Definition of Peak Virtual Power Brain Trauma Variables for the use in the JSOL THUMS injury post-processor web-based estimator

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1 Introduction

Road traffic accidents and falls are catastrophic events leading to serious injury and in some cases fatality. The dichotomy is that traumatic injuries are assessed using the Abbreviated Injury Scale (AIS), which is a measurement of the probability of death, whilst the engineering tools available to support the understanding of injury causation rely on engineering measurements of stress and strain. Further to this, the problem of ageing is not adequately dealt with using existing engineering tools. The research proposes the development of a generic mathematical injury severity model, based on Peak Virtual Power (PVP) [1], to establish relationships between AIS, ageing and collision speed. This method, newly implemented JSOL THUMS injury post-processor web-based estimator, has the ability to calculate all AIS levels from the white and grey matter and is defined as a polynomial function. This paper explains the underpinning of the Peak Virtual Power theory, as well as provide the coefficients to calculate brain injury severity under blunt trauma impact.

2 Method

A mathematical model is derived, tested and compared against cases where the Postmortem (PM) is known. Injuries are non-reversible phenomenon and can be captured by the Second Law of thermodynamics, relating to degeneration and decay. By using the Clausius-Duhem inequality, from the rate dependent form of the 2nd Law (Equation 1), it was demonstrated that AIS was proportional to the maximum rate of entropy inside any soft tissue.

$$\sigma : \dot{\varepsilon} - \rho\left(\dot{f} + s\dot{T}\right) - \frac{1}{T} q.\nabla T \geq 0$$

Equation 1: Clausius-Duhem equality [1]

This mathematical response is called Peak Virtual Power (PVP) [1] and is illustrated in Figure 1. The injury is continuously increasing, never to be reversed. This is mathematically illustrated in Equation 2.

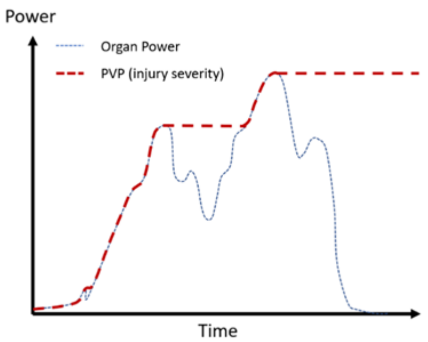

Figure 1: Evolution of injury severity against time [2]

PVP is generic (global), objective (theoretical), not subjective (empirical), dimensionally meaningful (not as HIC) and unique (peak values are unique).

Peak Virtual Power = $max(\sigma \cdot \dot{\varepsilon}) \propto AIS$

Equation 2: Relationship between Peak Virtual Power and Trauma Severity

By equating the organ kinetic energy and its deformation energy during the impact, it can be shown that AIS depends on the geometry of the organ at the time of impact, its material properties (age), the stiffness of the impacted surface and the velocity squared (Equation 3). The full derivation of this equation is provided in Appendix 1 and Appendix 2.

$$AIS \propto PVP = \frac{A_p}{2V_p}\sqrt{\left(\frac{\rho_p E_p \rho_c E_c m_p}{\rho_p E_p m_c + \rho_c E_c m_p}\right)}{v_{t_0}}^2$$

Equation 3: Algebraic Derivation of Trauma Severity

Note that in the case of severe injuries, brain AIS has been observed to also relate to the cubic of the velocity (over sampling), hence the user can use either a quadratic of a cubic interpolation.

Where, in the case of a pedestrian collision, for example:

- 'A_p' represents the contact of the Area of the organ, which is impacting the vehicle. This Area will change according to the kinematics of the pedestrian while wrapping around the vehicle profile
- 'V_p' is the volume of the organ (constant)
- 'ρ_p' is the density of the organ
- 'ρ_c' is the density of the contact surface
- 'm_p' is the organ mass
- 'm_c' is the vehicle mass
- 'E_p' represents the Modulus of Elasticity of the organ (Young's / Bulk Modulus)
- 'E_c' represents the stiffness of the vehicle
- 'v_{t0}' is the organ impact speed, at the time of contacting the vehicle surface. These velocities can be computed during the accident reconstruction phase.

The outcomes of Equation 3 are sensible, as the higher the impact speed 'v', the higher the injury, the stiffer the contact stiffness, the higher the injury and the heavier the contacted object, the higher the injury.

It is proposed to test the response of this method and provide the parameters for the polynomial function to extract all the AIS levels of brain white and grey matter.

3 Method

The research used the head model of THUMS 4.01 with the material properties of the brain white and grey matter from THUMS 4.02. In order to balance accuracy and runtime, it was judged that the average element size of THUMS 4.01 was adequate to extract an injury, whilst considering a reasonable post-processing time. This paper will refer to the THUMS 4.01M (modified model). This means that the polynomial parameters values provided in this paper are only available for this head model configuration, however the method provided can be applied to any human head models.

The method tested in the first instance the real-life relevance of the mathematical trauma response as a function of age, as material properties and brain volume change, as well as the effect of the impact direction, as dictated in Equation 3. In order to do this, a THUMS4.01M was subjected to pendulum impact in frontal, lateral and occipital directions. The base AIS 4 trauma curve is created using the methodology given in Appendix 3. It is constructed by using the first element ID, at the highest impact speed of the impact range, for which the MPS value exceeds the maximum AIS threshold level.

The human brain is also subject to shrinking with age [3]. Previous work has generated a regression relationship linking brain volume and age [4], which is illustrated in Equation 4. In the model used in this study, the brain white and grey matter were scaled about the brain centre of gravity to adjust for age. The grey and white matter were both scaled together with the same ratio (Table 1).

$$V_{age} = -0.0037 * age + 1.808$$

Equation 4: Relationship between Brain Volume and age

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Brain Volume	Age Group	20-29	30-39	40-49	50-59	60-69	70-79
	Brain Volume SF	1.022	1.000	0.978	0.956	0.934	0.912
	SF in all directions	1.007	1.000	0.993	0.985	0.977	0.970

Table 1: Brain scaling ratios as a function of age

The method reviewed a case of a fall and prove that the PVP method can compute the correct trauma severity and location and propose the best LS-Dyna DATABASE parameters to optimise the trauma predictions. During this phase, the JSOL THUMS injury post-processor web-based estimator was validated against the computer routines derived at Coventry University. It has to be noted that during the impact, elements deform, stretch and change shape, however their volume remains constant. It is called a “Lagrangian” representation of the problem. The consequence, is that, should bleeding occur in the real-world accident, i.e. loss of volume due to the blood escaping the organ, then the finite elements will not be able to capture this. This is an inherent limitation which became apparent upon the derivation of Equation 3. Looking at Equation 3, should bleeding occur, then V_p will reduce. As a consequence PVP, and consequently AIS, will increase, which is as expected. On the other hand, should bleeding not been observed, then Equation 3 should provide the correct answer. In order to investigate bleeding, it is proposed to include the effects of Subdural Hematoma (SDH) in the grey matter region, which has been defined for an MPS value of 25.5% [5]. The problem then is to assert the AIS outcome from bleeding, as a small bleed could add ‘1’ AIS level to the current trauma severity computed or ‘2’ if the bleeding is judged to be important by the pathologist [6]. In some cases, the quantity of blood loss could be subjective, hence for the purpose of being consistent and conservative, all instances of blood loss for the purpose of this study have a ‘+1’ AIS increment on the base AIS computed [7].

4 Results

4.1 Real-life relevance to the Peak Virtual Power Method

By performing occipital head impacts with a varying impact speeds on the THUMS4.01M model, it was then possible to extract how much power is required to initiate the onset of the injury, which can be observed when the Maximum Principal Strain exceed 26% for the grey matter (Figure 2). **These polynomial parameters (representing AIS 4) of the calibration line in Figure 2 are the parameters to enter in the JSOL THUMS injury post-processor web-based estimator.**

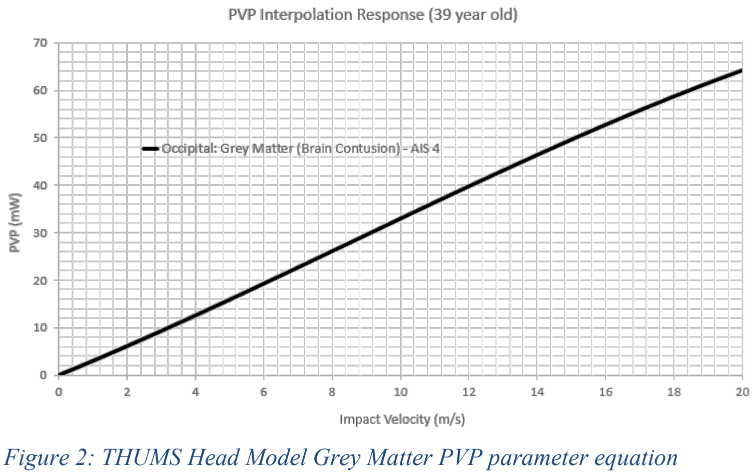

Figure 2: THUMS Head Model Grey Matter PVP parameter equation

The other AIS functions are internally computed, by the JSOL THUMS injury post-processor web-based estimator, by scaling the AIS levels by the ratios of the cubes, i.e. AIS5 scales the polynomial parameters by $5^3/4^3$, AIS3 by $3^3/4^3$ etc.. (Figure 3).

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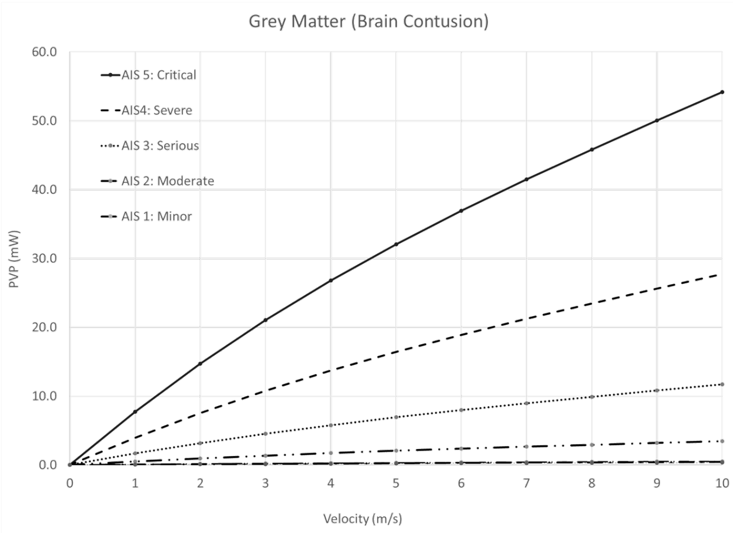

Figure 3: Relationship between PVP, AIS and Impact Velocity

The real-life trauma responses, based on Equation 3 were reflected upon and they confirmed that:

- Less power is required to injure an older person than a younger one (Figure 4), i.e. as observed in real life [2].

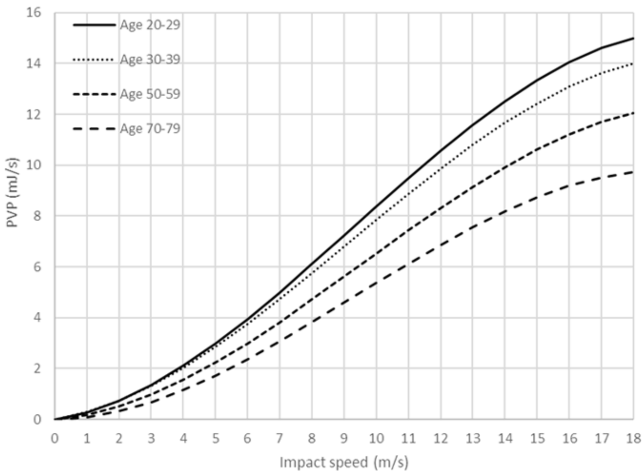

Figure 4: Brain White Matter (DAI) Injury response as a function of age [2]

- The trauma response depends on the direction of impact. It takes more power to inflict injury when impacting the forehead that the temple or the back of the head (Figure 5).

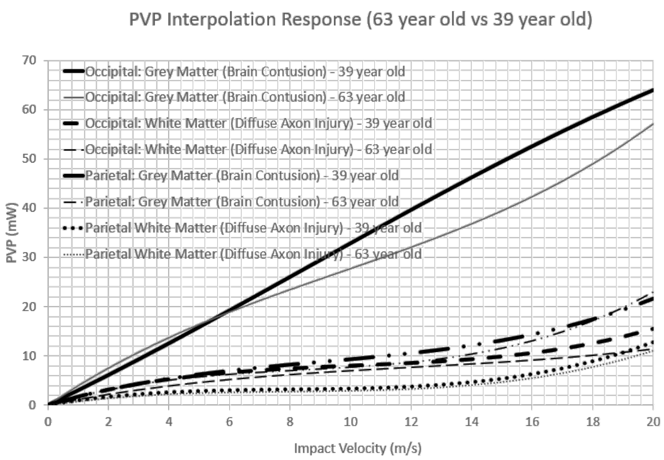

Figure 5: Trauma, Direction of impact and age [2]

Both statements relate to what is observed in real-life.

4.2 Application to a fall.

A fall case was studies, relating to a fatal occipital fall of a 63 year old estimated at 6.0m/s. Using the PVP method, it was possible to calculate the exact AIS and the trauma location. The injury severity is illustrated in Figure 6 and Figure 7 comparing the JSOL and the Coventry University tools. It can be observed that the THUMS4.01M's trauma severities fall within the post mortem results.

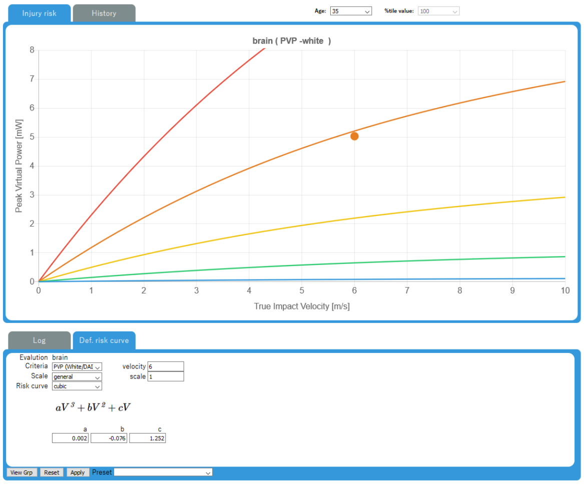	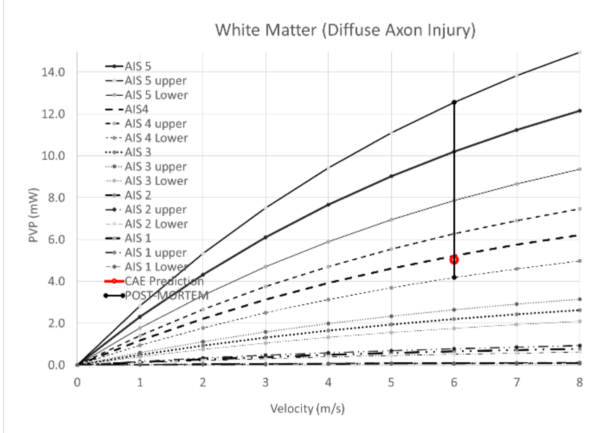
JSOL THUMS injury post-processor web-based estimator (White Matter) – orange dot	Coventry University PVP Trauma Calculator (White Matter) – red dot

Figure 6: Comparison between the JSOL and Coventry University Trauma Tool predictions (White Matter)- PVP=5.03mW

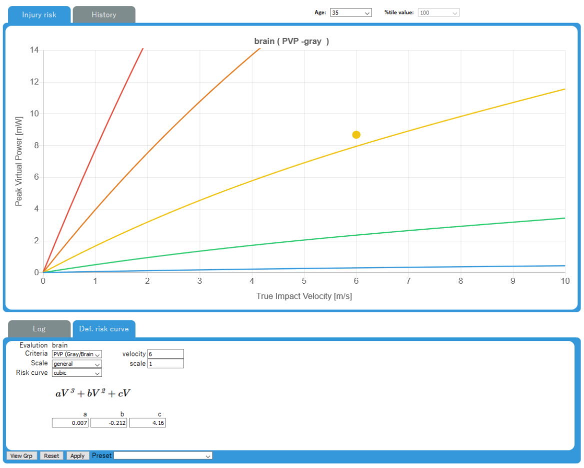	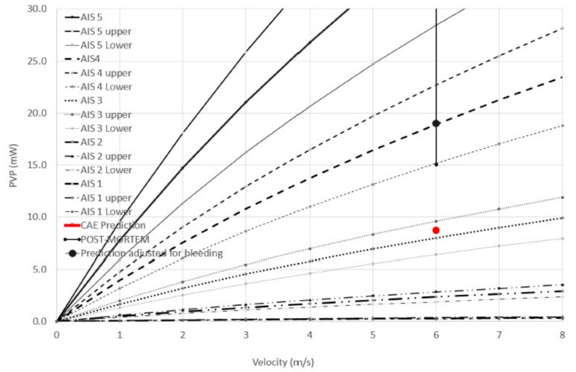
JSOL THUMS injury post-processor web-based estimator (Grey Matter) – orange dot	Coventry University PVP Trauma Calculator (Grey Matter). Note that the AIS of the red dot was augmented by +1, as bleeding was suggested because of a MPS greater than 25.5%

Figure 7: Comparison between the JSOL and Coventry University Trauma Tool predictions (Grey Matter). PVP=8.68mW

As PVP is differentiating the Von-Mises strains, it was noted that the JSOL and Coventry University results converged with the setting provided in Appendix 4.

The full calibration settings of THUMS4.01M, as function of age and impact directions, are provided in Appendix 5.

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5 Conclusions

The research has highlighted the use of a new soft tissue trauma injury extraction method, applied to brain trauma, using the Peak Virtual Power method, which is based on the 2nd law of irreversible thermodynamics, relating to inefficiency, degeneration and decay. Considering the physics, PVP is generic (global), objective (theoretical), not subjective (empirical), dimensionally meaningful, and unique (Peak values are unique). An algebraic derivation of PVP has shown that it could predict brain trauma severity as a function of impact direction, speed and age (based on material property degradation and volume reduction). In order to balance accuracy and runtime, the research used the mesh of THUMS 4.01 and replaced its white and grey matter material properties with the ones of THUMS 4.02, leading to model THUMS 4.01M Head Model ("M" for Modified). The PVP method is now available in the JSOL THUMS injury post-processor web-based estimator, and this paper has proven that the estimator matches the research work conducted at Coventry University and can predict accurately the exact AIS response on white and grey matter trauma injuries, checked against one Post Mortem.

6 Future Work

This method has also the capabilities to be applied in all human soft tissue injury severity estimations and is yet to be implemented for other organs.

7 Acknowledgements

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8 References

[1] Sturgess C., et al. (2001) "The relationship of AIS to peak virtual power". Annual proceedings / Association for the Advancement of Automotive Medicine. 45. 141-57

[2] Bastien, C., et al. (2020) "Computing Brain White and Grey Matter Injury Severity in a Traumatic Fall", Journal of Mathematical and Computational Applications. Math. Comput. Appl. 2020, 25(3), 61

[3] Svennerholm, L., Bostrom, K., Jungbier, B. (1997) "Changes in weight and compositions of major membrane components of human brain during the span of adult human life of Swedes." Acta Neuropathol 94, 345–352 (1997). https://doi.org/10.1007/s004010050717

[4] Sack, I., Streitberger, K.-J., Krefting, D., Paul, F. & Braun, J. 2011. The influence of physiological aging and atrophy on brain viscoelastic properties in humans. PloS one, 6, e23451.

[5] Oeur, A., Karton, C., Post, A., Rousseau, P., Hoshizaki, B., Marshall, S., Brien, S., Smith, A., Cusimano, M., Gilchrist, D. (2015) "A comparison of head dynamic response and brain tissue stress and strain using accident reconstructions for concussion, concussion with persistent postconcussive symptoms, and subdural hematoma" , J Neurosurg. 2015 Aug; 123(2):415-22. doi: 10.3171/2014.10.JNS14440. Epub 2015 Apr 24

[6] Perel, P., Roberts, I., Bouamra, O., Woodford, M., Mooney, J., Lecky, F., (2009) "Intracranial bleeding in patients with traumatic brain injury: A prognostic study". BMC Emergency Medicine volume 9, Article number: 15 (2009)

[7] Bastien, C., Sturgess, C. N., Davies, H., Hardwicke, J., Cloake, T., & Zioupos, P. (2021). A Generic Brain Trauma Computer Framework to Assess Brain Injury Severity and Bridging Vein Rupture in Traumatic Falls. Journal of Head Neck & Spine Surgery, 4(4), 47-60. https://doi.org/10.19080/jhnss.2021.04.555641

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Appendix 1: Algebraic Derivation of Trauma Severity (1/5)

This section is a mathematical proof to the derivation of the trauma severity, based on Peak Virtual Power. Three scenarios will considered: (1) pedestrian is deformable and the vehicle rigid; (2) vehicle and pedestrian sharing the same criteria; and (3) vehicle and pedestrian sharing different criteria in order to derive trauma severity. The rigour and validity of the final derivation of equation (3) will be verified by confirming that (1) and (2) can be re-derived by reducing the impact assumptions.
The proof concludes that Trauma is fundamentally proportional to the square of the velocity (also proven by accident data, $R^2 > 0.9$). The use of an existing empirical data set for pedestrian accidents has shown that this relationship maybe further refined by including an additional velocity term to provide a cubic relationship ($R^2 > 0.95$). The authors chose the cubic approach for the work reported in this paper, while the squared relationship would have also been acceptable.

1. Assuming that the pedestrian is deformable and the vehicle rigid

The impact kinetic energy of the pedestrian at t_0, is converted into strain energy (deformation) and kinetic energy. This is a time dependant relationship. V_{t0} is the impact speed, while σ_t and v_t are the stress and speed generated inside the system as the time passes.

$$\frac{1}{2}m{v_{t_0}}^2 = \frac{{\sigma_t}^2}{2E}vol + \frac{1}{2}m{v_t}^2$$

VP (virtual power) is the product of the stress and the strain rate. If the equation above is rearranged to make stress the subject and then multiplied through by strain rate the result is an equation for VP that is time dependent:

$$\sigma\dot{\mathcal{E}} = VP(t) = \frac{v_t}{L}\sqrt{\rho E\left({v_{t_0}}^2 - {v_t}^2\right)}$$

PVP is the maximum value of VP(t). VP(t) is maximum (proven in Appendix 2) when:

$$v_{t_0} = v_t\sqrt{2}$$

Giving

$$PVP = \frac{v_{t_o}}{\sqrt{2}L}\sqrt{\rho E\left({v_{t_0}}^2 - \left[\frac{v_{t_0}}{\sqrt{2}}\right]^2\right)}$$

Reducing to

$$PVP = \frac{1}{2L}\sqrt{\rho E}{v_{t_0}}^2$$

Conclusion: In this configuration, trauma severity, or PVP, is proportional to the square of the velocity (aligned with impact direction), however the trauma severity would be lower if the vehicle is not rigid, i.e. deforms, hence the next formulation, considering the vehicle deformable.

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Appendix 1: Algebraic Derivation of Trauma Severity (2/5)

2. Assuming that the pedestrian and the vehicle share the same stiffness characteristics

If a constant stiffness 'E' is assumed for the vehicle and the pedestrian, then:

$$\frac{1}{2}m{v_{t_0}}^2 = \frac{{\sigma_t}^2}{2E}vol + \frac{{\sigma_t}^2}{2E}vol + \frac{1}{2}m{v_t}^2$$

This then becomes

$$\sigma = \sqrt{\frac{m\left({v_{t_0}}^2 - {v_t}^2\right)}{2 * \frac{vol}{E}}}$$

Taking account that density = mass / volume, then:

$$\sigma = \sqrt{\frac{m\left({v_{t_0}}^2 - {v_t}^2\right)}{2 * \frac{m}{E\rho}}}$$

Reducing to:

$$\sigma = \sqrt{\frac{\rho E\left({v_{t_0}}^2 - {v_t}^2\right)}{2}}$$

Hence, if the collision partners share the same characteristics the stress, in comparison to the previous example, is reduced by $\sqrt{2}$.
As VP is the product of the stress and the strain rate:

$$\sigma\dot{\varepsilon} = \mathrm{VP} = \frac{v_t}{L}\sqrt{\frac{\rho E\left({v_{t_0}}^2 - {v_t}^2\right)}{2}}$$

Note that the strain rate is the same for both collision partners in this example. Further the maximum value can be found (Appendix 2) when:

$$v_{t_0} = v_t\sqrt{2}$$

Giving

$$PVP = \frac{1}{2L}\sqrt{\frac{\rho E}{2}}{v_{t_0}}^2$$

Again, trauma severity is proportional to the square of the impact velocity (aligned with impact direction). It can be here noted that when two partners that both deform, that PVP is lower, which is logical. The stiffness of the vehicle is therefore important.

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Appendix 1: Algebraic Derivation of Trauma Severity (3/5)

3. Assuming that the pedestrian and the vehicle share the different stiffness characteristics

Assuming that the collision partners have different stiffness characteristics (c is car and p is pedestrian):

$$\frac{1}{2}m{v_{t_0}}^2 = \frac{{\sigma_t}^2}{2E_c}vol_c + \frac{{\sigma_t}^2}{2E_p}vol_p + \frac{1}{2}m{v_t}^2$$

The full equation where both collision partners are deformable and have different values of E is shown below:

$$\sigma = \sqrt{\frac{m\left({v_{t_0}}^2 - {v_t}^2\right)}{\frac{vol_c}{E_c} + \frac{vol_p}{E_p}}}$$

VP is the product of the stress and the strain rate then for the pedestrian, hence:

$$\sigma\dot{\varepsilon}_p = \mathrm{VP} = \frac{v_t}{L_p}\sqrt{\frac{m_p\left({v_{t_0}}^2 - {v_t}^2\right)}{\frac{vol_c}{E_c} + \frac{vol_p}{E_p}}}$$

Taking account that density = mass / volume.

$$VP = \frac{v_t}{L_p}\sqrt{\frac{m_p\left({v_{t_0}}^2 - {v_t}^2\right)}{\frac{m_c}{\rho_c E_c} + \frac{m_p}{\rho_p E_p}}}$$

VP tends to a maximum value (appendix 2) when:

$$v_{t_0} = v_t\sqrt{2}$$

Giving:

$$PVP = \frac{1}{2L_p}\sqrt{\left(\frac{\rho_p E_p \rho_c E_c m_p}{\rho_p E_p m_c + \rho_c E_c m_p}\right)}{v_{t_0}}^2$$

Again, trauma severity is proportional to the square of the vehicle impact velocity (aligned with the impact direction).

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Appendix 1: Algebraic Derivation of Trauma Severity (4/5)

Assuming that L is the ratio between the contact area A and the volume V of the pedestrian.

$$AIS \propto PVP = \frac{A_p}{2V_p}\sqrt{\left(\frac{\rho_p E_p \rho_c E_c m_p}{\rho_p E_p m_c + \rho_c E_c m_p}\right)}{v_{t_0}}^2$$

The equation above is the generic algebraic formulation of trauma severity.
It can be noted that the injury severity is also dependant on the contact area, hence the vehicle profile.

Conclusion AIS is function of:

- the contact area between the vehicle and the pedestrian
- Volume of material supporting the impacted Area impacted
- pedestrian mass, density and stiffness
- vehicle mass, density and stiffness
- Impact speed (speed orthogonal to the impacted structure)
- Ageing, as material properties and volume are age dependant.

4. Verification of the generic algebraic formulation of trauma severity

If both partners have the same characteristics (section 1), then the generic equation reduces to:

$$PVP = \frac{1}{2L_p}\sqrt{\frac{\rho E}{2}}{v_{t_0}}^2$$

If we refer back to previous example (section 2) and assume that collision partner is rigid then:

$$PVP = \frac{1}{2L_p}\sqrt{\left(\frac{\rho_p E_p \rho_c m_p}{\frac{\rho_p E_p m_c}{E_c} + \rho_c m_p}\right)}{v_{t_0}}^2$$

As E_c tends to infinity, the term containing E_c tends to zero and can be discarded, hence:

$$PVP = \frac{1}{2L_p}\sqrt{\left(\frac{\rho_p E_p \rho_c m_p}{\rho_c m_p}\right)}{v_{t_0}}^2$$

Or

$$PVP = \frac{1}{2L_p}\sqrt{\rho_p E_p}{v_{t_0}}^2$$

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Appendix 1: Algebraic Derivation of Trauma Severity (5/5)

5. Generic algebraic formulation of trauma severity and real-life accident evidence

The generic equation below is the Generic algebraic formulation of trauma severity:

$$AIS \propto PVP = \frac{A_p}{2V_p}\sqrt{\left(\frac{\rho_p E_p \rho_c E_c m_p}{\rho_p E_p m_c + \rho_c E_c m_p}\right)}\, {v_{t_0}}^2$$

This equation is compatible with real-life accident published evidence illustrated in Figure 8.

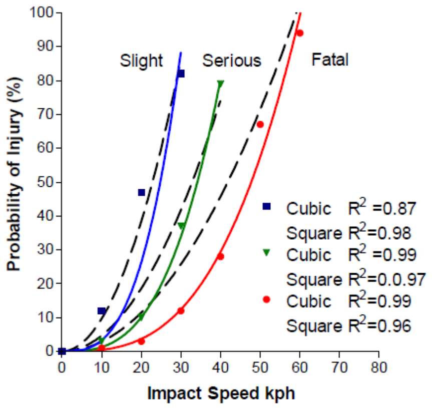

Figure 8: Pedestrian accident cases: relationship between threat to life (AIS) and vehicle impact speed ***Error! Reference source not found.***.

It can be noticed that for serious (AIS3) and fatal accident (AIS4+) that the correlation exponent is at least 0.96 for a squared interpolation and 0.99 for a cubic interpolation. This is showing that there is already a very strong relationship between AIS and the square of the impact velocity, hence proving the generic algebraic formulation of trauma severity derivation is reasonable and representative of the trauma severity representation phenomenon. In the case of fatal injuries, the polynomial fit is already very good (0.96), however it is even more accurate with a cubic exponent, suggesting that the cubic formation can capture more accurately, but marginally more accurately than a squared relationship, the real-life events of the fatality phenomenon, due to the simplification of the equations, assuming a linearity of stiffness and disregarding the non-linear visco-elastic material responses. Hence as the calibration will be based on AIS4, the authors have decided to use a cubic interpolation. Note that this choice does not void the validity of the generic algebraic formulation of trauma severity formulation derived in Appendix 1.

$$AIS \propto PVP = \frac{A_p}{2V_p}\sqrt{\left(\frac{\rho_p E_p \rho_c E_c m_p}{\rho_p E_p m_c + \rho_c E_c m_p}\right)}\, {v_{t_0}}^3$$

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Appendix 2: Derivation of the maximum of VP.

Finding the maximum of:

$$\sigma\dot{\varepsilon} = \mathrm{VP} = \frac{v_t}{L}\sqrt{\frac{\rho E\left({v_{t_0}}^2 - {v_t}^2\right)}{2}}$$

This equation can be re-written as:

$$\mathrm{VP} \propto {v_t}^2\left({v_{t_0}}^2 - {v_t}^2\right)$$

Therefore

$$\mathrm{VP} \propto -{v_t}^4 + {v_t}^2.{v_{t_0}}^2$$

The maximum can be found by differentiating against ${v_t}^2$

$$\frac{d\left({v_t}^4 - {v_t}^2.{v_{t_0}}^2\right)}{d{v_t}^2} = 0$$

Giving:

$$2.{v_t}^2 = {v_{t_0}}^2$$

Hence:

$$\boxed{v_{t_0} = v_t\sqrt{2}}$$

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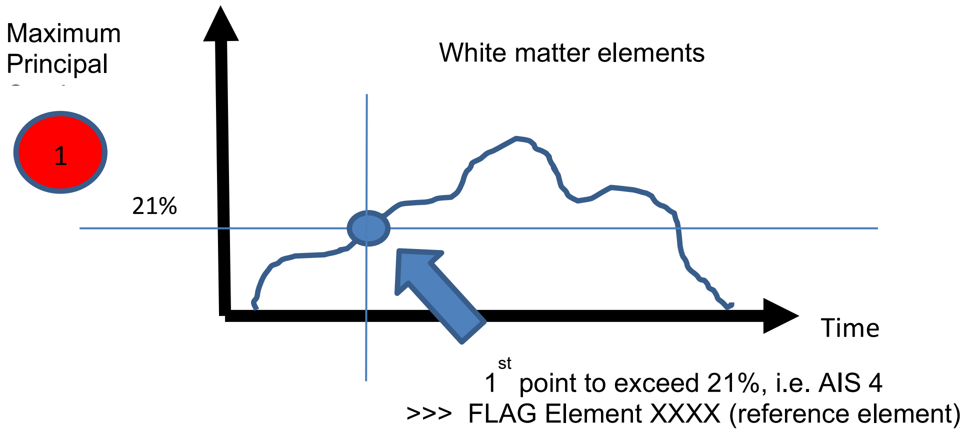
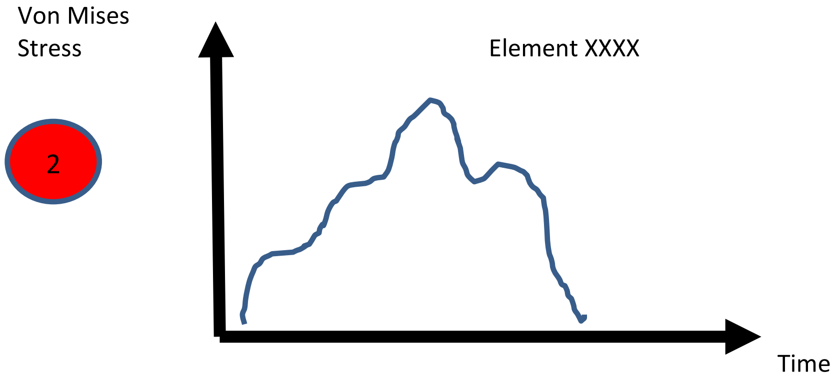
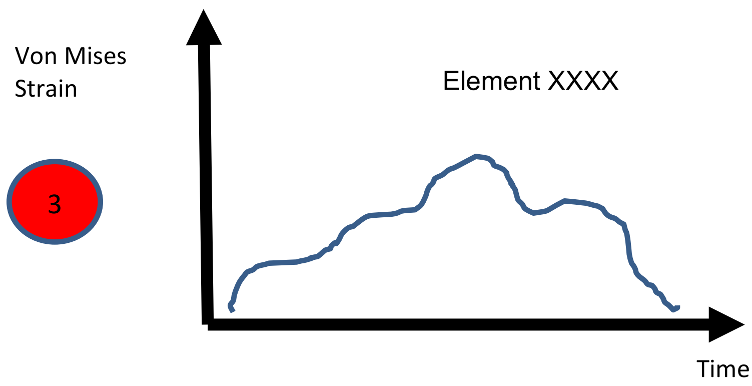
Appendix 3: Creation on the base PVP trauma reference curve (1/2)

In the JSOL THUMS injury post-processor web-based estimator, all trauma reference curves must refer to AIS 4.

Example 1: Maximum Principal Strain: White matter > AIS 4 = 21%







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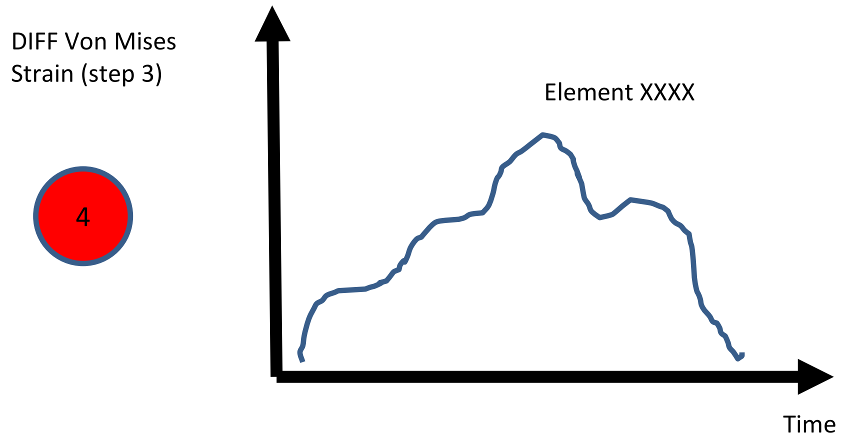
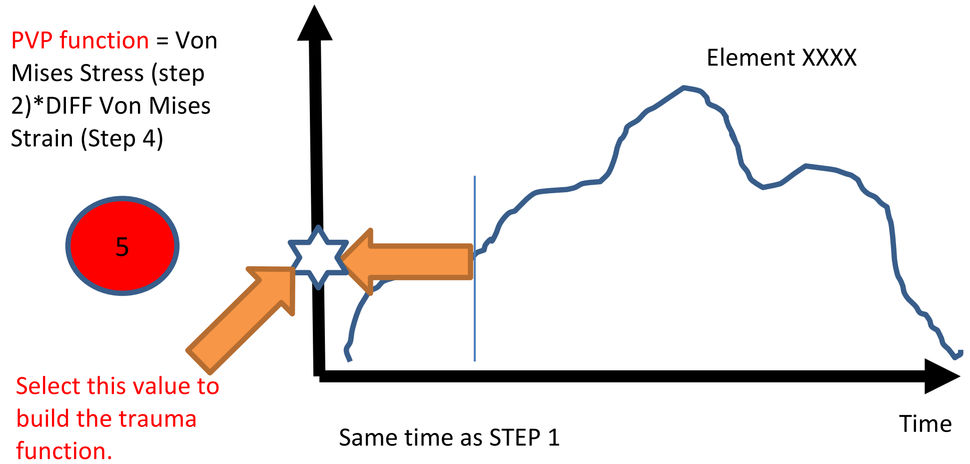
Appendix 3: Creation on the base PVP trauma curve (2/2)





6 Plot PVP as a function of speed. Best fit this function by using a second order polynomial. Third order (over sampling) can also be used.

Example 2: Method if the MPS cut-off value does not relate to AIS 4.

For the grey matter, the Maximum Principal Strain value for AIS 3 is 26%. Repeat the steps 1 to Step 6 to create an AIS 3 PVP trauma reference curve. To convert AIS 3 to AIS 4, all the polynomial terms of the AIS 3 best-fit function must be multiplied by ($4^3/3^3$).

Appendix 4: LS-Dyna DATABASE CARD to extract Trauma from JSOL Tool

```
$ ==============
$ DATABASE cards
$ ==============
$
*DATABASE_ELOUT
   1.0E-5        3        0        1        0        0        0        0
*DATABASE_GLSTAT
   1.0E-4        3        0        0
*DATABASE_MATSUM
   1.0E-4        3        0        1
*DATABASE_NODOUT
   1.0E-5        3        0        1      0.0        0
*DATABASE_BINARY_D3PLOT
   1.0E-4        0        0        0        0
*DATABASE_BINARY_D3THDT
   1.0E-5        0
*DATABASE_EXTENT_BINARY
        0        0        3        1        1        1        1        1
        1        0        0        0        2        0        0        0
        0        0      0.0        0        0        0
        0        0        0
$
```

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Appendix 5: Peak Virtual Power Trauma Interpolation Coefficients

	Head Calibration Values for THUMS4.01 Pedestrian with 4.02 brain material properties					
	WM (white Matter) GM (Grey Matter)	Risk to life	a	b	c	Age Group
Frontal	Brain WM	AIS4	-0.00370	0.10320	0.17430	20-29
	Brain GM	AIS3	0.00130	0.03570	0.35800	
	Brain WM	AIS4	-0.00330	0.09160	0.19760	30-39
	Brain GM	AIS3	0.00110	0.03440	0.37960	
	Brain WM	AIS4	-0.00300	0.08610	0.09190	50-59
	Brain GM	AIS3	0.00190	-0.00270	0.54480	
	Brain WM	AIS4	-0.00290	0.08180	0.00800	70-79
	Brain GM	AIS3	0.00320	-0.05040	0.75700	
Lateral	Brain WM	AIS4	0.00520	-0.12320	1.06370	20-29
	Brain GM	AIS3	0.00260	-0.06440	0.75430	
	Brain WM	AIS4	0.00520	-0.12530	1.06790	30-39
	Brain GM	AIS3	0.00220	-0.05960	0.76890	
	Brain WM	AIS4	0.00440	-0.10600	0.91350	50-59
	Brain GM	AIS3	0.00320	-0.08010	0.80810	
	Brain WM	AIS4	0.00380	-0.09150	0.77700	70-79
	Brain GM	AIS3	0.00330	-0.08360	0.77930	
Occipital	Brain WM	AIS4	0.00550	-0.16730	2.00830	20-29
	Brain GM	AIS3	-0.00080	0.02410	1.27820	
	Brain WM	AIS4	0.00520	-0.15840	1.86570	30-39
	Brain GM	AIS3	-0.00090	0.02330	1.24580	
	Brain WM	AIS4	0.00210	-0.07610	1.25220	50-59
	Brain GM	AIS3	0.00310	-0.08950	1.75490	
	Brain WM	AIS4	-0.00003	-0.01980	0.78370	70-79
	Brain GM	AIS3	0.00580	-0.16580	1.97990	

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