WITkit – Whiplash Injury Risk Claims, Methodology and Theory of Operation

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Abstract: Claims for whiplash type injuries in most motorised countries cost more than all other injury claims put together. In Britain changes in the legal process within the last 10 years have led to a 50% increase in such claims. When followed up in detail a proportion of such claims have been shown to be invalid. The aim of this research is to develop an analytical technique for assessing the severity (delta-v, average acceleration and other parameters) of an impact to a car involved in a low speed rear end collision. That information, when combined with other factors (i.e. gender, occupant position and posture, seat performance and published data on injury incidence) allow the injury risk to be assessed for each given case. The aim is to provide a filter which will identify those cases where the crash severity is so low that the chances of a whiplash injury are remote.

This paper presents a new way to combine the state of the art in whiplash research into one system using damage severity estimation, seat performance information and published modifier data for factors which influence the likelihood of whiplash in rear end collisions.

Keywords claims handling tool, injury risk estimation, rear end collision, whiplash injury

I. INTRODUCTION

Claims for whiplash type injuries in most motorized countries cost more than all other injury claims put together [45]. In Britain changes in the legal process within the last 10 years have led to a 50% increase in such claims. When followed up in detail a proportion of such claims have been shown to be invalid.

The aim of this research is to develop an analytical technique for assessing the severity (delta-v, average acceleration and other parameters) of an impact to a car involved in a low speed rear end collision. That information, when combined with other factors (gender, occupant position and posture, seat performance and published data on injury incidence) allow the injury risk to be assessed for each given case. Furthermore, such a filter would identify those cases where the crash severity is so low that the chances of a whiplash injury are remote.

Whiplash injury risk is often quoted as being the consequence of the transfer of energy which is approximated to the change in velocity (delta-v). However there are many other factors that influence injury risk, including seat design characteristics, vehicle weight, occupant morphology, and bumper characteristics. Bumpers are not typically single items, but a complex system of components that include a transverse beam and energy absorbers. These are usually covered by a flexible tall plastic facia that hides the bumper structure and allows for individual styling. [26] , [27] , [28] , [29] , [30] , [31], [32]

In the evaluation system (WITkit) which has been developed, the damage to both cars in a low speed front to rear collision is assessed from photographs and descriptions of the exterior damage. The amount of offset and the presence of any override or underride are considered. From an extensive library of low speed crash tests, comparisons are made and the normal Newtonian calculations result in an estimate of the delta-v and average acceleration. Considerations of gender, occupant position and posture, and seat performance are then related to the incidence of whiplash injury based on published research. This process results in an injury risk factor for each specific case.

The paper describes the test data used to build the damage severity estimator models and the methodology of deriving risk factors based on the available information about the accident. The physical models behind the

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calculations are presented and the reasoning chain for combining the different factors of influence are described.

The target application is a whiplash injury claims handling tool. For this reason the available information about a particular accident might be limited, but this is taken into account by the system.

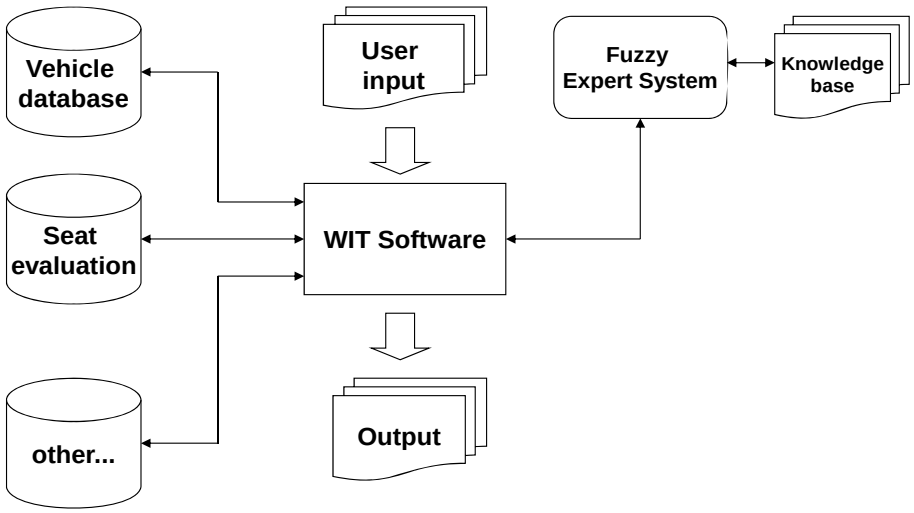

Fig. 1: WITkit system topology and information flow

The WITkit (Whiplash Injury ToolKit) software combines user input, different databases, a fuzzy expert system (reflecting the knowledge base about injury risk factors and modifiers) and internal calculations to derive an output (the injury risk factor) as shown in Fig. 1. In this way the system takes into account the different factors which influence injury risk and combines the state of the art in whiplash research into one system as shown below.

The steps in evaluating an incident are described in detail in the following section.

II. METHODS

The injury risk calculation is performed in two stages (Fig. 2). Firstly, the base risk factors are calculated based on damage severity and vehicle data using a delta-v calculation based on conservation of energy, conservation of linear momentum and a constant separation velocity. The base risk calculation is also influenced by the seat rating which is seen to be one of the major modifier factors of injury risk.

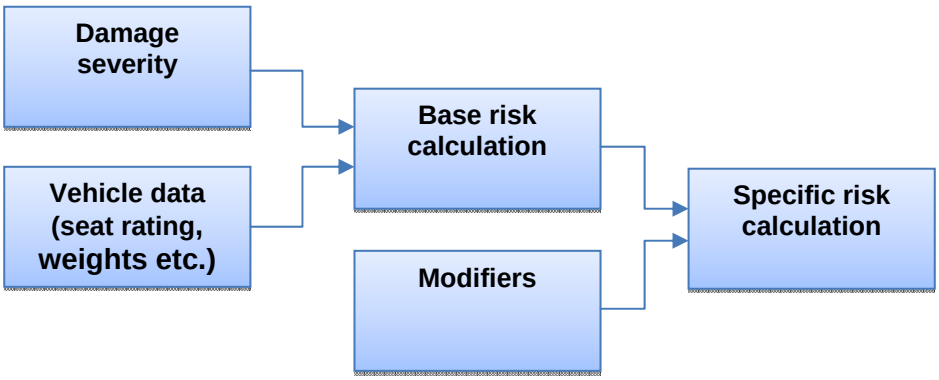

Fig. 2: WITkit risk calculation steps

Delta-v and seat rating are then combined to get the base risk factors using a fuzzy expert system which reflects published risk factors. [9], [10], [11], [12], [14]

In the second stage the following modifiers are applied to take into account that risk factors may increase or decrease depending on certain circumstances.

Modifiers:

- Underride and Engagement [26], [29],
- Occupant position (front or rear seating, out of position or not) [15]
- Awareness
- Occupant profile (gender, weight, height, age)
    - Females have higher risk [17], [18], [19]

As the users of the tool and the persons involved in the accident may have limited engineering background, this very specific information about the accident is often difficult to ascertain. A questioning system has been derived based on a set of generic crash tests and case studies on available information at the time an accident is reported.
The modifiers used are selected based on identification of being influential by the whiplash research community and availability of support data and studies for the amount of influence on whiplash risk. Modifiers are also limited to the ones which can be assessed in the application environment of the system.

Vehicle database

The vehicle database (Fig. 3) includes information about the vehicle itself (dimensions, weight, type) and the seat rating as evaluated in the IIWPG (International Insurance Whiplash Prevention Group) procedure. [1], [2], [3], [4], [5], [22], [23], [24], [25]

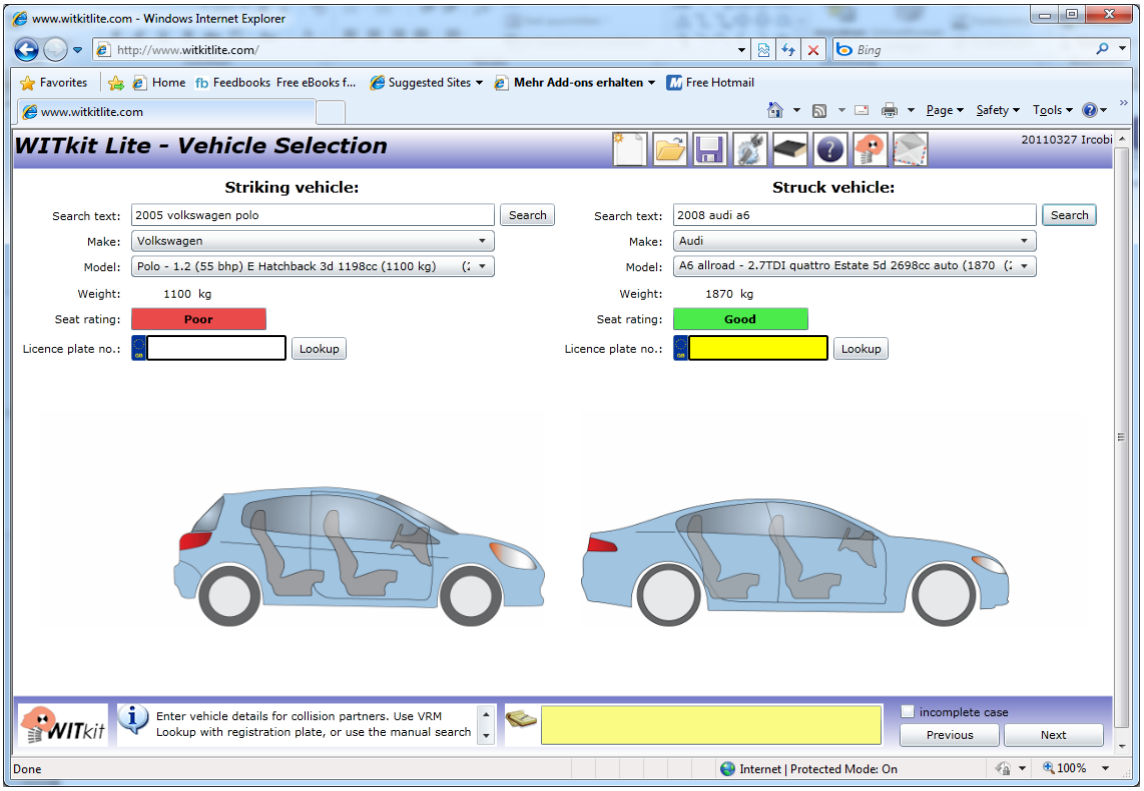

Fig. 3: Vehicle selection and vehicle database

Accident circumstances

In the accident circumstances section, general information about the accident is gathered (Fig. 4). The questions in this section cover offset and full overlap conditions (contact area), potential out of position conditions using accident location questions (junction, stop line) and driver awareness.

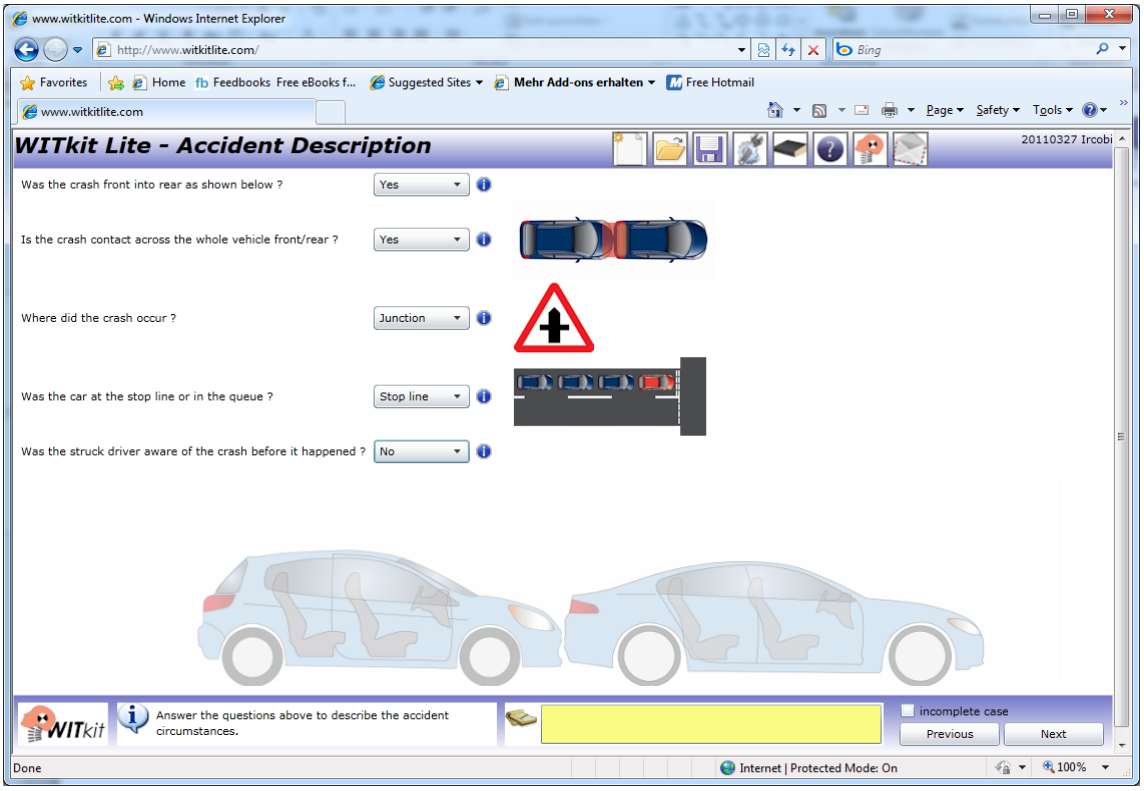

Fig. 4: Information about the accident circumstances

Damage severity description

Damage severity in the collision is one of the key factors describing the severity of the accident. A generic questioning system has been derived based on a set of crash tests performed. These crash tests have been done with delta-v ranging from 1.5 km/h up to 24 km/h for both underride and bumper engagement collisions.

In order to identify the influence of underride vs. bumper engagement on whiplash injury risk, a series of paired crash tests were undertaken using the same vehicle to represent the typical range of delta-v where whiplash injuries occur. Identical vehicles were used featuring a popular car with good performance in insurance repairability tests. The vehicle also had a seat design that had been tested in the IIWPG whiplash test and so comparative test data were also available. Although each vehicle type has its own crash performance characteristics and associated repair costs (often due to parts pricing), the vehicle selected for these tests has many design features associated with the fleet as a whole and as such was deemed to be representative of a typical modern vehicle.

Seventeen impact tests were undertaken, featuring thirty-four impacts to identical Volkswagen Golf Mark 5s 2.0 GT TDi. All cars were purchased together, had identical seats and were produced consecutively. All except the 1 km/h test used a unique pair of new vehicles; due to the absence of damage in the 1 km/h test, the pair of cars were re-used for the 3km/h test.

The vehicles were impacted in pairs. After their first impact the cars were swapped so that the striking car in the first impact became the struck car in the second impact, and the struck car from the first impact became the striking car in the second impact. In the first impact the cars were in standard ride height condition with the bumper systems aligned to ensure stable engagement beam to beam.

For the second impact pair (with the striking and struck cars swapped over) an underride condition was simulated. Typical brake dive results in the vehicle's front pitching downwards by 20 to 80mm. Rear lift is often less, being in the region of 10 to 40mm. In order to ensure that the beams in this underride condition did not engage, a vertical offset of 56mm was required. Therefore the front springs of the striking vehicle were compressed by 28mm and the rear of the struck vehicle lifted by 28mm, resulting in an offset of 56mm overall.

All crashes used a full overlap. However, the 16 km/h delta-v crash was repeated (with new test vehicles) using a 50% offset. This was undertaken to look at the influence of offset crashes where only a single side structural element was involved. This crash was again repeated in the underride condition. Only the 25 km/h

engagement crash was undertaken since the underride condition was deemed potentially unsafe for laboratory staff and a risk of vehicle rollover was identified at this speed. The results of these crash tests are seen in Table 1.

The specific damage pattern for the different collisions has been analyzed and a matrix of questions has been generated. This questioning system covers firstly the damage severity; and secondly the engagement and underride situation. [42], [43]

Table 1: Generic crash tests performed for damage severity analysis

TestNo	Underride/ Engagement	Impact velocity [km/h]	Post impact vel bullet [km/h]	delta-v bullet [km/h]	delta-v target [km/h]	Separation velocity [km/h]	Restitution
WG01-01E	E	1.8	0.3	-1.5	1.5	1.2	0.66
WG03-3E	E	6.2	1.6	-4.6	4.7	3.1	0.50
WG13-05E	E	10.1	2.4	-7.7	8.2	5.8	0.58
WG11-08E	E	16.2	5.8	-10.4	9.9	4.1	0.25
WG09-10E	E	20.1	-	-	12.2	-	-
WG07-12E	E	24.2	9.5	-14.7	14.5	5.0	0.21
WG05-16E	E	32.2	13.8	-18.4	18.7	4.9	0.15
WG02-01U	U	1.8	0.5	-1.4	1.4	0.9	0.51
WG04-3U	U	6.2	2.2	-4.0	3.8	1.6	0.26
WG14-05U	U	10.1	3.1	-7.0	6.8	3.8	0.37
WG12-08U	U	16.2	6.1	-10.1	9.6	3.5	0.22
WG10-10U	U	20.1	8.2	-11.9	11.5	3.3	0.16
WG08-12U	U	24.2	9.6	-14.6	13.5	3.9	0.16
WG05-16U	U	32.2	11.7	-20.5	16.0	4.4	0.14

The visible damage can be quite different at the same or similar velocity change for bumper engagement (Fig. 6) and underride collisions (Fig. 5). In the underride situation strong vehicle structures are not aligned and especially for the striking vehicle large deformations will occur as soft structures are involved in the contact. In the bumper engagement situations strong structures are involved in the contact and the visible damage might be low, however, structures underneath the bumper might still be deformed but these deformations might be hidden by the bumper cover (Fig. 6).

Fig. 5: 11.5 km/h delta-v collision underride

Fig. 6: 12.2 km/h delta-v collision bumper engagement

The damage severity description is then converted to a range of deformation energies for the two vehicles involved in the accident. The deformation energy is expressed as energy equivalent speed (EES). The damage severity description is also used to determine if underride or engagement of the vehicles occurred. This is further used as a modifier in the calculation and influences the damage severity level.

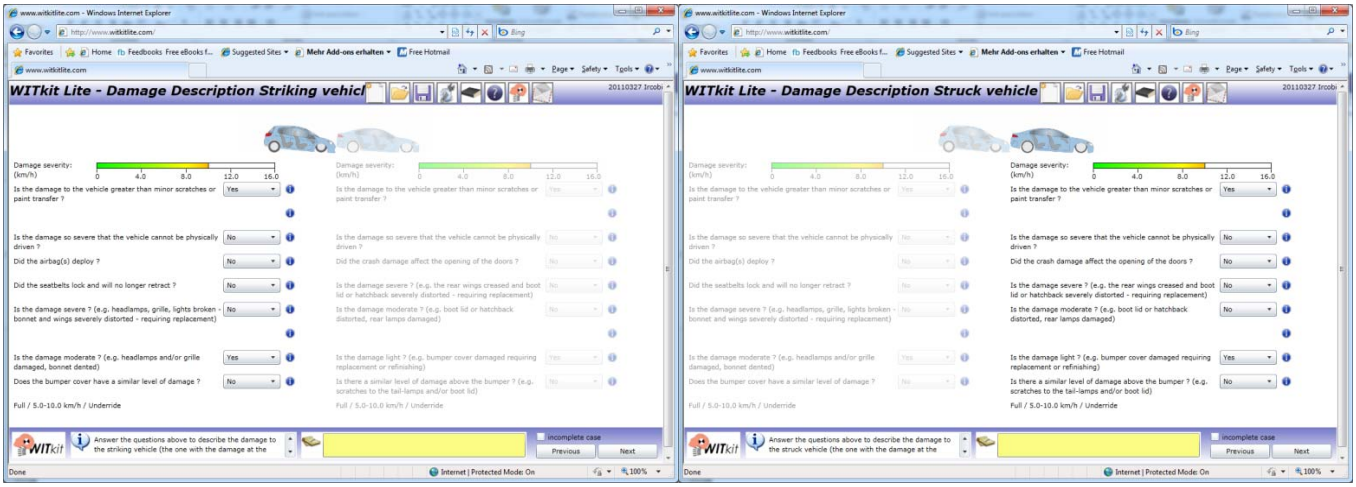

Fig. 7: Damage severity estimation for striking (left) and struck (right) vehicle

Delta-v calculation

Once the damage severity is evaluated the velocity change and post impact velocities for the vehicles can be calculated based on conservation of energy and linear momentum. To take into account that the amount of elasticity in the collision (restitution) is significantly higher for lower impact speeds than for higher impact speeds, a constant separation velocity is used for the calculation. The dependency of separation velocity and coefficient of restitution in the above crash tests is displayed in Fig. 8. The mass of the occupants is also considered in the calculation.

Conservation of linear momentum:

$$m_1 \cdot v_1 + m_2 \cdot v_2 = m_1 \cdot v_1^{\varepsilon} + m_2 \cdot v_2^{\varepsilon} \qquad (1)$$

Conservation of energy:

$$\frac{m_1 \cdot v_1^2}{2} + \frac{m_2 \cdot v_2^2}{2} = W_{Def\,1} + W_{Def\,2} + \frac{m_1 \cdot v_1^{\varepsilon 2}}{2} + \frac{m_2 \cdot v_2^{\varepsilon 2}}{2} \qquad (2)$$

$$W_{Def\,1} = \frac{m_1 \cdot BES_1^{\,2}}{2} \qquad (3)$$

$$W_{Def\,2} = \frac{m_2 \cdot BES_2^{\,2}}{2} \qquad (4)$$

Separation velocity:

$$v_{sep} = v_2^{\,c} \quad v_1^{\,c} \qquad (5)$$

Where (index 1 striking vehicle, index 2 is struck vehicle):

v_1, v_2	pre impact velocities (m/s)
v_1^c, v_2^c	post impact velocities (m/s)
m_1, m_2	vehicle mass (kg)
$W_{Def\,1}, W_{Def\,2}$	deformation energy (J)
BES_1, BES_2	energy equivalent speed (m/s)
v_{sep}	separation velocity (m/s)

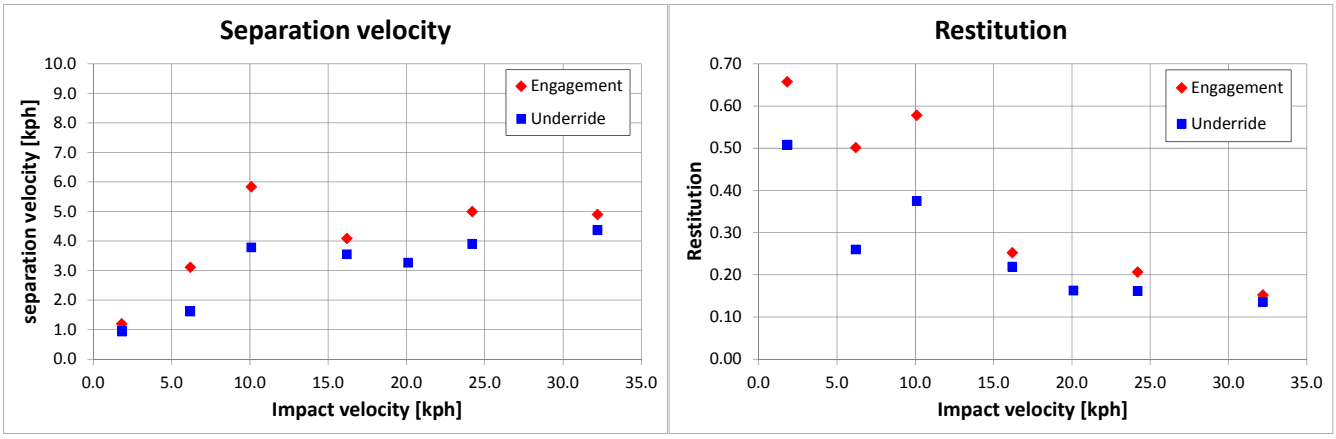

Fig. 8: Separation velocity and coefficient of restitution of the crash tests performed

Risk calculation

In the first step the base risk is calculated based on damage severity, vehicle data and seat rating. This calculation uses a delta-v calculation as described above with a constant separation velocity of 4 km/h. The separation velocity was derive from the test data in Fig. 8, a higher separation velocity would result in a higher coefficient of restitution and a higher amount of elasticity in the collision in general. The use of a constant separation velocity automatically adjusts restitution depending on the relative velocity of the vehicles. A fuzzy expert system is then used to combine delta-v and seat rating to derive the base risk. As the inputs from the user for damage severity cannot be accurate to a single figure, a range for the damage severity is used based on the damage specification. The system then uses this range for all further calculations. For this reason all calculated risk values are presented as ranges as well.

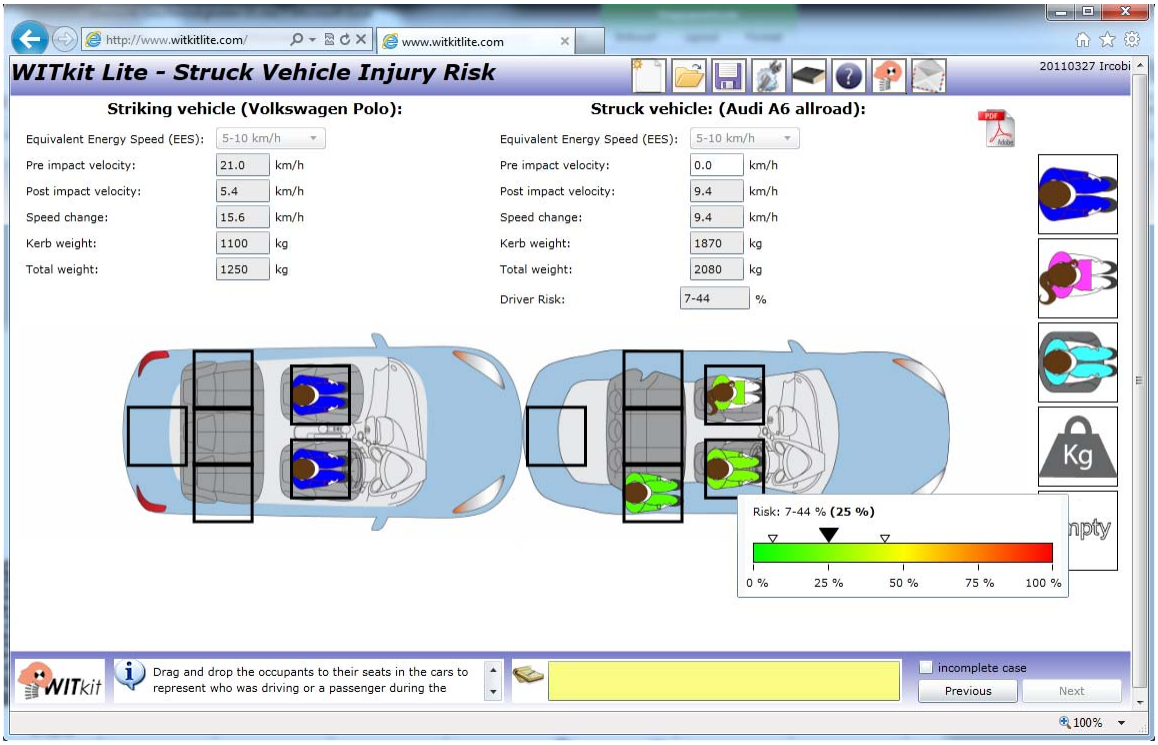

Fig. 9: WITkit risk calculation

In the second step this base risk is combined with modifiers to take additional factors into account which may increase or decrease the risk of getting injured.

Table 2: Modifiers used and effect of modifiers on risk calculation

Modifiers	++	+	0	-	--
Seat rating	Poor, Marginal		Acceptable		Good
Occupant position	Driver		All other seated positions		
Gender	Female		Male		
Offset			No Offset	Offset	
Underride/Engagement			Engagement	Underride	
Awareness				Awareness	
Out of position (OOP)		OOP	Not OOP		

The fuzzy expert system first converts discrete values for the inputs (delta-v, seat rating) into degrees of membership to the specific membership functions. This process is called fuzzyfication. The membership functions used for the inputs and outputs are shown in Fig. 10 and Fig. 11. Using a set of rules described below, the inputs are combined to determine membership to the output distributions. This way of representing knowledge has shown to be easy to handle and suitable to express expert knowledge.

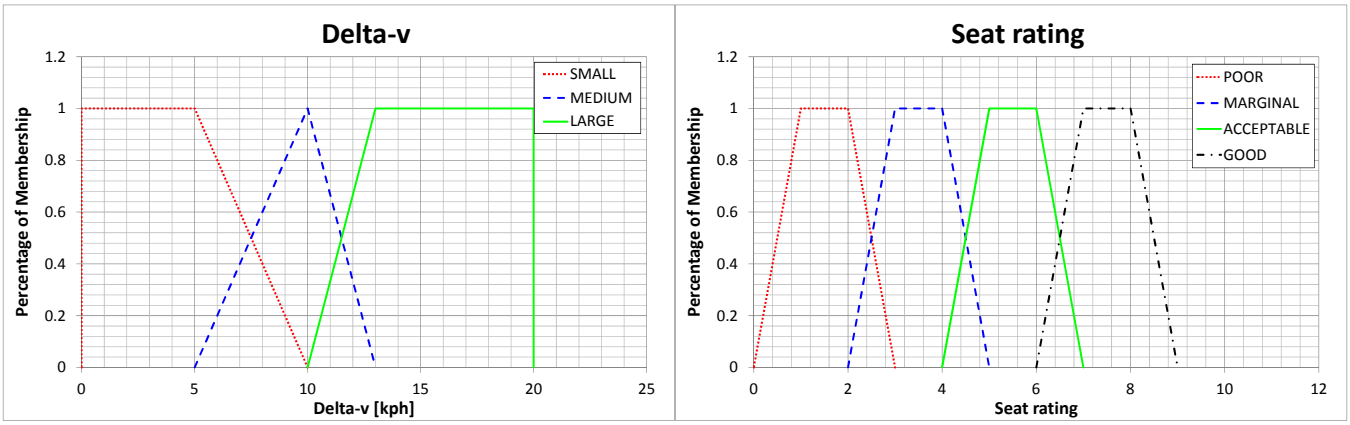

Fig. 10: Membership functions for the classification of delta-v and IIWPG Seat rating

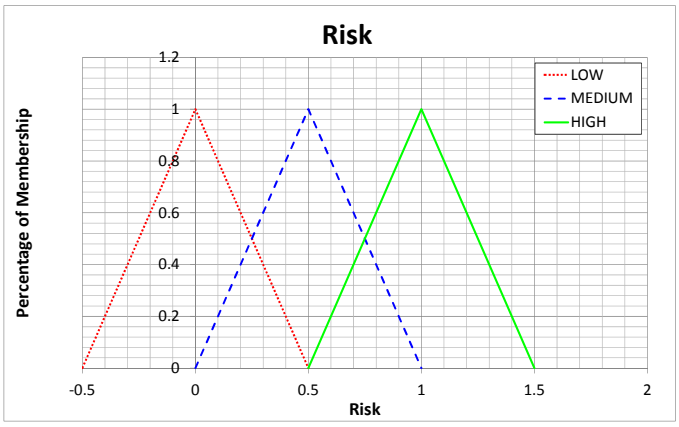

Fig. 11: Membership functions for the classification of risk

The basic rules used in the expert system to combine delta-v and seat rating to estimate the base risk factor are shown in Table 3. A certain delta-v value for example is now classified as small, medium or large with certain degrees of membership to these classes. The evaluation of the rules works with these percentages of membership deriving degrees of membership to the output classes (risk low, medium and high). To get a discrete value for the risk factor a de-fuzzyfication process is used, which determines a risk value based on degrees of membership to the individual classes.

Table 3: Rules used to combine inputs and outputs of the expert system

No	Rule
1	IF DELTAV = SMALL AND SEATRATING = POOR THEN RISK = LOW+
2	IF DELTAV = MEDIUM AND SEATRATING = POOR THEN RISK = MEDIUM+
3	IF DELTAV = LARGE AND SEATRATING = POOR THEN RISK = HIGH+
4	IF DELTAV = SMALL AND SEATRATING = MARGINAL THEN RISK = LOW+
5	IF DELTAV = MEDIUM AND SEATRATING = MARGINAL THEN RISK = MEDIUM+
6	IF DELTAV = LARGE AND SEATRATING = MARGINAL THEN RISK = HIGH+
7	IF DELTAV = SMALL AND SEATRATING = ACCEPTABLE THEN RISK = LOW
8	IF DELTAV = MEDIUM AND SEATRATING = ACCEPTABLE THEN RISK = MEDIUM
9	IF DELTAV = LARGE AND SEATRATING = ACCEPTABLE THEN RISK = HIGH
10	IF DELTAV = SMALL AND SEATRATING = GOOD THEN RISK = LOW-
11	IF DELTAV = MEDIUM AND SEATRATING = GOOD THEN RISK = MEDIUM-
12	IF DELTAV = LARGE AND SEATRATING = GOOD THEN RISK = HIGH-

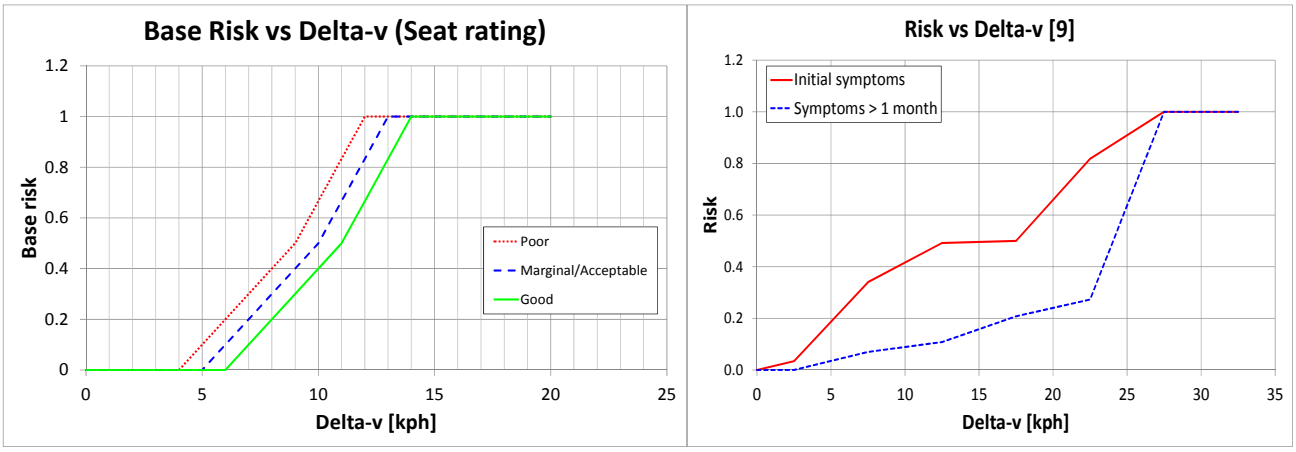

Fig. 12: Sample base risk distributions for different delta-v values depending on seat rating compared to published risk factors [9]

III. RESULTS

This proposed system to determine the probability of whiplash injury in low speed rear end collisions has been tested operationally on several thousand cases. Early results indicate that it is an effective mechanism for testing the validity of claims relating to whiplash.

So far the system parameters are set to be conservative, which means that where there is doubt, a higher risk is displayed so that the evaluation does not underestimate risk. In the situation of missing data (e.g. seat rating) a worst case scenario is used so risk is not underestimated.

IV. DISCUSSION/CONCLUSION

The evaluation of the results showed that a high number of cases with extremely low injury risk can be separated from those cases where a whiplash injury can be expected. In this way approximately 70% of the cases can be categorised which guarantees a much more effective claims handling for rear end whiplash cases. For example, in cases with a very low risk of whiplash injury the claims are identified for further investigation by the claims handlers. Conversely, for cases with a high risk of whiplash injury the claim can be more quickly passed to departments involving medical support, since early treatment of whiplash injuries is often effective in reducing the long term prognosis.

The development of this tool is an ongoing process and additional factors of influence will be incorporated into the system to reflect more detailed knowledge about accident and risk correlations.

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VI. APPENDIX:

Damage severity questions for frontal damage:

- Is the damage to the vehicle greater than minor scratches or paint transfer ?
- Is the damage extremely minor ie. No damage sustained at all or no parts require refinishing ?
- Is the damage so severe that the vehicle cannot be physically driven ?
- Did the airbag(s) deploy ?
- Did the seatbelts lock and will no longer retract ?
- Is the damage severe ? (e.g. headlamps, grille, lights broken - bonnet and wings severely distorted - requiring replacement)
- Does the bumper cover have a similar level of damage ?
- Is the damage moderate ? (e.g. headlamps and/or grille damaged, bonnet dented)
- Does the bumper cover have a similar level of damage ?

Damage severity questions for rear damage:

- Is the damage to the vehicle greater than minor scratches or paint transfer ?
- Is the damage extremely minor ie. No damage sustained at all or no parts require refinishing ?
- Is the damage so severe that the vehicle cannot be physically driven ?
- Did the crash damage affect the opening of the doors ?
- Is the damage severe ? (e.g. the rear wings creased and boot lid or hatchback severely distorted - requiring replacement)
- Is the damage moderate ? (e.g. boot lid or hatchback distorted, rear lamps damaged)
- Is there a similar level of damage above the bumper ? (e.g. broken tail-lamps and dented tailgate or boot lid)
- Is the damage light ? (e.g. bumper cover damaged requiring replacement or refinishing)
- Is there a similar level of damage above the bumper ? (e.g. scratches to the tail-lamps and/or boot lid)