Analysis of the influence of trauma injury factors on the probability of survival

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Analysis of the Influence of Trauma Injury Factors on the Probability of Survival

M. Saleh, R. Saatchi, F. Lecky and D. Burke

Abstract— The probability or likelihood of survival in trauma injuries is a clinically important parameter for triage, setting treatment priorities and research and management audit. The existing methods for determining it have short comings that necessitate further development. In this study, an artificial intelligence method called fuzzy inference system (FIS) for determining the likelihood of survival in trauma injuries is being developed and evaluated. The accuracy of the FIS primarily depends on the design of its knowledge base. The required knowledge base is being designed by carrying out a detailed statistical analysis of the trauma injury profiles contained in a large data base of injury cases. As part of this analysis, the relationships between the body regions affected by trauma injuries, physiological measures (such as blood pressure, respiration rate and heart rate), age, gender , the neurological factors assessed by the Glasgow Comma Score and pre-exiting medical conditions on the probability of survival were analysed and a FIS system to indicate the likelihoods survival was proposed. The preliminary results obtained are presented.

Keywords—Computational analysis of injuries, probability of survival, Fuzzy logic.

I. Introduction

Trauma injury is an important cause of death and disability [1]. Determining the probability or likelihood of survival in trauma injuries is important for triage, setting treatment priorities and research and management audit [2]. Numerous parameters influence the probability of survival that include the extent, type and location of body injuries, pre-existing medical conditions (such as the heart condition), physiological measures (such as body temperature, heart rate, blood pressure and respiration rate), age, gender, frailty and neurological measures that indicate the level of conscious state. The manner and extent of interaction and interrelations of these parameters on the probability of survival is important and require further investigation.

In order to quantify the anatomical and neurological trauma injury related information, a number of standard scoring systems are currently available. A commonly used system for assessing anatomical injuries is the Abbreviated Injury Scale (AIS) [3]. It was introduced in 1971 by the Association of the Advancement of Automotive Medicine (AAAM) to assist with vehicle crash investigators. AIS has been since been revised to be more relevant to medical audit and research. Using AIS the injuries in all body regions can be classified according to their relative importance. In AIS a six points ordinal severity scale is defined as 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, 6=maximum (currently untreatable). AIS defines body region injuries in a dictionary that has nine separate chapters defined as; (i) Head, (ii) Face, (iii) Neck, (iv) Thorax, (v) Abdomen and Pelvic contents, (vi) Spine, (vii) Upper Extremities, (viii) Lower Extremities and (ix) External (skin), Burns and Other Trauma.

In order to determine combine the trauma injury scores (assessed by AIS), for patients with multiple trauma injuries, the Injury Severity Score (ISS) could be used. ISS is an anatomical scoring system with the maximum total score of 75 that selects the highest AIS values in each body region [4]. The three most severely injured regions (corresponding to 3 largest AIS scores) have their scores squared and then summed to produce the overall ISS value. However ISS has shortcomings. In ISS dissimilar trauma injuries can produce similar ISS scores in different injuries, in different body regions and the scores are not weighted. For example, it does not differentiate between an AIS score of 4 for the head trauma injury and injuries in the limb regions [5].

In assessing trauma injuries, the level of consciousness is also important. A well-known neurological trauma injury scoring system to determine the level of consciousness is the Glasgow Coma Scale (GCS) [6]. It allocates scores by examining eye opening, verbal response and motor response as indicated in Table I.

TABLE I. OVERVIEW OF INJURY CASES

Eye Opening	Verbal Response	Motor Response
4=spontaneous	5=normal conversation	6=normal
3=to voice	4=disoriented conversation	5=localised to pain
2=to pain	3=words, but not coherent	4=withdraws to pain
1=none	2=no words only sounds	3=decorticate posture
	1=none.	2=decerebrate
		1=none

The goal of this ongoing study is to develop techniques to improve the accuracy of determining the probability or likelihood of survival in trauma injuries. As part of this, we are currently developing techniques that use fuzzy inference system (FIS). FIS processes information in linguistic form, rather than numeric and thus provides flexibility to the manner attributes can be described. For example, a head injury could be described in fuzzy logic form as mild or severe. Therefore to facilitate processing by FIS the numeric data such as injury scores, age, physiologic measures such as respiration and pulse rates and blood pressure need to be converted to linguistic form through a number of membership functions. The shape of the membership function can vary. For example, they can triangular or trapezoidal shape. A set of membership functions for an input such respiration rate establishes the degrees that measure values belong to a set of low, average or high rates. A measure could simultaneously be members of multiple sets with varying degrees of memberships. For example, a measured respiration rate can simultaneously be a member of low and average respiration rates with their associated degrees of memberships.

The mapping of the inputs to the FIS to its output(s) is based on the domain knowledge base. The knowledge is typically coded by a series of IF-THEN rules. Inferencing is used to draw conclusion for inputs by relating them to the information in the knowledge base.

The FIS provides likelihood rather than probability (i.e. measure of chance). Although probability and likelihood could be related, they are not the same measure. To illustrate the point, if for a person the probability of being frail is 0.5, that person has a 50% chance of being frail (i.e. he or she may not fail at all or be completely frail. However, if the same person (in fuzzy logic domain processing) has the likelihood of being frail equal to 0.5 (from maximum of 1), that person is definitely frail to an extent represented by 0.5.

In the next sections a brief overview of a number of existing methods for determining the probability of survival is provided, study's methodology and its results are then explained.

II. APPROCHES TO DETERMINE PROBABILITY OF SURVIVAL

Trauma and Injury Severity Score (TRISS) uses anatomical and physiological scoring systems to determine the probability of survival (p_s) for adults sustaining traumatic injuries from blunt and penetrating mechanisms [7], where p_s is calculated by

$$p_s = \frac{1}{1+e^{-b}} \quad (1)$$

$$b = \alpha_i + \beta_{AGE,i} \times \beta_{RTS,i} \times RTS + \beta_{ISS,i} \times ISS$$

where i = 1 is for blunt mechanism and i=2 is for penetrating mechanism, α_i is a constant for mechanism i, $\beta_{AGE,i}$ is the coefficient associated with AGE and mechanism i, $\beta_{RTS,i}$ is the coefficient associated with RTS and mechanism i, and $\beta_{ISS,i}$ is the coefficient associated with ISS and mechanism i. RTS is defined by

$$RTS = \beta_{RR} \times RR + \beta_{SBP} \times SBP + \beta_{GCS} \times GCS \quad (2)$$

where β_{RR} is the coefficient associated with respiration rate (RR), β_{SBP} is the coefficient associated with systolic blood pressure (SBP), and β_{GCS} is the coefficient associated with GCS. TRISS however has a number of shortcomings as explained in [8].

Another method of evaluating injury severity is the Emergency Severity Index (ESI) [9]. It uses a five-level algorithm that incorporates respiratory rate (RR), heart rate (HR), blood oxygen saturation (SpO2), body temperature (T), and peak expiratory flow rate (PEFR) [10]. The approach can provide clinically related stratification of patients into five groups according to a range of urgency by considering the patient injury severity and supply needs [11].

Harborview Assessment for Risk of Mortality (HARM) is an effective tool for predicting the likelihood of in-hospital mortality for trauma patients [12]. The approach is also valuable for both calibration and discrimination using information that is readily accessible from hospital discharge coding.

In 2004, Trauma Audit and Research Network (TARN) [13] proposed a Probability of Survival model called PS12. This model uses age, gender, Injury Severity Score (ISS) and GCS and intubation.

In 2014, PS14 model was introduced by incorporating Charlson Comorbidity Index (CCI) [14] to the assess Pre-Existing Medical Conditions (PMC). To predict the probability of survival using PS14, age, gender, GCS, intubation and PMC parameters are required. It determines the p_s by performing retrospective measure of a new patient with same profile on TARN database (that has information on a very large number of trauma injury cases and their associated outcomes as survived or not survived). It uses the formula

$$p_s = \frac{e^b}{1+e^{-b}} \quad (3)$$

where e=2.718282 and b is defined as the linear combination of the regression coefficients and the values of the corresponding patient's characteristics (ISS, GCS, the categorised modified Charlson Comorbidity Index, age and sex).

III. METHODOLOGY

This ongoing study is in collaboration with Trauma Audit and Research Network (TARN). The trauma injury data provided by TARN for the purpose of this study included 47,702 trauma injuries cases. The personal identities of the subjects were fully anonymized prior to receiving the data base and the work was subject ethics committee approval by Sheffield Hallam University, UK. The trauma injury data contained subject details (such as age and sex), their associated trauma injury information (AIS and GCS values, blood pressure, heart rate, respiration rate etc.) and outcome of trauma injury as survived (lived) or not survived (died).

The development of the knowledge based for the FIS required a computation analysis of the trauma injuries to establish the manner they influenced the probability of survival. This analysis is the main focus of this paper, however an outline of the prototype FIS to determine the likelihood of survival is also provided. The processes involved in the study are shown in Fig.1.

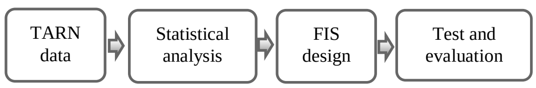


Fig.1 FIS system development stages to determine the likelihood of survival.

The computation analysis was performed using the statistical analysis package SPSS© and the FIS was implemented in the data analysis package Matlab© . The analysis examined the manner single and multiple trauma injury factors influenced the probability of survival.

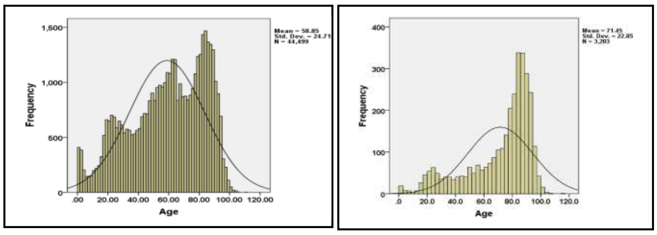
IV. Results and Discussion

Table II indicates the number of cases used in the study, their sexes, ages, injury types and injury outcomes. There are about 10% more males than females and 97% of the injuries were in the blunt category and the rest penetrating type. A blunt traumatic injury is caused by the application of mechanical force to the body or when the body strikes a surface in which the skin is not penetrated. A penetrating traumatic injury is caused when a sharp object such as knife penetrates the body. The proportion of cases that survived (lived after the trauma injury) was 93.3% and the remaining cases not survived (died).

TABLE II. Overview of injury ttauma cases

Sex (%)		Mean Age (years) (standard deviation)	%Injury Type		Injury Outcome (%)	
Male (%)	Female (%)		Blunt	Penetrating	Lived	Died
26098 (54.7)	21604 (45.3)	60.7 (24.8)	97	2.4	44499 (93.3)	3203 (6.7)

Figs.2a and b show the distributions (histograms) indicating the effect of age on the individuals surviving and not surviving in traumatic injuries. The distribution for survived cases shows peaks at 20, 60 and 80 years but for those that did not survive, there is a single dominant peak at about 90 years. The peaks in the distribution of cases that survived do not infer that more injuries occur at those ages but there are more subjects with those ages in the analysed data base.



(a) (b)

Fig.2 (a) Age distribuition of indiviuals suviving and (b) those not surviving.

Fig.3 shows the number of cases for different injury mechanisms. The dominant injuries in order of magnitude are: fall less than 2 m, vehicle incident collisions, fall more than 2 m and blow(s).

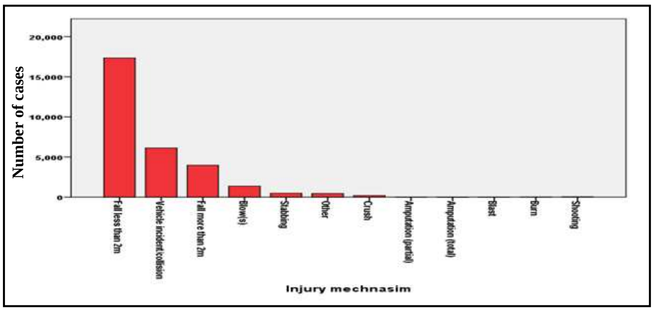


Fig.3 Number of cases for different injury mechanisms.

Fig.4 shows the injury numbers in relation to AIS defined body regions. Lower limbs injuries followed by head, thorax, spine and upper limbs are the main affected regions.

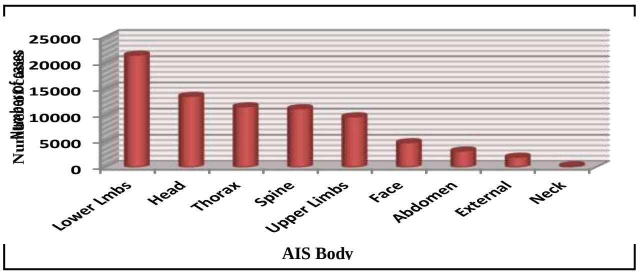


Fig.4 Injury numbers in relation to the AIS defined body regions.

Fig.5 provides the percentages of cases with AIS injury scores 3-6 that did not survive. The majority of these cases had head injury (43.93%) and next highest percentages were for thorax (22.04%) and lower limbs injuries (15.55%).

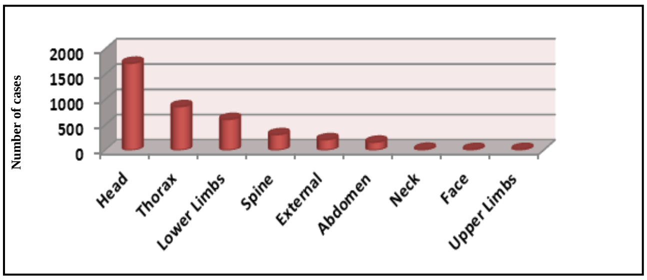
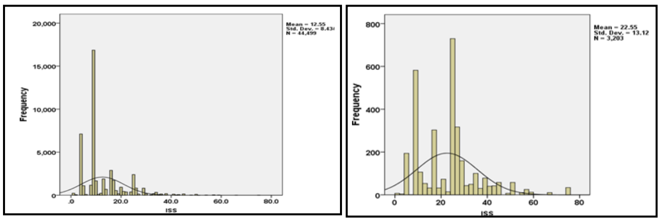


Fig.5 Body region injuries with AIS scores 3-6 and associated number of cases that did not survive.

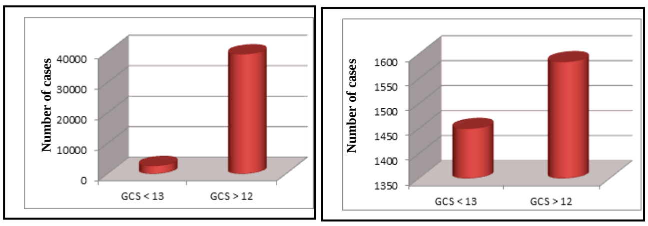
Figs.6a and b show the distributions the ISS scores for (a) those that survived and (b) those that did not. For those that survived the ISS values peak around 15 and for those that did not, the ISS distribution has multiple peaks, with the largest at round 30.



(a) (b)

Fig.6 (a) Distribuition of ISS values for (a) those that survived and (b) those that did not survive.

Figs.7a shows the number of cases with GCS less than 13 and more than 12 that survived. Fig.7b shows similar information for those that did not survive. Comparing the proportion of cases with GCS less than 13 against those with more than 12, for those who did not survive this proportion is much higher.



(a) (b)

Fig.7 (a) GCS values (a) those that survived and (b) those that did not survive.

Figs.8a and b show the effects of pre-existing medical conditions (PMC) on the probability of survival for cases that (a) survived and (b) those that did not survive. PMC<1 indicates no pre-existing condition and PMC>0 indicates existence of at least one pre-existing medical condition. The majority of those that survived did not have a pre-existing medical condition but the opposite is the case for those that did not.

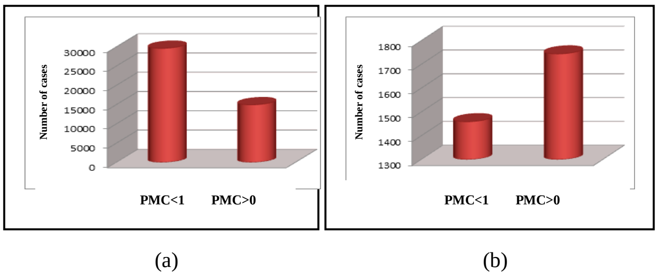


Fig.8(a) The effect of pre-existing medical condition on (a) those that survived and (b) those that did not survive.

Figs. 9a and b show the number of adult cases with emergency department respiratory rate in the normal range (16 to 20 breaths per minute) for cases (a) that survived and (b) those that did not survive. The proportion of cases with emergency department respiratory rate 16-20 breaths per minute that did survive is much higher than the cases that did not. Therefore the respiratory rate is an important factor in determining the probability of survival.

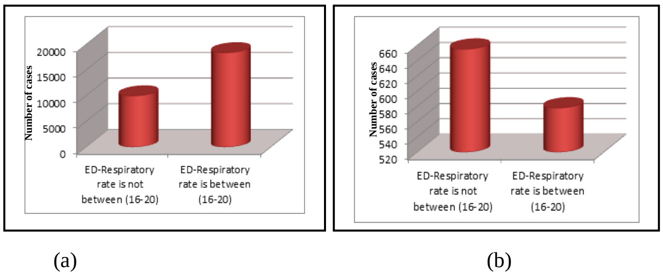


Fig.9 (a) Number of cases with normal (15 to 20 cycles per minute) emergency department respiratory rate (a) those that survived and (b) those that did not survive.

Figs.10a and b show the effect of normal pulse rate (heart rate) on survival in adult cases. Pulse rate for healthy adults is typically between 60-100 beats per minute. In survived cases (Fig.10a), a much higher proportion of individuals had normal pulse rate. Fig.10b shows the proportion of the individuals with a normal and abnormal emergency department pule rate for cases that did not survive is much closer than those that did survive.

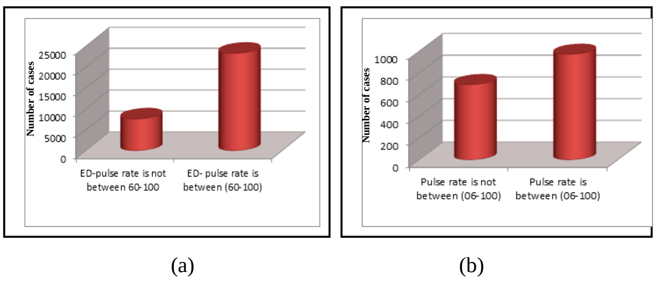


Fig.10 Effect of emergency department pulse (heart) rate on probabbility of survival in adults (a) survived cases (b) those that did not survive.

Blood pressure is one of the vital sign for medical examinations. Figs. 11a and b show the number of adult cases with emergency department (ED) -Systolic blood pressure (SBP) in the normal range (90 to 140 mmHg) and outside this range for the cases that survived and (b) those that did not survive. The proportion of cases with SBP in the normal range is higher in individual that survived than those who not survive indicating this physiological measure in an important indicator of survival.

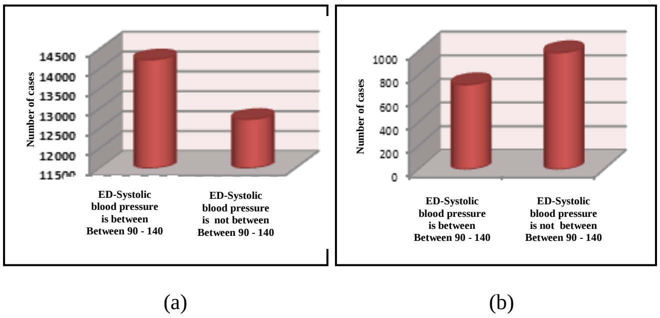


Fig.11 Impact of emergency department systolic blood ressure rate on probabbility of survival in adults (a) survived cases (b) those that did not survive.

Fig. 12 shows the AIS scores of the cases with joint head, thorax and lower limb injuries (i.e. the main body areas affected by trauma injury) that did not survive. The largest number of deaths is for head (score 5), thorax (score 3) and lower limbs (scores 4 and 5) injuries.

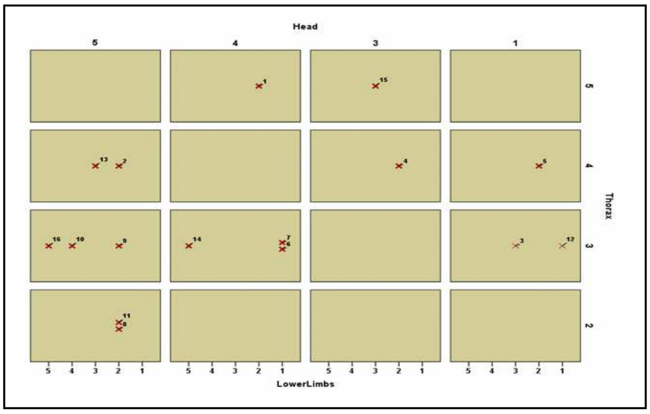


Fig.12 The interrelationship between trauma injuries associated with head, thorax, and lower limb in cases that did not survive represented by AIS values 1-5.

Figs.13a and b show box plots that indicate the relation between head injury only and thorax injury only for cases that did not survive. Both injury types have mainly AIS value 5 but age ranges are different. Age ranges could have been obscured by the distribution of age in the data base that itself is influenced by the age distribution of the population in the UK.

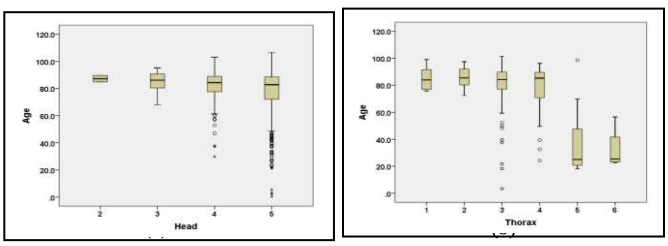


Fig.13 Box plots indicating the relationship between (a) head only injury and (b) thorax only injury for those that did not survive.

Fig. 14 shows the correlation between trauma injuries associated with the 8 body regions as defined in AIS standard for cases that did not survive. Head injuries occurred more often with face and thorax injuries. Face injuries are more common with head injury. Thorax injuries occur more often with head and abdomen injuries.

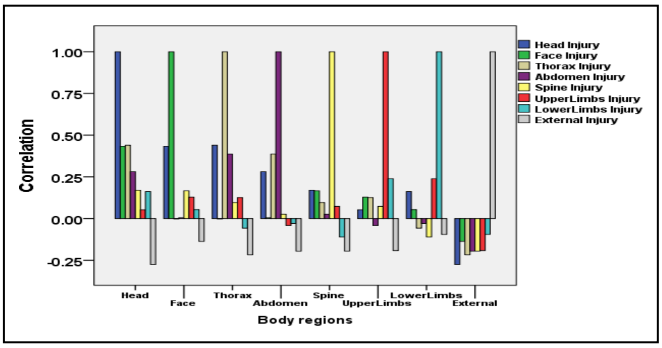


Fig.14 Correlation analysis of trauma injuries associated with the AIS defined body regions in cases that did not survive.

Fig.15 shows the interrelationship between age, GCS and head only injuries in cases that did not survive. Most cases are related head injuries AIS=5, ages around 80 years. Most head injuries with AIS=4 had GCS values 3 to 5 or 11 to 15.

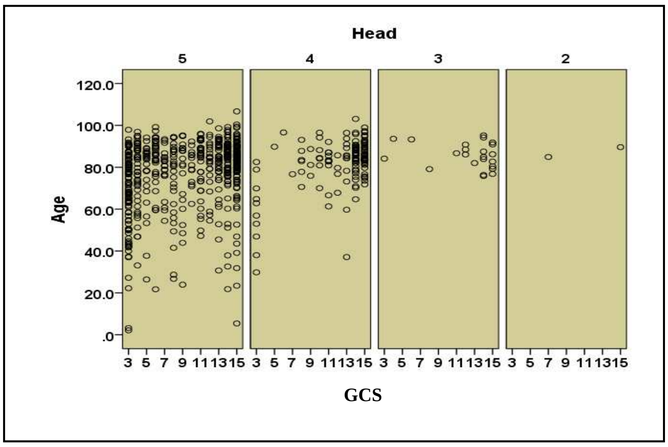


Fig.15 The interrelationship between GCS and head injuries in cases that did not survive.

Fig.16 shows analysis in Fig.15 extended with inclusion of gender. Gender is a more significant factor in determining the probability of survival in older subjects. A larger number of older (aged around 80 years) males have head injury than females. Age can be important in determining the probability of survival [15].

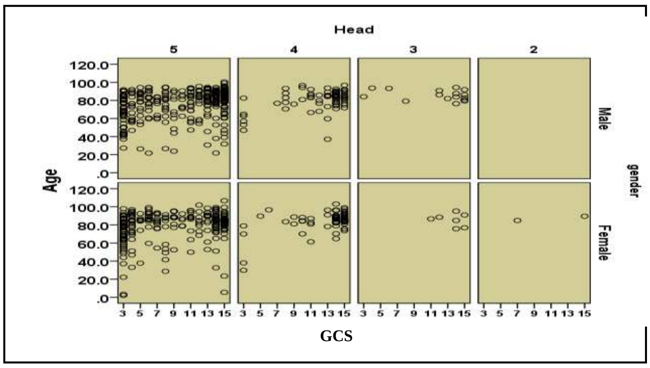


Fig.16 The interrelationship between GCS, head injury and age in cases that did not survive.

Fig.17 shows the relationships between trauma injury mechanisms, GCS, pre-existing medical condition (PMC) and head only injury in cases that did not survive. Most cases that did not survive were associated with falls less than 2 m, AIS values 4 and 5 and PMC values -1 to 15.

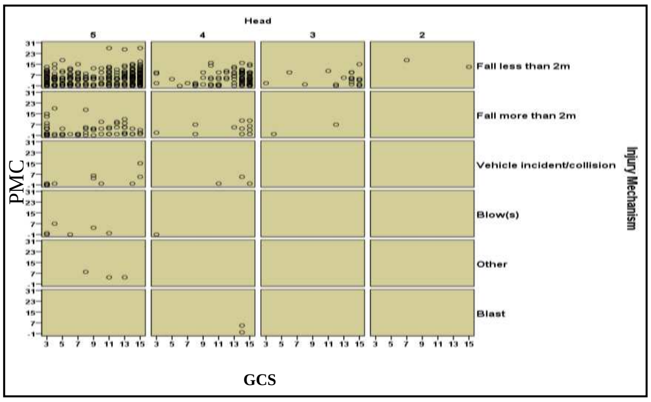


Fig.17 Relationship for GCS, PMC, injury mechanisms and head only injuries for cases that did not survive.

Fig.18 shows the relationships for intubation, GCS, head and face only injuries, and GCS in cases that did not survive. Most cases were associated with intubation and head injury AIS=5, face injuries AIS=2 and GCS=3 to 7.

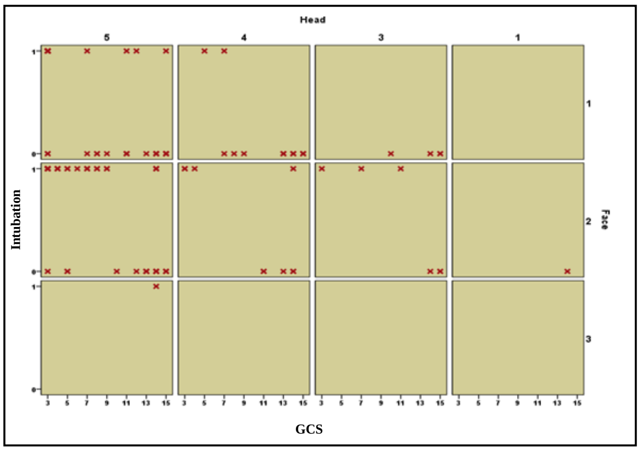


Fig.18 The relationships for intubation, GCS, head and face regions, and GCS in cases that did not survive.

Table III provides a summary the interrelationships between injuries associated with specific body regions and factors affecting the probability of survival (age, PMC, GCS and gender) in cases that did not survive. Both the number of cases and respective percentages are included.

TABLE III. OVERVIEW OF INJURY CASES

Body regions	Total	Age (%)		PMC (%)		GCS (%)		Gender (%)	
		>57	<55	<=0	>0	<13	>=13	Male	Female
Head	811	745 (91.9)	66 (8.1)	289 (35.6)	522 (64.4)	402 (49.6)	409 (50.4)	362 (44.6)	449 (55.4)
Lower Limbs	347	335 (96.5)	12 (3.5)	105 (30.3)	242 (69.7)	9 (2.6)	338 (97.4)	119 (34.3)	228 (65.7)
Thorax	194	166 (85.6%)	28 (14.4)	76 (39.2)	118 (60.8)	35 (18.0)	159 (82.0)	110 (56.7)	84 (43.3)
Head & Face	129	103 (79.8)	26 (20.2)	49 (38.0%)	70 (54.3)	64 (49.6)	62 (48.1)	79 (61.2)	50 (38.8)
Head, Thorax and Lower limbs	16	11 (68.8)	5 (31.3)	10 (62.5)	6 (37.5)	12 (75.0)	4 (25.0)	7 (43.8)	9 (56.3)

A block diagram of the FIS system being developed to determine the likelihood of survival is provided in Fig.19.

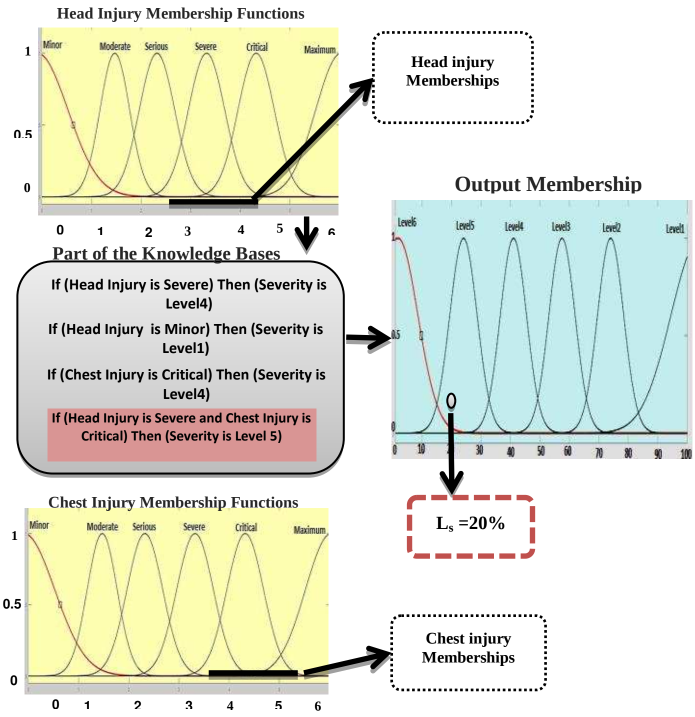


Fig. 19. Illustration of the FIS system operation

The patient in this situation had two trauma injuries associated with chest and head. The AIS code for head and chest injuries were 4 and 5 respectively. AIS code 4 represents severe injury and 5 is a critical injury. The FIS system determined the degree of membership of the injury levels (i.e. 4 and 5) belonging to a set of six membership functions labelled as minor, moderate, serious, severe, critical and maximum. The rules in the knowledge base process mapped the fuzzified inputs to determine degrees of membership to each membership function. The overall results was then defuzified by a set of output membership functions to indicate the likelihood of survival (L_s) [16].

The system is currently partially developed and work is currently ongoing to complete the FIS knowledge base. We plan to carry out a detailed evaluation of its performance. Illustrative examples the likelihoods of survival (Ls) determined by the FIS system for 6 cases (taken from TARN data base) are shown in Table IV. The determined Ls values reflect the rules in the FIS knowledge base. Fig.19 shows the FIS processing for case 2 in Table IV.

TABLE IV. TYPICAL RESULTS PROVIDED BY THE FIS FOR DETERMINING THE LIKELIHOOD OF SURVIVAL

patient case	Age (years)	Sex	GCS	AIS Body regions										%Ls
				Head	Neck	Face	Chest	Abdomen	Spine	Upper extremities	Lower extremities	External	Others	
1	50	M	13				2			2				99.4
2	88	M	4	4			5							20.1
3	31	F	12	2		3			1					97.4
4	70	M	6					3						99.5
5	56	M	10	1			2				2			98.2
6	20	F	15			1		2				2		99.3

V. CONCLUSIONS

A preliminary computational analysis of a number of important factors that influence the probability of survival in traumatic injuries was performed. The study highlighted some of the complexities associated with the manner traumatic injuries affect the probability of survival. We are currently building on this analysis to develop a model that can indicate the likelihood of survival and overcome some limitations of the existing probability survival indication approaches. The main element of this model is its knowledge base that will be derived from the TARN trauma injury data base. The processing of the information in the knowledge base will be based on the artificial intelligence method of fuzzy logic. The fuzzy logic compares injury information about a case with those in the data base to determine the likelihood of the survival.

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