault rate.





Fault Rate

Current Status in Turkey

❖**Controversial Cases:** The most challenging issue in analyzing an accident and determining fault rates rises in debated situations which are defined as neither at-fault nor not at-faults according to the THTA.

Current Status in Turkey

AT-FAULTS

- ❖Breaching red light and/or stop sign of authorized officer,
- ❖Encroaching "No vehicle" sign on roadway or lane, ramp or connection road occupied by opposite traffic stream,
- ❖On two or more-lane highways, encroaching lane or section where opposite traffic stream flows on,
- ❖Rear crash,
- ❖Disobeying "No Passing" sign,
- ❖Incorrect weaving maneuvers,
- ❖Encroaching lane,
- ❖Violation of passing priority rules on intersections,
- ❖Intrusion of "maneuver rules",
- ❖Parking or stopping on rural highways except of compulsory situations and not to take necessary precautions,
- ❖Crashing into vehicles on parking lots or appropriate parked cars outside of vehicle roadway.

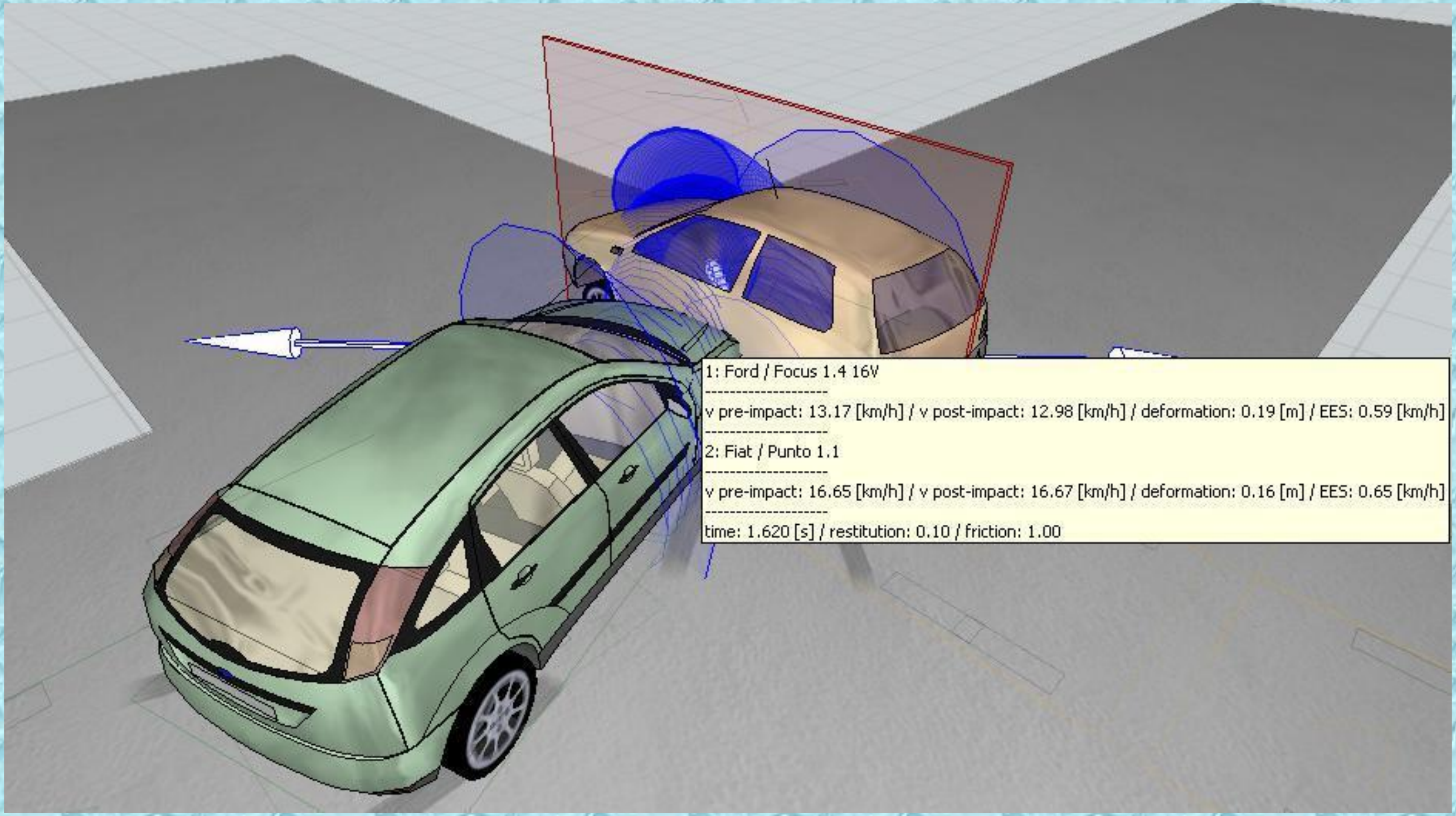
Current Status in Turkey

NOT AT-FAULTS

- ✓Disobeying "STOP" sign,
- ✓Drop-off/loading passengers and goods incorrectly on faulty places,
- ✓Carrying goods or passengers incorrectly on faulty places,
- ✓Driving vehicle inappropriate for safe traffic stream,
- ✓Driving sleepless, fatigued, ill, pensive,
- ✓Not blinking in case of encountering or on urban roads, not using short lights,
- ✓Absence of reflectors on vehicle,
- ✓Absence of haul rope, mounting, tire chains,
- ✓Existence of alcohol while driving,
- ✓Driving on excessive speed.

A Case Study

Sample Controversial Case: Fault rate analysis of an accident at an equal-arm intersection (no traffic lights, “STOP”, “YIELD”, etc. warning signs)



A Case Study

- What were the speeds of vehicles just before the contact to each other?
- Are there any skid marks on the road surface in order to compute the collision velocities of the vehicles?
- If the right side vehicle enters the intersection above legal speed limits, can he/she be deemed not at-faulty?
- Is there any systematic method to determine the fault rates?

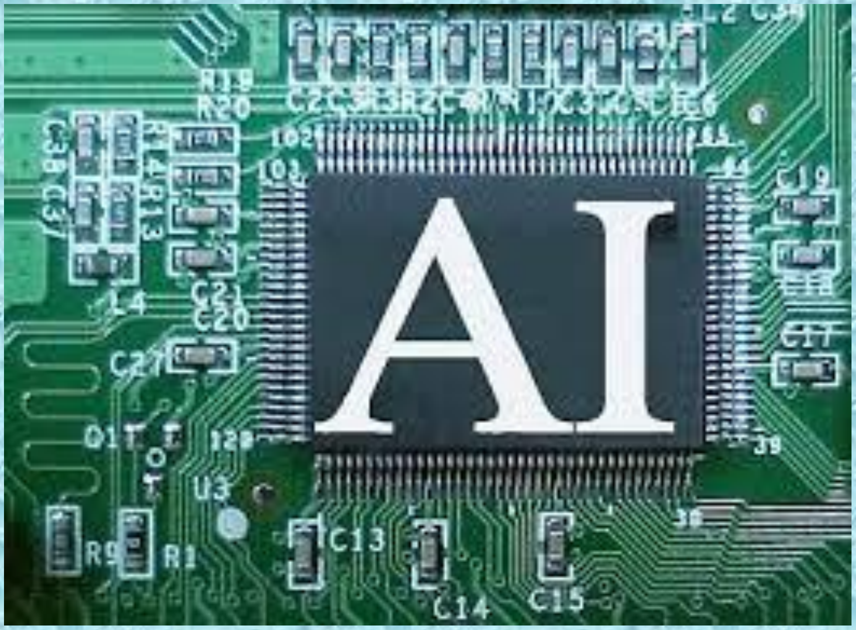
Data Set Constitution for EES

	Statistics Name			
Data	**Mean**	**Maximum**	**Minimum**	**Std. Deviation**
t	1,662	5,623	0,06	1,174
x	8,525	111,657	-78,109	30,132
y	-1,436	8,756	-80,962	16,494
z	0,431	0,642	0,005	0,114
phi	86,912	169,632	0,066	45,521
Δv_1	8,771	75,095	0,237	14,759
Imp	10232,695	100421,035	532,244	19552,068
E	74885,498	1112047,522	781,718	203235,981
ε	***0,200***	***0,705***	***0,025***	***0,142***
v_1	28,290	90,471	0	25,613
ω_1	0,053	1,724	-0,487	0,270
v_2	25,234	69,384	0,055	19,391
ω_2	0,245	8,085	-3,708	1,597
Δv_2	14,814	48,092	0	12,620
GEV	0,988	1,614	0	0,388
EES	14,521	44,215	0,002	10,938

Artificial Neural Network Methods

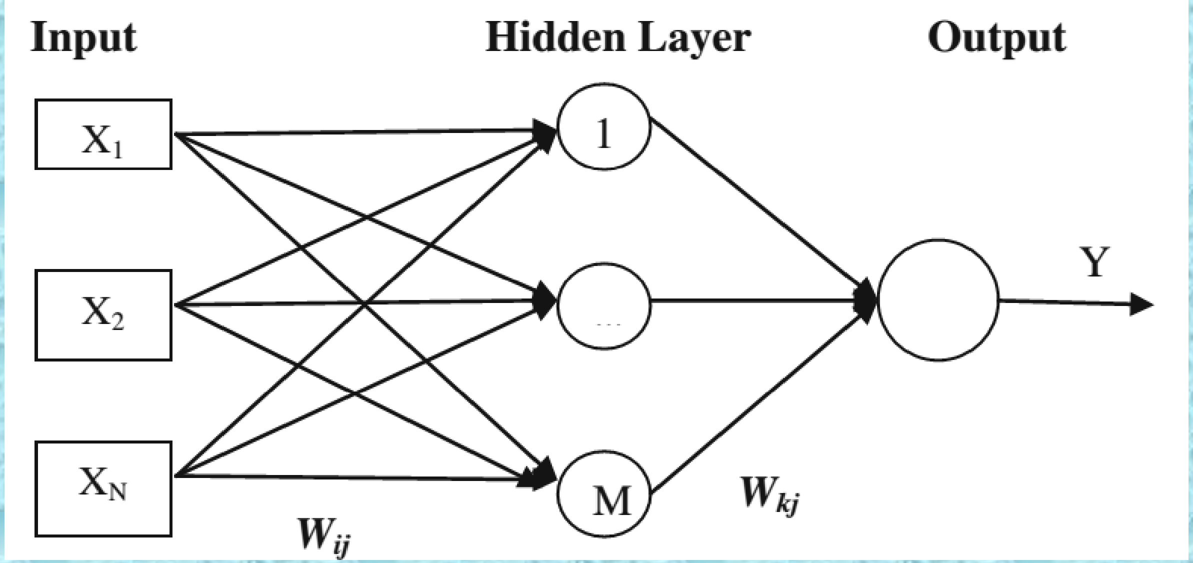
❖Artificial Neural Network (ANN)

- *Multi-Layer Feed Forward Neural Network (MFFNN)*
- *Generalized Regression Neural Networks (GRNN)*



MFFNN

An MFFNN consists of at least three layers: input, output and hidden layer. Each neuron in a layer receives weighted inputs from a previous layer and transmits its output to neurons in the next layer. The summations of weighted input signals are calculated and this summation is transferred by a nonlinear activation function. The results of the network are compared with the actual observation results and the network error is trained until the error reaches an acceptable value [1].



[1] E. Alpaydın, Introduction to Machine Learning, 2nd ed. MIT press, London, 2010.

GRNN

The main function of a GRNN is to estimate a linear or nonlinear regression surface on independent variables (input vectors) U, given the dependent variables (desired output vectors) X. That is, the network computes the most probable value of an output, O_x, given only training vectors U. Specifically, the network computes the joint probability density function of U and X [2].

$$E[X/U] = \frac{\int_{-\infty}^{+\infty} X\, f(U, X)\, dx}{\int_{-\infty}^{+\infty} f(U, X)\, dx}$$

[2] M. Khashei, A. Z. Hamadani and B. Bijari, "A novel hybrid classification model of artificial neural networks and multiple linear regression models," Expert Syst App.,vol. 39, pp. 2606–20, 2010.

MFFNN & GRNN Comparison for EES Prediction

- Two different training algorithms (trainlm,trainlp) within MFFNN and GRNN were used in order to compare the multiple corelation coefficient (R) and standard error of estimates (SEE) values.

	MFFNN-based model		GRNN-based model	
Folds	***R***	***SEE***	***R***	***SEE***
Fold 1	0,86	3,32	0,93	3,69
Fold 2	0,87	3,63	0,88	4,55
Fold 3	0,90	3,51	0,87	3,71
Fold 4	0,83	4,43	0,89	4,41
Fold 5	0,93	2,19	0,91	4,75
Average	**0,88**	**3,42**	**0,90**	**4,22**

R and *SEE* values of the MFFNN and GRNN models by means of 5-fold cross-validation (EES prediction)

Assumptions for Fault Rate Prediction

- ❖Referring to the case study, one of the most important parameter is speed (EES) of the involvements. In case of absence of skid marks, the biggest clue about the speeds of vehicles is the damage formed on the vehicles. More damage on the vehicle(s), more energy transformed into deformation energy which is defined as crush depth (S_{def}) in terms of meters.
- ❖Similar vehicles with ones in real world accident were crashed into each other in the way they were exposed to various average crush depths on the collision region of each (1000 trials).
- ❖The larger the crush depth the bigger the EES value
- ❖Thanks to simulation software, since every EES value corresponding to an average deformation amount and every deformation amount corresponding to an average EES value were known, at the accident scene average crush depths were used as main parameter to predict EES values of involvements.
- ❖Every average 5 km/h increment in EES of an involvement corresponds to 3 increment in fault rates of the related vehicle.
- ❖Every crush depth amounts versus every EES values and every fault rates were obtained which are to be training data for MFFNN and GRNN.

Descriptive Statistics for the Scenario

	ε_1 (m)	ε_2 (m)	EES_1 (km/h)	EES_2 (km/h)	FR_1 %	FR_2 %
Minimum	0,072	0,065	15	20	0	18
Maximum	1,637	1,598	170	175	82	100
Mean	0,849	0,774	68,818	74,108	28,028	72
Std. Dev.	0,421	0,408	37,198	36,672	26,786	26,797

Results of the scenario by means of 5-fold cross-validation (Fault rate prediction)

	MSE		R	
Fold number	**MFFNN**	**GRNN**	**MFFNN**	**GRNN**
1	1,011110	2,512337	0,999492	0,997346
2	1,016606	3,517386	0,999598	0,994529
3	2,100327	3,800502	0,999190	0,993723
4	4,081504	4,292495	0,998548	0,991565
5	0,705644	2,934098	0,999708	0,995829
Average	**1,783038**	**3,411364**	**0,999307**	**0,994598**

Results and Discussion

The followings can be concluded from 5-fold cross validation results for both EES and FR predictions:

- ❖In average, MFFNN model performed better results (i.e., higher R and lower MSE) than GRNN prediction model in terms of fault rate prediction.
- ❖For EES prediction, MFFNN gave lower MSE and R values whereas GRNN gave higher for both.
- ❖Since there is no training phase in GRNN, the GRNN model produced results much faster than MFFNN.
- ❖The R values for prediction of fault rates were close to 1 for all folds.

Sample Fault Rate Application Interface on a Portable Device

Vehicle Brand:

Model:

License Plate:

Alcohol.............................. YES ☐ or NO ☐

Driver License.................. YES ☐ or NO ☐

Weather Condition:

Date:

AT-FAULTS

☐ ....

☐ ....

☐ ....

☐ ....

MINOR FAULTS

☐ ....

☐ ....

☐ ....

☐ ....

Choose Occurence Type of Accident

☐ ....

☐ ....

☐ ....

☐ ....

☐ ....

Enter the crush-depth of the involvement-1 (m):

Enter the crush-depth of the involvement-2 (m):

Estimated Velocity-1: .... km/h

Estimated Velocity-2: .... km/h

Estimated Fault Rate-1: ....

Estimated Fault Rate-2: ....

Conclusions

❖A scientific, systematic and initiative-independent approach was tried to be achieved by simulating one of the most frequent type of accidents and predicting fault rates of involvements.

❖Precise fault rate prediction of involvements in terms of neutral decisions is especially beneficial on events like matter for the courts or forensic investigations.

❖Deficiencies in THTA, especially in terms of fault rates, can be eliminated with this approach.

❖Probable useful approach for insurance companies which just consider 100%, 50% and 0% fault rate situations in case of an accident at present.

❖Appropriate for implementable and developable interface on portable devices for traffic police and/or experts

❖Impartial and systematic approach for controversial cases.

❖Suitable application to commercialize.

THANK YOU
FOR
LISTENING