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TNO report

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WitnessMan
The software tool to design, analyse and assess a witness pack with respect to military and medical effects on an (un)protected (dis)mounted soldier

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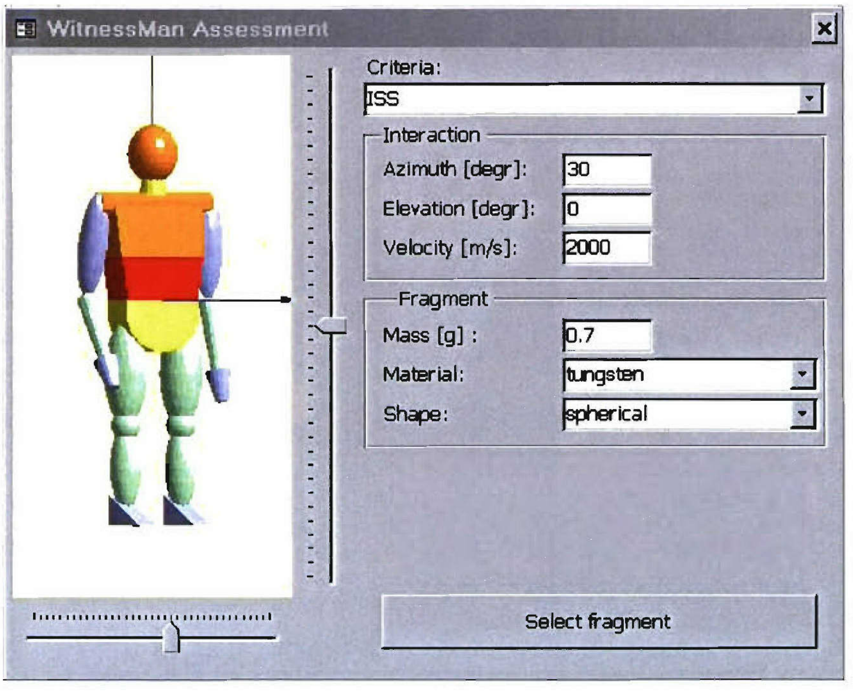
WitnessMan: Het software pakket om een ballistisch getuigenpakket te ontwerpen, te analyseren en de uitwerking tegen (on)beschermde personele doelen te bepalen vanuit militair en medisch oogpunt.

Een getuigenpakket wordt bij experimenteel ballistisch onderzoek gebruikt om de scherfkarakteristieken (achteraf) te kunnen bepalen. Met kwetsbaarheid/letaliteitsonderzoek wordt vervolgens de uitwerking tegen personele doelen bepaald. De ontwikkeling van het softwaresysteem WitnessMan is gericht op het verkorten van de doorlooptijd en het realiseren van een directe terugkoppeling tussen experimenteel ballistisch onderzoek en kwetsbaarheid/letaliteit uitwerking



Probleemstelling

Tijdens experimenteel ballistisch onderzoek is het lastig een indicatie van de uitwerking van de schervenwolk op een (on)beschermde persoon vast te stellen. Een getuigenpakket (Witness Pack, platenrek) is een experimenteel hulpmiddel om tijdens het experiment de schervenwolk 'vast' te leggen. Aan de hand van het schadebeeld, zoals gatgrootte en geperforeerde platen, worden geruime tijd na afloop van het experiment de scherfkarakteristieken bepaald. Dit is invoer in de kwetsbaarheid-/letaliteitanalyses (V/L–analyses) om de uitwerking te simuleren op het doel. De doorlooptijd van het huidige proces is lang, waardoor terugkoppeling van de V/L-analyse naar aanpassen van het experiment vrij lastig is. Dit kan nadelige gevolgen hebben voor de invulling en kwaliteit van de experimenten en uiteindelijk de meerwaarde, de kosten en doorlooptijd van het onderzoek.

Beschrijving van de werkzaamheden

De werkzaamheden van TNO Defensie en Veiligheid zijn gericht op het verkorten van de doorlooptijd en het mogelijk maken van terugkoppeling (in het veld) tussen V/L-uitwerking en -experiment. Hiervoor is een gebruiksvriendelijk, interactief, modulair uitbreidbaar softwaresysteem WitnessMan ontwikkeld. De nadruk is hierbij gericht op de onderlinge afstemming en terugkoppeling van het ontwerp van het getuigenpakket, het bepalen van de scherfkarakteristieken en de uitwerking tegen het doel binnen een gebruikersomgeving.

Resultaten en conclusies

WitnessMan 1.0 ondersteunt de gebruiker bij het opzetten en ter plaatse verbeteren, integreren en visualiseren van experimenteel ballistische en V/L-onderzoeksresultaten voor aan scherven blootgesteld personeel.
De interactieve designmodule ondersteunt de gebruiker bij het iteratief samenstellen van een getuigenpakket. De designmodule maakt gebruik van een materiaaldatabase.
De interactieve analysemodule ondersteunt de gebruiker bij het bepalen van de scherfkarakteristieken uit het experimentele schadebeeld aan het getuigenpakket. De V/L-assessmentmodule stelt de gebruiker in staat ter plaatse de militaire en medische gevolgen voor blootstelling van een onbeschermd persoon aan de scherf te visualiseren, gebaseerd op een database met ComputerMan-simulatieresultaten. Gebruikersanticipatie om antwoord te kunnen geven op de 'what

WitnessMan: Het software pakket om een ballistisch getuigenpakket te ontwerpen, te analyseren en de uitwerking tegen (on)beschermde personele doelen te bepalen vanuit militair en medisch oogpunt.

if'-vraag is mogelijk door een directe koppeling tussen de verschillende modules.

Toepasbaarheid

De inzet van WitnessMan als uitbreiding van de huidige werkwijze geeft een verbetering van de kwaliteit, een verkorting van de doorlooptijd en een kostenbesparing van het onderzoek.

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Summary

Witness packs are widely used to enable the characterization of fragments generated during ballistic experiments. To assess the effect of fragment impact on an exposed (dis)mounted soldier a follow-up Vulnerability/Lethality (V/L) simulation is essential. The overall process is elaborative and time consuming.
TNO started an effect based, combined ballistic & V/L approach. This report describes the development of a consistent, balanced method, WitnessMan.
WitnessMan should:

- facilitate the design of a witness pack that is in balance with the experimental conditions and assessment objectives;
- enables an in-the-field 'real-time' analysis of the exposed witness pack;
- enables an in-the-field 'real-time' V/L assessment of the consequences for exposed soldiers.

WitnessMan [19] incorporates and integrates knowledge of TNO ballistic and V/L research. WitnessMan 'in-the-field' analysis and assessment capability offers the opportunity to adapt the witness pack configuration during the experiments to improve the fragment discrimination and thus improve the overall value of experimental research. WitnessMan modular software structure enables future improvements and

Contents

1 Introduction

1.1 Current situation

TNO has a long standing tradition in ballistic research to support the Dutch Defence Organisation. Part of the (experimental) research effort is focussed on fragmenting ammunition and behind armour debris.

TNO has put a large effort in the development of a measurement technique of fragment clouds by digital image processing of X-ray shadowgraphs [11]. This technique is used during in-house instrumented fragmentation experiments to determine the dynamic three dimensional fragment cloud.

Parallel to this development [15] describes the relation between the fragmentation pattern and the probability of kill of the soldier. Based on [15] TNO also initiated the research to develop a witness pack to measure characteristics of steel fragments. Attention was focussed on the relation between fragment penetration depth, velocity and mass in combination with the hole size ([5], [12], [13]). The relation with human vulnerability assessment was not investigated in these activities. Activities ([3], [14]) did focus on the combination of the ballistic work on calibrated witness packs and the human vulnerability assessment for mounted soldiers. The attention was focussed on military (incapacitation) and medical (casualties and fatalities) consequences. ComputerMan simulations were used to generate a database to enable a quick relation between the fragment characteristics and the effect on an unprotected soldier. With ComputerMan it is possible to assess the effect of an injury by a fragment with respect to a military and medical reference frame [15].

With regard to modern soldier close combat engagements important points for attention are to minimise own casualties, to assess anti-personnel ammunition, to assess local ballistic protection, and to understand the medical consequences ([16], [17]). Yet we regard the use of averaged ComputerMan values [14] as a deficiency to the altered needs for research. Averaged values neglect the asymmetry of the human body which may become apparent with anti-personnel close combat ammunition and result in predictions which are neither conservative nor optimistic, i.e. not realistic. Dealing with protection of own soldiers as well as with their lethality it is evident that the averaged values don't contribute to assess either objective.

Our need for a correct characterisation and assessment of the individual fragments has resulted in a re-examination of the techniques developed so far. From this another restriction of the reported method became evident: the calibrated witness pack approach is a stand alone approach focussed on the human vulnerability. The experimental conditions such as the ammunition characteristics, the distance between burst point and witness pack and therefore the a priori knowledge of the fragment cloud at the witness pack location are not used. From this it is evident that the information gained from experimental research programs can be improved considerably by fine tuning the measurements based on the specific available a priori knowledge, conditions and in-house experience.

The analysis of the results of an experimental testing program by means of witness packs is time consuming and performed only after finishing the complete experimental program. The information gathered is used as a starting point for a Vulnerability/Lethality (V/L) assessment with respect to (dis)mounted (un)protected soldiers. As a consequence, the time from start of experiments up to the V/L study results will take some time. Therefore feedback of increased insights is difficult if the ongoing experimental program is not allowing instant redesign of experiments.

1.2 Problem definition

Witness packs are widely used to enable the characterization of fragments generated during ballistic experiments. To assess the effect of fragment impact on an exposed (dis)mounted soldier a follow-up Vulnerability/Lethality (V/L) simulation is essential. The overall process is elaborative and time consuming.

1.3 Objective

The objective of the present study is to develop a consistent, balanced method to support the design, analysis and V/L assessment of ballistic experiments. This method will be incorporated in a new software system called WitnessMan. WitnessMan should:

- facilitate the design of a witness pack that is in balance with the experimental conditions and assessment objectives;
- enable an in-the-field 'real-time' analysis of the exposed witness pack;
- enable an in-the-field 'real-time' V/L assessment of the consequences for exposed soldiers.

1.4 Activities

The activities during this study were driven by an 'effect-based' approach; the 'design – analysis – assessment' chain was considered as the overall integral chain instead of gluing together individual parts. A global design of the overall WitnessMan structure was worked out with respect to the underlying modules design, analysis and assessment.

With regard to the Design and Analysis modules the initial attention was focused on the definition of the current baseline. Based on available in-house (implicit) knowledge and literature an explicit description of the underlying ballistic model was formulated. It became evident that the purpose of Design and Analysis modules should be classified as 'decision support module for the ballistic expert'.

The activities with respect to the Assessment module were straightforward. Based on a number of (experimental) pre-formatted fragment characteristics, a database was filled with ComputerMan simulation results. It was decided to include a large number of parameters such as the traditional Pk values for various military infantry functions (assault, defence, support, reserve) and operational time horizons (30 sec, 5 min, 30 min etc.) according the well known JMEM definitions, and also a large set of parameters related to the medical world (Abbreviated Injury Score, Injury Severity Score etc. for individual body regions such as head, neck, thorax, abdomen, pelvis, upper- and lower arms, upper- and lower legs etc.).

1.5 Setup of the report

This report shows the proof of concept of a combined ballistic and V/L assessment approach to optimize the design, analysis and assessment of experimental facilities using witness packs.
The setup of this report is focused on the global technical description of the modules and underlying methods. Chapter 2 deals with the global design of WitnessMan. The three modules of WitnessMan (Design, Analysis and Assessment) are described in more detail in Chapter 3, 4 and 5. The conclusions are presented in Chapter 6. Background information is collected in the appendices.

1.6 Follow-on activities

As a benefit of the modular software structure it is relatively easy to include future features in WitnessMan. Topics for improvement or alternatives are:

- the penetration/perforation methods used in the design and analysis modules;
- the incorporation of non-steel fragments;
- alternatives of the assessment module (e.g. for soft-targets such as land vehicles and air targets);
- an additional module dealing with the effect of the addition of local (ballistic) protection alternatives.

2 Global design

The objective of a combined (experimental) ballistic research and V/L program is to investigate the overall effect of the exposure of the target from a vulnerability or lethality point of view.

The design of the witness pack is guided on its ability to discriminate with regard to fragment characteristics. The objective of the analysis of the witness pack is to estimate the fragment characteristics from an exposed witness pack. Discrimination however is considered from the V/L point of view: what is the sensitivity of the target for variation of fragment characteristics.

The 'design – analysis – assessment' chain was considered as the overall integral chain instead of gluing together individual parts. Key-elements of WitnessMan are:

- the WitnessMan Design module,
- the WitnessMan Analysis module,
- the WitnessMan Assessment module.

An 'effect-based' approach resulted in the global design of the WitnessMan system. The objective is to have a proof of concept which is well designed, thus enabling us to expand its possibilities in the near future.

Figure 1 visualises the global design, which not only summarizes the capabilities of each module, but also specifies the typical workflow of the complete WitnessMan system.

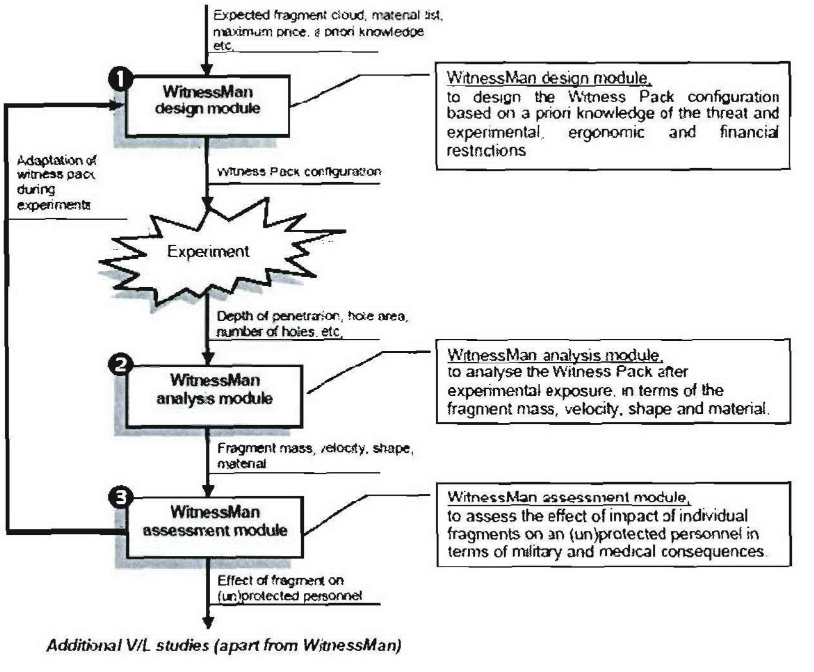


Figure 1 Global design of WitnessMan.

2.1 Step 1: design a witness pack

In preparation of an experimental program a witness pack is designed to estimate the individual fragment characteristics up to an acceptable level of detail. To this end the designer may use different plate materials, plate thicknesses and plate angles, while paying attention to availability of material, industrial specifications such as plate thickness and weight, and costs of plate material.

The Design module enables the designer to evaluate a witness pack configuration in advance. Analysis of the 'virtually exposed' configuration should result in a sufficient discrimination of the fragment characteristics. To check if the discrimination is also sufficient with respect to the V/L demands the designer has the opportunity to simulate and examine various virtual exposures.

2.2 Step 2: analyse exposed witness pack

After the experiment the user is able to immediately analyse the exposed witness pack 'in-the-field' in terms of fragment characteristics. The Analysis module serves as a decision support tool for the man-in-the-loop, the ballistic expert. Based on his experimental (implicit) knowledge, simple measurements and a priori knowledge, he should be able to present a first analysis.

2.3 Step 3: assess V/L consequences

Based on his first analysis it is immediately possible to assess the preliminary consequences for an exposed unprotected soldier for various impact angles. The results are graphically and may be a starting point for discussion. The results are taken from a databases filled with ComputerMan simulations, including a broad scope of military and medical effect parameters.

2.4 The benefit of iterative use

It is evident that a combined (experimental) ballistic research and V/L study will be an iterative process in which WitnessMan serves as a decision support tool for the man-in-the-loop, the ballistic expert.

Based on the assessment ability, the experimenter and third parties may immediately after an experiment decide to adjust or improve the witness pack design for the next experiment, as indicated in Figure 1 by the feedback arrow. Setting up experiments this way it is no longer a straightforward process but enables an ongoing fine tuning and improvement of the experimental program.

A detailed analysis of the exposed witness pack and accompanying V/L study are still required to fully understand the merits of the experiments.

3 Design module

3.1 Introduction

The general idea of designing witness packs is that we can do better than just using a predefined witness pack. Commonly used witness packs characterize the ballistic protection level of a certain target. In this way the effects of a fragment cloud on the exposed witness pack directly indicate the damage level of the target.

In the WitnessMan system however this feature has been assigned to the Assessment module. Witness packs are now solemnly used to characterize the fragment cloud and do have to indicate a direct V/L effect. Nevertheless a V/L assessment may put demands on the configuration of the witness pack (see Chapter 5).

3.2 Objective

The objective of the Design module is to design a witness pack which is able to discriminate the fragment cloud with respect to mass, velocity and shape up to a certain level of detail.

To get the most valuable information, one should match the ballistic resistance of the witness pack to the expected fragment cloud. The point of interest of the fragment cloud may vary from determining a high resolution velocity overview to distinguishing between fragment sizes more easily.

The Design module should help the user by visualising the quality of his design efforts.

3.3 Workflow

This paragraph describes the high level workflow of the Design module. For more detail is referred to Appendix A.

3.3.1 Fragment cloud definition

The general idea of the Design module is to design a witness pack based on a priori 'expert' knowledge of the fragment cloud at the witness pack position.

As we want to match the ballistics resistance of the witness pack to the expected threat, we need to define the cloud explicitly. The expected fragment cloud is therefore a design parameter in the Design module.

The designer simply depicts a number of specific fragments (mass, shape, velocity) of the fragment cloud, or loads a fragment cloud from the Fragment library. When the cloud is defined sufficiently, the cloud may be stored in the library for future use. This may lead to a collection of generic clouds for different weapons.

3.3.2 Plate library definition

Now the user can define the set of possible plate material-thickness combinations, or rely on ones that have been stored previously. This list is stored in the Plate library.

3.3.3 *Witness pack configuration*

Next the user may compile a witness pack configuration, limited by the constraints as indicated in Appendix A.1. The design process may start from scratch or by choosing an already available witness pack from a Witness pack library.

3.3.4 *Immediate visualisation & adaptation of configuration*

Immediately the user is faced with a virtually exposed witness pack, as if the witness pack is really hit by the specified fragment cloud. The visualisation depicts the envelope of the remaining fragment cloud after penetrating the successive plates. Additionally a price indication and surface weight of the witness pack configuration are calculated. Visualisation is a great way to optimize and speed up the witness pack design process.

3.3.5 *Storage of witness pack configuration*

If the witness pack configuration fulfils its requirements, the user may want to store it for later use in the Witness pack library. The witness pack may need to be adjusted after analysing the experiment in the Analysis module or after the V/L study in the Assessment module.

3.4 Impression

Figure 2 shows an impression of the feature of the Design module to visualise the fragment cloud envelopes for successive plates.

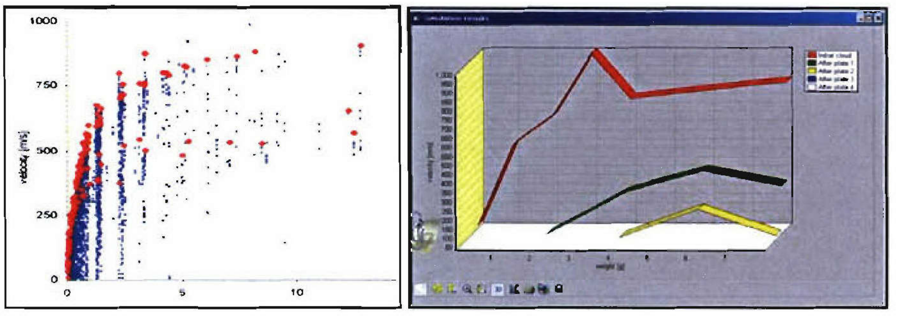


Figure 2 Impression of the Design module: on the left an original fragment mass-velocity envelope, on the right the envelope after virtually exposing successive witness pack plates.

3.5 Summary

The Design module enables the designer to visualise the positive and negative effects of choosing a particular witness pack plate configuration, while at the same time limiting the number of design options. This enables the user to quickly design a witness pack that fulfils his needs. To recap the Design module has the following benefits:

- Use experimental conditions/restrictions;
- Use V/L assessment demands;
- Use financial aspects;
- Match ballistic resistance for better discrimination;
- Simulate and examine various ‘virtually exposed’ witness packs.

4 Analysis module

4.1 Introduction

In general, analysis of a witness pack should result in a specification of the fragment cloud. The tenor is that mass and velocity can only be obtained adequately by using flash photography. This is not suitable for our purpose, as we want a fast (possibly in-the-field) analysis.

4.2 Objective

The objective of the Analysis module is to be able to quickly analyse an exposed witness pack. Developing a complete new approach was not the research objective, we only wanted to keep up with the current level of knowledge.

4.3 Workflow

This paragraph describes the high level workflow of the Analysis module. For more detail is referred to Appendix B.

The first plate is inspected visually, and fragments of interest are identified (e.g. fragments that have left a clear signature on the plate after perforation). It is not our intention to identify or label all individual fragments, we will only deal with the fragments of which an estimated density, shape and trajectory can be determined. These particular fragments are associated with a basic fragment shape and material density (see Appendix B.1 and B.2).

In the next step the fragment mass has to be determined, which is usually done by measuring the hole size in the first plate and applying a secondary hole growth algorithm (see Appendix B.3).

Then the trajectory through the witness pack of individual fragments and thus the number of perforated plates is determined (see Appendix B.4).

Finally we can determine mass and velocity ranges of the selected fragments by using threshold curves (see Appendix C) of the witness pack configuration. The challenge is to determine both impact velocity and mass from limited data, being the guessed shape factor, expected initial fragment cloud and the witness pack threshold curves to successive plates. This approach is described in Appendix C. In our case the curves are based on the penetration/perforation relation THOR, as used in the Design module as well.

For these calculations an inverse penetration relation is needed. This introduced some problems. First, no mathematical equations exist for inverse THOR. Secondly, the Analysis module deals with ranges of values instead of accurate values (v_{min} and v_{max}, $mass_{min}$ and $mass_{max}$). And finally the estimated mass is velocity dependent (due to hole growth, see Appendix B.3.2). These issues resulted in using an analytical and iterative approach.

4.4 Impression

Figure 3 shows an impression of features of the Analysis module.

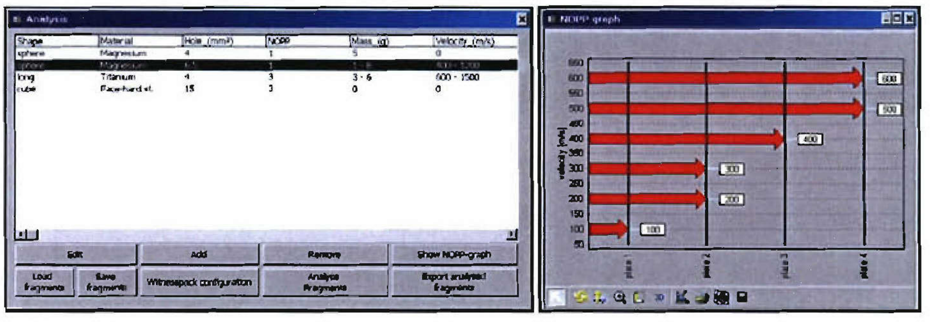


Figure 3 Impression of the Analysis module.

The Analysis module relies on visual inspection thus incorporating subject matter expert knowledge and selectiveness to speed up the analysis process. This will lead to a first estimation of mass and velocity, which is adequate for our purpose.

4.5 Summary

The Analysis module has the following benefits:

- Visual inspection incorporating experts knowledge;
- Fast analysis;
- Cloud estimation through penetration relations;
- Instant optimisation of witness pack configuration by means of feedback to the Design module.

5 Assessment module

5.1 Introduction

In the scope of this project, a Vulnerability/Lethality (V/L) simulation is used to assess the effect of fragment impact on an exposed (dis)mounted soldier. The characterization of a fragment cloud using witness packs is assigned to the Analysis module, whereas the V/L study is assigned to the Assessment module.

5.2 Objective

The objective of the WitnessMan assessment module is to enable an immediate, in-the-field assessment of the military and medical effects of a fragment injury on an unprotected standing person.

5.3 Workflow

Starting point of the WitnessMan assessment module is the specification of the fragment by its characteristics (mass, shape, material) and its velocity as estimated by the WitnessMan analysis module. The user is able to select the fragment impact (azimuth and elevation) with regard to a standing, unprotected person. Of course, the predicted fragment characteristics don't exactly match the available information in the underlying database. Regarding the discontinuities in the effects it was decided not to interpolate between adjacent database points, but to enable the user to assess the effects of these adjacent database points. This also enables the user to become familiar with the sensitiveness of the data.

The assessment is worked out for the military or medical effect of a fragment injury and offers a wide variety of scales.

The military effect is expressed in terms of the Probability of Incapacitation (P_{kill}) with respect to the military functions (assault, defence, supply and reserve) and operational time horizon. The user is able to select estimates based on ComputerMan simulations or the Kokinakis-Sperrazza [18] relation. Rapid incapacitation (P_{kill}) is also included.

The medical effect is expressed in the Abbreviated Injury Score (AIS) and the Injury Severity Score (ISS). The AIS scale expresses the severity of the fragment injury for a specific body region on a 0-6 scale. The medical assessment of the total body is expressed with the ISS on a 0-75 scale. The P_s (survivability probability) is based on the ISS as well as the Anatomical Profile [15].

Two different body region definitions are used to enable a realistic military and medical interpretation. The military body regions are related to the geometry of the person enabling an easy exchange between the ComputerMan simulations and the Kokinakis-Sperrazza body regions. The medical body regions of WitnessMan and ComputerMan coincide.

ComputerMan simulations are known to be time consuming. Considering the objective of WitnessMan it was decided to develop an extensive database to include pre-simulated ComputerMan results. Characteristics of this database:

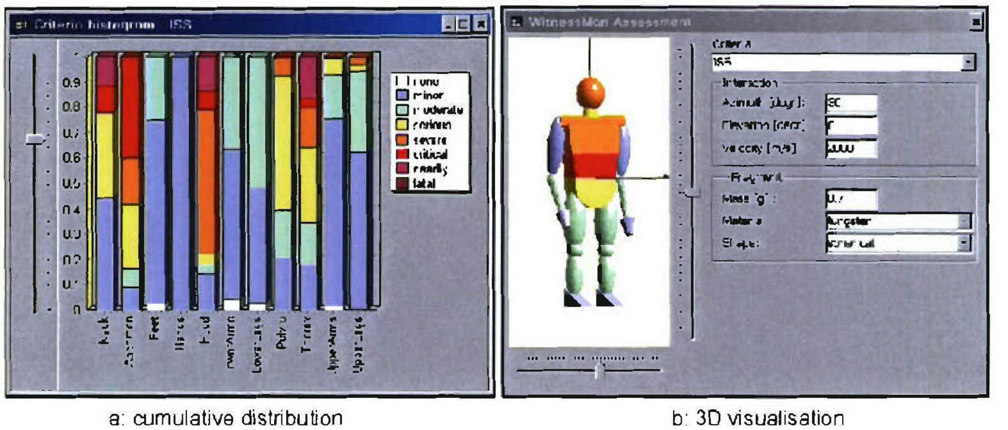
- A number of pre-defined fragments, i.e. the set of FSP's in use by the TNO Laboratory of Ballistic Research was used. An overview is presented in Appendix D.
- The velocity range (100-2000 m/s) of the simulated fragments reflects present day fragment velocity ranges.
- The simulations were performed with ComputerMan, Standing Person, azimuth 0 to 360 degrees, elevation -90 to 90 degrees impact and a high geometrical resolution.
- Parameters determined: AIS, ISS, Ps, Ps Ap, Pk RIM, Pk.

The set-up of the database enables the incorporation of additional data, for instance simulations from other fragment materials.

WitnessMan assessment is focussed on the effect of a *single* fragment; the assessment of a *multiple* fragment exposure is part of the TNO V/L simulation environment.
The WitnessMan assessment module may also be used as a 'stand alone' tool to assess a user defined fragment.

5.4 Impression

An impression of the WitnessMan assessment feature is presented in Figure 4.



a: cumulative distribution b: 3D visualisation

Figure 4 Impression of the WitnessMan assessment module.

The user is able to visualise the assessment for a specific fragment and impact condition on an unprotected soldier from his specific military or medical point of interest.

5.5 Summary

The Assessment module has the following benefits:

- Instant in-the-field military evaluation of V/L effects (Pk, Ps).
- Based on extensive database high geometrical resolution ComputerMan simulation results.
- Suitable to enhance with additional local personal protection.
- Adapt witness pack configuration to experimental results.
- Instant in-the-field medical injury criteria (ISS, AIS).

6 Conclusion & discussion

Witness packs are widely used to enable the characterisation of fragments generated during ballistic experiments. To assess the effect of fragment impact on an exposed (dis)mounted soldier a follow-up Vulnerability/Lethality (V/L) simulation is essential. The overall process is elaborative and time consuming.

An improvement of the available research support capabilities was started by the development of a combined (decision) software support tool WitnessMan. WitnessMan covers the design, analysis and assessment of a witness pack in one software system. WitnessMan should:

- facilitate the design of a witness pack that is in balance with the experimental conditions and assessment objectives;
- enable an in-the-field 'real-time' analysis of the exposed witness pack;
- enable an in-the-field 'real-time' V/L assessment of the consequences for exposed soldiers.

This report presents the successful proof of concept of WitnessMan. WitnessMan incorporates (implicit expert) knowledge and experience of (experimental) ballistic as well as Vulnerability/Lethality TNO research. Tacit knowledge of experts is codified and becomes available for a larger audience.

WitnessMan assists when designing a witness pack for sufficient discrimination of a fragment cloud, while deliberately limiting the designer in his design options and showing a virtually exposed witness pack before the actual experiment has taken place. Instant evaluation of V/L effects in-the-field just after an experiment has taken place provides the ability to adapt the witness pack configuration during the experiments to improve the fragment discrimination and thus improve the overall value of the experimental research and avoid high costs of inefficient experiments.

The benefits of the WitnessMan system may be attributed to the different categories:

Customer	User	Developer
• Reduced time • Reduced costs • Visualisation of first results • Instant redesign of experiments • Improved quality	• Design, analysis & V/L assessment in 1 tool • Ability to use modules stand alone • Ease of use • User defined constraints • Situational defined constraints • Adaptive during experiments (iterative)	• Ballistic and V/L TNO knowledge • Integrated software system • Large extendable database • Modular design

The present version offers limitations and opportunities, which can be dealt with in future versions:

- The fragment penetration relations used in the Design and Analysis module are based on the THOR penetration equations. We are fully aware of the limitations of these equations. Nevertheless, the penetration equations can be easily changed or new penetration equations included as a benefit of the modular design of WitnessMan.
- The ComputerMan database can be extended easily to refine the resolution of the data set, but can also be extended with respect to fragment shape and material.
- Suitable to enhance the current assessment for a personnel target in ComputerMan with additional local personal protection.
- Suitable to include a similar database focussed on the effect of fragment impact on non-personal targets.

7 References

[1] Haverdings, W. and Van Meerten, E.,
'Munitie Handboek WE voor kwetsbaarheids/letaliteitsstudies, Deel 1: Verschervende munitie', TNO-Report PML 1997-IN18.

[2] Dinovitzer, A.S.; Szymczak, M.; Steele, M. and Glen, I.F.,
'Characterization of behind-armour debris', Proceedings 16th International Symposium on Ballistics, San Francisco, USA, pp. 133-142, Maart 1996.

[3] Baillargeon, Y.; Szymczak, M.; Dinovitzer, A.S.; Brown, T. and Xu, B.,
'Major issues affecting characterization and modeling of behind-armour debris', Proceedings 19th International Symposium on Ballistics, Interlaken, Switzerland, pp. 945-952, May 2001.

[4] Yatteau, J.D.,
'High Velocity multiple plate penetration model', Naval Surface Weapons Center, Dahlgren, Virginia, Report NSCW TR 82-123, February 1982.

[5] Verolme, J.L.,
'Experimental en Numerical Calibration of Metallic Witness Packs', TNO Prins Maurits Laboratorium, Memorandum 97D3/1470, september 1997.

[6] Verolme, J.L.,
'Calibration of Witness Packs, Phase 3', TNO Prins Maurits Memorandum 99D3/0929, Augustus 1999.

[7] Meulman, J.H. and Van der Voorde, M.,
'Calibration of witness packs for aluminium fragments', TNO PML memorandum 03D3/413m/MB, september 2003

[8] Corbett, S.E., and Martin, R.F.,
'Calibration of spaced metal witness pack for behind armour debris assessment', The Technical Cooperation Program (TTCP), Subgroup W Technical Panel W-1, Key Technical area 12, AWE FTN 103/89, Atomic Weapons Establishment Foulness UK, December 1988, Restricted.

[9] Broos, J.P.F.,
'Resultaten Kalibratie Getuigepakketten', TNO Prins Maurits Laboratorium, Memorandum 97D3/1409M, augustus 1997.

[10] Dinovitzer, A.S.; Szymczak, M. and Brown, T.,
'Behind-armour debris modeling', Proceedings 17th International Symposium on Ballistics, Midrand, South Africa, pp. 3-275 to 3-283, TB035, March 1998.

[11] Verhagen, Th.L.A. and Van Bree, J.L.M.J.,
'Reconstruction of fragment mass distribution from flash radiographs', Proc. of the 1989 Flash Radiography Topical Symposium, Rippling River, OR, USA, 15-18 August 1989.

[12] Verolme, J.L. and Szymczak, M.,
'Behind-armour debris modelling for high-velocity fragment impact', Proceedings 17th International Symposium on Ballistics, Midrand, South Africa, 23-27 March 1998.

[13] Van der Wulp, C.J.M.; Meulman, J.H. and Verolme, J.L.,
'Digitization of witness pack plates', 19th International Symposium on Ballistics, 7–11 May 2001, Interlaken, Switzerland.

[14] Bourget, D.; Baillargeon, Y. and Northrop, S.,
'Witness Pack Calibration for Human Vulnerability Assessment',
20th International Symposium on Ballistics, Orlando, Florida, US,
September 23-27, 2002.

[15] Saucier, R. and Kash III, H.M.,
'ComputerMan Model Description', ARL-TR-500, August 1994.

[16] Verhagen, Th.L.A. and Huisjes, H.,
'Casualty Reduction Analysis – Military and Medical Consequences' International Soldier Systems Conference & Exhibition Bath, England, November 27-30, 2001.

[17] Jager, H.; Schrijer, G.; Wegdam, F.; Van Houwelingen,T.; Van Bree, J.M.L.J.; Verhagen, Th.L.A.; Reffeltrath, P. and Reulink, H.G.B,
'Towards the design of an integrated protection system for the combat soldier', Personal Armour System Symposium (PASS-2004), The Hague, the Netherlands, September 2004.

[18] Kokinakis, W., and Sperrazza, J.,
'Criteria for incapacitating soldiers with fragments and flechettes', BRL Report Number 1269, January 1965.

[19] Verhagen, Th.L.A.; Kemper, R.; Huisjes, H.; Knijnenburg, S.G.; Pronk, A. and Van Klink, M.H.,
'WitnessMan: *The* software tool to design, analyse and assess a wit-ness pack with respect to military and medical effects on an (un)protected (dis)mounted soldier', Proceedings 22nd International Symposium on Ballistics, Vancouver, Canada, pp. 1341-1348, November 2005.

8 Signature

Rijswijk, March 2006

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A The Design module

This appendix explains the design constraints of the Design module and the visualisation of the ballistic effects.

A.1 Design constraints

The WitnessMan system enables an interactive witness pack design process. When designing a witness pack to optimize the match between witness pack and threat, one may vary virtually any parameter to meet the requirements.

Besides, the designer has to consider additional constraints regarding the experimental conditions. For example, the ergonomic aspects of a witness pack configuration will impose restrictions on the maximum weight and geometrical dimensions of the witness pack.

The constraints below are enforced by the Design module. It will deliberately limit the designer in his design options, which actually helps to simplify the design efforts. This will result in a highly practical witness pack configuration.

A.1.1 Constraint 1: Maximum number of plates

Current witness packs always consist of a relative high number of plates, in the typical range of 5-8 plates. This is necessary, as current witness packs characterize the ballistic protection properties of specific targets.

One may be tempted to use a high number of plates for WitnessMan as well: the more plates, the more detailed the information may be. However, TNO has identified in many studies (e.g. see [1]) that fragments will start tumbling after penetrating a number of plates. Analyzing the fragment trajectory will therefore be complex or even impossible. This is unsuitable for our application, which is defined as in-the-field usage.

To minimize this effect as much as possible, the witness pack configuration will consist of a maximum of 4 plates (the number of 4 has been chosen arbitrarily).

A.1.2 Constraint 2: Predefined list of plate materials

The material types and plate thicknesses of the successive plates are the most important design options to match the witness pack configuration to the threat.

Ideally, the designer may want to use the most exotic materials to get the best ballistic match. In practice however, he has to take into account that the witness pack configuration has to consist of materials that are already in stock, or of materials that manufacturers can deliver only in some particular thicknesses.

Therefore the Design module supports the designer in this task. The designer first has to define a list of predefined plates. These plates are stored in the so called plate library. This limits the set of available plate choices with respect to the combinations of material type and plate thickness. This assures that any design of a witness pack configuration can actually be manufactured.

A.1.3 *Constraint 3: Predefined elevation angles*

The elevation angle of a plate in a witness pack may be used to adjust the line of sight thickness in order to match the witness pack configuration to the threat.

The mechanical construction for the plate array will be a flexible construction to allow easy adjustment of individual plates, angles and plate sequence. As a benefit an already exposed witness pack may be used in more experiments by replacing only plates which are too damaged, thus reducing the overall costs of the experimental setup.

Due to this construction, the Design module only allows a limited number of fixed elevation angles.

A.1.4 *Constraint 4: Estimation of total weight*

The Design module estimates the total weight of a witness pack configuration. In this way a weight difference between similar concepts may be evaluated.

A.1.5 *Constraint 5: Estimation of price*

The Design module estimates the price of a witness pack configuration. As costs of experiments usually are an issue, the indication of price difference between alternative witness pack configurations is highly appreciated.

A.2 Visualisation of effects

The designer will compose a witness pack configuration by selecting material, accompanying plate thickness and plate angle for each successive plate.

A big advantage is that the Design module immediately visualises the ballistic performance of the witness pack configuration as if it already has been exposed to a predefined (and adjustable) fragment cloud. This visualisation enables the user to get immediate feedback on parameter value changes, which increases the understanding of the consequences of his design efforts. The user can intuitively design a witness pack that fulfils his needs.

A penetration relation is used to determine threshold curves for the successive plates. For each plate the penetration/perforation process is calculated. As a consequence the shape of the fragment cloud envelope will change, and after a number of plates the fragment cloud envelope has disappeared, viz. all fragments have been stopped.

For practical reasons the THOR penetration relation is used. The THOR relation is used so that we line up with current TARVAC lethality study software at TNO. See [1] for a detailed description of the THOR relation.

We are fully aware of the THOR limitations (e.g. compact steel fragments) and other underlying assumptions (e.g. no air drag and gravity, no erosion of fragments), but we are only stating a proof-of-concept of the WitnessMan system. It is expected that in future versions the designer is able to choose from a penetration/perforation relation collection. Due to the modular WitnessMan software design, replacing the THOR relation by another penetration algorithm (for example suitable for other fragment materials) is easy.

B The Analysis module

This appendix describes in detail how the different fragment cloud properties are determined in the Analysis module. It should be noted that the approach in the Analysis module highly relies on the knowledge of the experimenters as visual inspection is used as the only means of measurement.

B.1 Material

It is very hard, not to say impossible, to determine the density of the material of all fragments which perforated the witness pack. The density of the fragment material is necessary to calculate the shape factor (see Paragraph B.2) and to determine its mass (see Paragraph B.3). It is however not our intension to label all individual fragments, we only deal with those fragments of which information can be gathered sufficiently.

In the current WitnessMan system we only deal with steel fragments, which is imposed by the fact that THOR is used as a penetration relation, see [1].

B.2 Shape and shape factor

The shape factor is used in the WitnessMan penetration calculations (see Appendix C) and should be determined for every selected fragment.

In Haverdings [1] the shape and shape factor definitions are given. The **shape** (NL: vormgetal) is defined as:

$$\overline{S}_n = \frac{\overline{A}_f}{Vol^{2/3}} = \rho_f^{2/3} \frac{\overline{A}_f}{m^{2/3}} \text{ (no dimension)} \tag{1}$$

with A_f the mean presented area, Vol the volume and ρ_f the density. Typical values of S_n are 1.209 for a sphere, 1.5 for a cube and 1.86-2.0 for natural fragments. The value 1.209 (sphere) is also the minimum possible value.

The **shape factor** (NL: vormfactor) is then defined as:

$$\overline{C} = \frac{\overline{A}_f}{m^{2/3}} = S_n \cdot \rho_f^{-2/3} \text{ (m}^2\text{/kg}^{2/3}\text{)} \tag{2}$$

Visual inspection is not expected to result in detailed fragment shape determination. For ease of use the selected fragments are attributed to categories of shape (S_n) instead of numerical values. The user may only choose from a limited set of shapes. If the identified fragment is prefragmented, the known shape factor is of course used instead of a category. Fragments with an unusual shape should not be used as no category is associated. The selected shape category is mathematically converted to shape factor, leading to a coarse arrangement of shape factors (C).

B.3 Mass

There are several approaches to determining the mass of the fragments. If prefragmented fragments are encountered, visual inspection of the first plate may already result in identified fragments with a known mass. However in case of other fragments the mass is generally unknown and has to be determined from inspection of the witness pack.

One again we have chosen to rely on visual inspection. The challenge is to determine the mass of fragments only from visual inspection and using mathematical relations. This will introduce errors but we are aware of this fact.

B.3.1 *Mass from hole size*

A widely used approach for mass determination during witness pack analysis is by using the hole size in the first plate [2]. The assumption is made that the presented area during impact is an indication for the shape factor.

Equation 1 shows that the mass may be determined if density, shape factor and mean presented area are known. The mean presented area may however not be identical to the actual shape of the fragment due to impact conditions. This is called secondary hole growth.

We state that the 'ease of use' requirement of WitnessMan makes it impossible to ask the experimenter to determine exact hole sizes. Therefore the Analysis module provides a measurement framework to ease his work, by means of selection of shape category and typical geometrical identification (e.g. for a sphere-like fragment only the diameter has to be entered).

B.3.2 *Secondary hole growth*

Secondary hole growth indicates that the hole in the first plate usually will be larger than the actual area of the fragment. The ratio of witness plate hole area to fragment presented area is the hole growth ratio or hole growth factor:

$$\gamma = \frac{A_{hole}}{A_{frag}} \geq 1 \qquad (3)$$

The hole size area is identical to the mean presented value if $\gamma = 1$.

The fragment mass can be determined from the hole diameter using Equation 2 and Equation 3:

$$m_{frag} = \left(\frac{A_{hole}}{\gamma C} \right)^{3/2} \qquad (4)$$

With A_{hole} measured and C estimated the m_{frag} may be calculated if is γ known. However, it is generally stated that the hole growth factor γ is velocity dependent:

$$\gamma = f(v_{frag}) \qquad (5)$$

The function $f(v_{frag})$ is an important point of interest of many TNO studies and third party studies. The most promising approaches are described below.

Baillargeon

The paper of Baillargeon [3] features an elaborate investigation on the accuracy of using the hole growth equation of Yatteau [4] as used by Dinovitzer [2].

The hole growth ratio turned out to be very high if the velocity is smaller than 350 m/s. This may be the result of a change in the fragment penetration mode from plugging at higher velocities to petalling at lower velocities, resulting in bigger holes.

Therefore Baillargeon has changed the hole growth equation to a polynomial function:

$$\frac{A_h}{A_f} = Av^2 - Bv + C \tag{6}$$

The values of the constants *A*, *B* and *C* have been determined from experimental data. For their specific field of application the accuracy of hole size prediction is better than 10%, if fragments of velocity < 350 m/s are neglected.

Verolme
The hole growth equation of Yeatteau [4] as used by Dinovitzer [2] is also evaluated in the TNO study by Verolme [5]. Verolme states that the hole growth equation is apparently only valid for velocities higher than 2000 m/s. Verolme also states that for lower velocities a linear fit can be used instead, as long as $V_{impact} > 4*V_{50}$, where V50 is the ballistic limit velocity of the fragment-plate combination.

Conclusion
Many approaches have been investigated, varying from Yatteau for high velocities to polynomial or linear approaches for low velocities.

It is however not clear which one is the best, as they contradict each other. Besides, the relations are highly dependent of plate material, whereas in the Design module we use several different plate materials. So far no sufficient method has been chosen.

For now, a generic hole growth equation has been used in the Analysis module. Due to the modular design of WitnessMan, this generic equation can easily be adjusted if better equations are determined in the future. The hole growth factor is assumed to be the constant value 1 (i.e. no hole growth).

B.4 Number of perforated plates (NOPP)

In this step the trajectory of the selected fragments through the witness pack is determined. With this trajectory the number of perforated plates (also known as NOPP or depth of penetration) of these fragments is determined. The direction of the fragments is not determined, as a trajectory perpendicular to the plates is assumed.

To determine the NOPP, holes in subsequent plates have to be correlated. For this purpose high tech solutions have been developed [13] that try to determine the NOPP of as many fragments as possible. In practice this is a time consuming process and unsuitable for the use in the Analysis module, being fast (intended for in-the-field) analysis.

We use visual inspection again, leaning on the knowledge of the expert to speed up the analysis process. The inspection of the perforation of a fragment through several plates may lead to another fragment shape that originally was selected. If so, the shape of course has to be changed in Paragraph B.2. The same applies to fragments that were originally selected but of which the trajectory can not be determined; those should be skipped.

C Using threshold curves

C.1 Introduction

The idea is to use an inverse penetration relation to determine a velocity range and mass range of fragments that have encountered the witness pack. For each plate inside the witness pack the critical velocity V50 (also known as ballistic limit velocity) was determined. The V50 velocity limits the range of velocity and mass of the fragments. Below 3 approaches are described, TTCP, TNO and THOR.

C.2 Approaches

C.2.1 *TTCP*

These 'threshold curves for successive plates' are based on experiments performed by TTCP [8]. In the experiments cubic fragments were used to represent natural fragments. By carrying out a multivariate analysis on the results, an equation was obtained to describe the relation between V50 and fragment mass:

$$K_{WP,i} = m^{1/3} V_{50} \rho_f^{1/6} (\cos\theta)^{1/2} \tag{7}$$

where

$K_{WP,i}$	the boundary constant ($kg^{1/3} \cdot m^{1/2}/s$) for each plate in the witness pack
V_{50}	the critical fragment velocity (m/s) at which there is a 50% probability that the plate will be penetrated
m	the fragment mass (kg)
ρ_f	the fragment density (kg/m^3)
θ	the angle between fragment path and a normal through the witness pack

The constant $K_{witness\ pack,i}$ which is specific for each plate is related to the total aerial density of the witness pack material penetrated. This constant is independent of the material of the witness plate, therefore calibration curves for other materials could be composed using scaling laws for density or impact angles.

TNO memos [6] and [7] feature experiments with aluminium FSP's. In [6] a conversion function of the K factor for aluminium in threshold curves is defined to relate the K factors of steel [8] to any other material:

$$K_{mat} = K_{staal} \left(\frac{\rho_{staal}}{\rho_{mat}} \right)^{1/6} \tag{8}$$

However, in [7] it is proven that this conversion function is not valid.

The Dinovitzer [10] paper is basically a product description of the DECAM software tool, which is similar (but not as extensive) to the WitnessMan system. A remarkable statement however is that the accuracy of velocity determination as described in [2] may be less than 50% compared to double exposure flash radiography velocity determination, at least in the velocity range <450 m/s. This is also described in [3].

C.2.2 *TNO V50*

TNO memo [9] features the V50 values for 5 FSP's for 1 to 7 plates of 2 types of witness packs (the TNO M1 plate array and the Canadian DREV M2 plate array). The V50 values have been determined using the Kneubühl method.

One observation is that the trajectory of the FSP's is not in line with the original path. This may be caused by a) yaw or 2) plates not being parallel. The V50 values are therefore a mean value for a yaw range (also see [1] for influence of tumbling on penetration capacity). This means that the calculated threshold curves overestimate the real threshold velocities.

The TNO velocity threshold curves are defined in [5]. If this equation is used to determine mass and velocity, the average mass computed is overestimated by an average factor of 2.4 (and 1.3 if mass is greater than 0.5 g), whereas the fragment velocity presents an average factor of 0.55 times the real velocity.

C.2.3 *Conversion of TTCP and TNO*

The way of presentation in TNO research differs from the TCCP approach, but essentially holds the same information. Conversion of both data sets is attempted in TNO memo [6]. The converted K factors of TNO are however lower than of TTCP, possibly because TTCP used a harder aluminium plate material and TNO used FSP's whereas TTCP used cubes (the V50 of a cube is higher than of an FSP). Overall it is stated that the accuracy of the TTCP method is estimated to be 15%.

C.2.4 *THOR*

Another approach is to use the THOR penetration relation [1]. As an inverse THOR is not available, an iterative algorithm can be used. Using THOR the number of perforated plates can be calculated for velocity-mass combinations. This will result in a velocity range and mass range of which the NOPP is the same as measured.

C.2.5 *Selected approach*

In WitnessMan the THOR penetration equation is used. For practical reasons the THOR relation is used in WitnessMan, as THOR is used in the TNO V/L software TARVAC. We are fully aware of the THOR limitations (e.g. steel fragments, compact fragments) and other underlying assumptions (e.g. no air drag and gravity, no erosion of fragments), but we are stating a proof-of-concept of the WitnessMan system. Moreover, the penetration equations can be easily changed due to the modular design of WitnessMan.

D FSP's

This appendix describes (partly in Dutch) the FSP's that are in the V/L database.

Description	Mass [g]	Material	Density [g/cm³]	Shape [-]
FSP stanag 2920 PML werk tek.nr. 11435, type A3/6723/2, cilinder met chisel tip; diameter 2.65mm, lengte 3.2mm, tip 1.25mm, HH 280 HB	0.162	staal	7.8	0.730
FSP stanag 2920 PML werk tek.nr. 11435, type A3/6723/3, cilinder met chisel tip; diameter 3.25mm, lengte 3.8mm, tip 1.5mm, HH 280 HB	0.237	staal	7.8	0.852
FSP stanag 2920 PML werk tek.nr. 11435, type A3/6723/6, cilinder met chisel tip; diameter 3.6mm, lengte 4.3mm, tip 1.75mm, HH 280 HB	0.325	staal	7.8	0.846
FSP stanag 2920 PML werk tek.nr. 11435, type A3/6723/4, , cilinder met chisel tip; diameter 4.05mm, lengte 4.6mm, tip 2mm, HH 280 HB	0.486	staal	7.8	0.812
FSP stanag 2920 PML werk tek.nr. 11435, type A3/6723/1, cilinder met chisel tip; diameter 5.38mm, lengte 6.35mm, tip 2.55mm, HH 280 HB	1.1	staal	7.8	0.839
FSP stanag 2920 PML werk tek.nr. 11435, type A3/6723/5, cilinder met chisel tip; diameter 7.5mm, lengte 8.75mm, tip 3.2mm, HH 280 HB	2.786	staal	7.8	0.878
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 5.56 mm, HH 280 HB	1.1	staal	7.8	0.952
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 7.62 mm, HH 280 HB	2.85	staal	7.8	0.954
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 9 mm, HH 280 HB	5.3	staal	7.8	0.866
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 13 mm, HH 280 HB	13.4	staal	7.8	0.940
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 15.8 mm, HH 280 HB	26	staal	7.8	0.901
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 18.1 mm, HH 280 HB	39	staal	7.8	0.909
FSP TNO-PML werk tek.nr. 113508 (Mil-P-46593A), cilinder met chisel tip en geleide band; kaliber 20 mm, HH 280 HB	54	staal	7.8	0.944

E User manual

This manual is intended for the WitnessMan application user. The WitnessMan program helps a user to prepare a test and analyse results afterwards. The application itself is divided into three parts to assist the work of the user, these parts are: designer, analysis and assessment. When the application is started, the main menu (Figure E.1) will show these options. Normally the parts will be used in this sequence. In the next paragraphs these parts will be described.

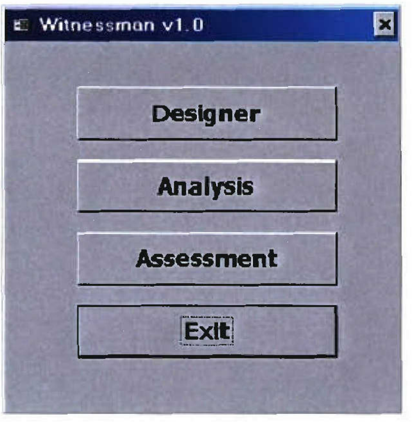


Figure E.1 Main menu.

E.1 The designer

The designer is meant to assist the user to construct an experiment. With this tool you can design the plates in a witness pack-configuration and test it with a user defined fragment-cloud. Beside a cost and weight estimate, this part will give an indication about how far the different fragments will penetrate the plates in the witness pack. With this information you can adjust the witness pack's thickness/angle/material or the number of plates.

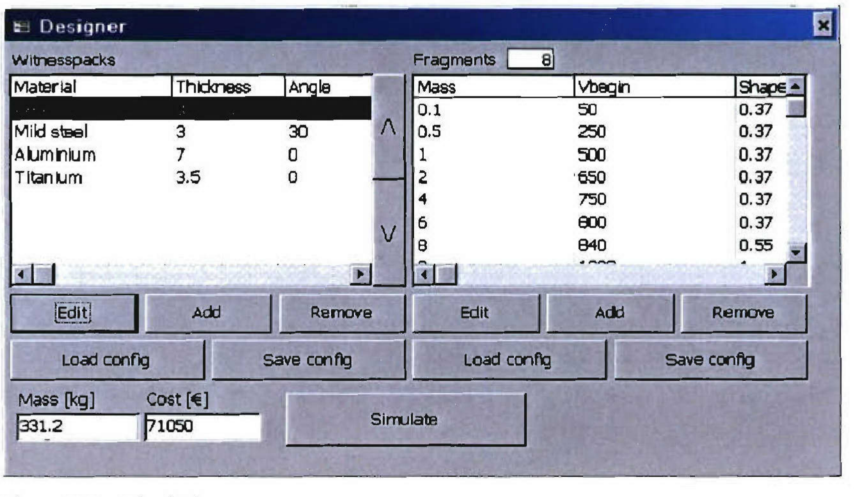


Figure E.2 The designer.

The left side of the designer window contains the witness pack configurator. To add, edit or remove a plate in the witness pack use the corresponding buttons. After adding a new plate, you have to select a plate-type from the available types in the selection box. You can also open the plate types window by clicking the button next to the plate type selection box. In this window you can edit the available plate types and save or load the configuration. Beside the plate type you can change the angle of the witness pack-plate. This is limited to a few angles, because of the witness pack-construction. After the plates have been created, you can change the sequence of the plates. The plate in the top will be the first plate encountered by the fragments. You can change the order by selecting one plate and using the up and down button next to the witness pack plates overview.

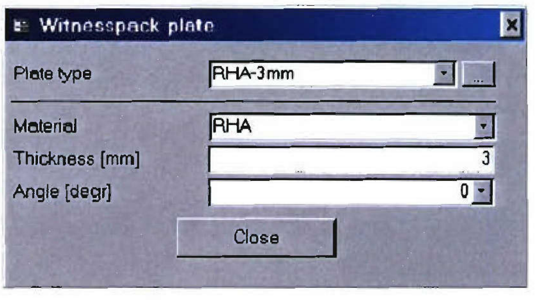


Figure E.3 Witness pack-plate edit.

On the right side of the designer window you can define the fragment-cloud that will be used for simulation. You can add, edit or remove fragments by using the button below the overview. After adding or editing a fragment, you have to define the begin velocity, mass and shape of the fragment. When selecting a shape, the matching shape number will be entered in the corresponding field. You are also able to enter the shape number for the fragment by yourself, the shape will then change to 'user-defined'.

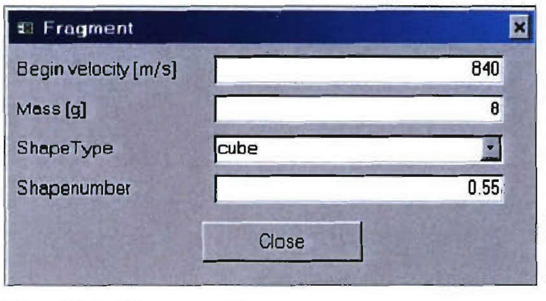


Figure E.4 Fragment edit.

After completing the definition of the witness pack and fragments, you can start the simulation by using the simulate-button in the bottom of the window. A new window will pop-up with a graph that shows the highest penetration speed of the different mass-groups through the plates (Figure E.5). In the example below the initial speed of the fragments mass-groups are shown in red. Fragments that made it through the first plate are shown in green. In this example fragments below two grams didn't make it through. No fragments went through third plate. By adjusting this third plate, for example reducing the thickness or by using softer material, fragments can also go through it to the last plate in the configuration.

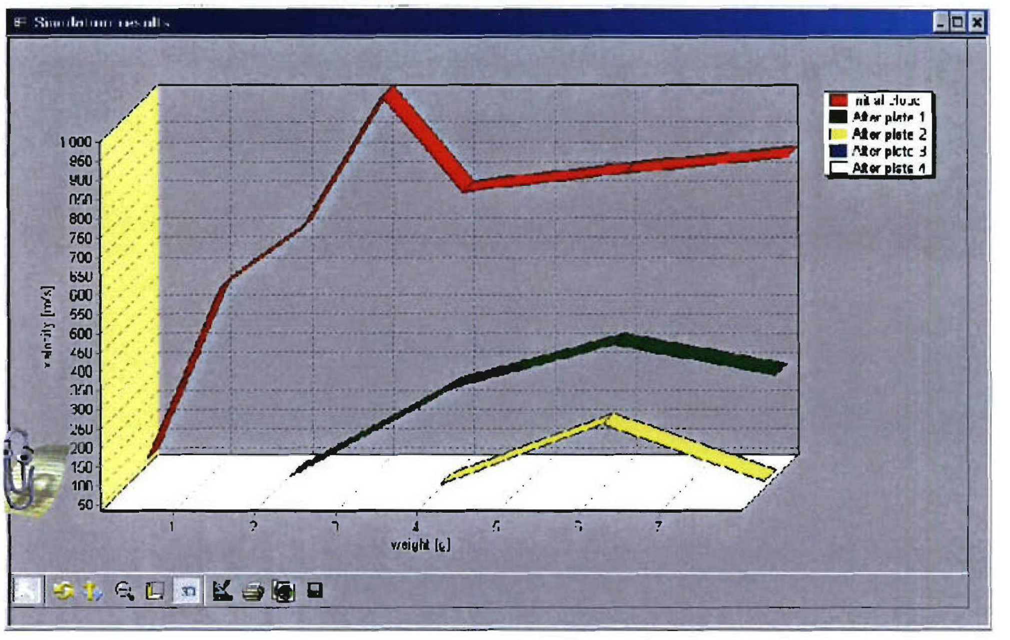


Figure E.5 Designer simulation results.

E.2 Analysis

This is the second part of the WitnessMan application. With this part you can analyse the results after the experiment is finished. The analysis module needs data from the experiment to determine the weight and speed of fragments. In the main window of the analysis-module the user can add new fragments profiles (Figure E.6). Because not all information is known, the description doesn't have to be complete. To approximate the fragment's mass and initial velocity the user needs to specify the following data:

- fragment's shape (sphere, cube, long) and approximate dimensions;
- fragment's material;
- hole size in first plate;
- number of fully penetrated plates;
- fragment's weight(range) (optional);
- fragment's initial velocity-range (optional).

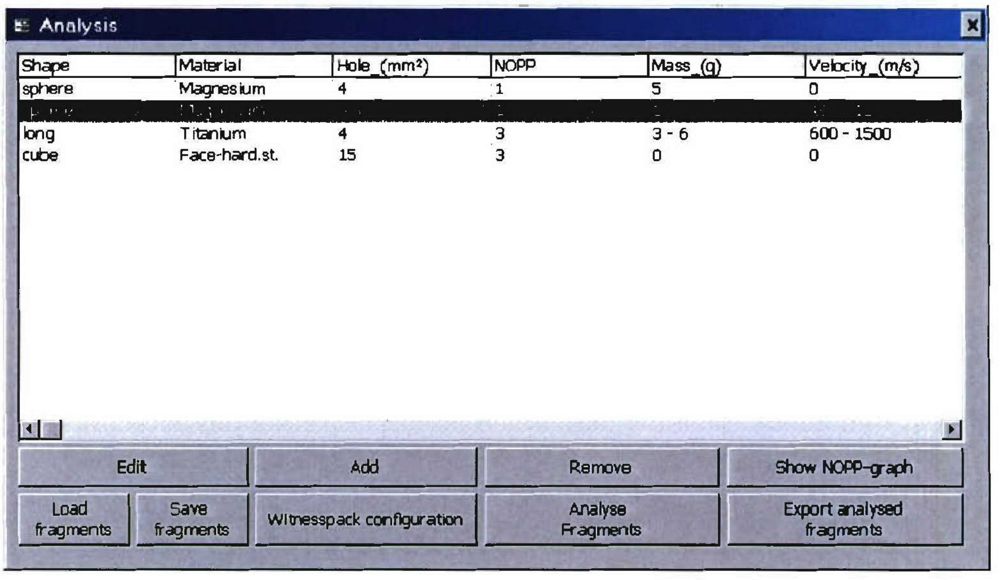


Figure E.6 Analysis window.

Fragment information can be added, edited and removed with the corresponding buttons. When adding a new fragment the window as shown in Figure E.7 will be shown. Here you can enter measured information from the experiment. After choosing a shape of the fragment, the dimension(s) that has to be entered, will be shown below the control. The weight and the initial velocity of the fragment can be entered as an absolute value or a range. If a value of 0 is entered for velocity, a standard range of 0-2000 will be used. If the mass-value is 0, then the corresponding mass will be calculated for each velocity. When all fragment profiles are added to the module, the ranges will be used to limit the search options of the algorithm. For each range you can adjust the steps that will be used by the algorithm. The number of steps for the weight and velocity range has a default value of 10.

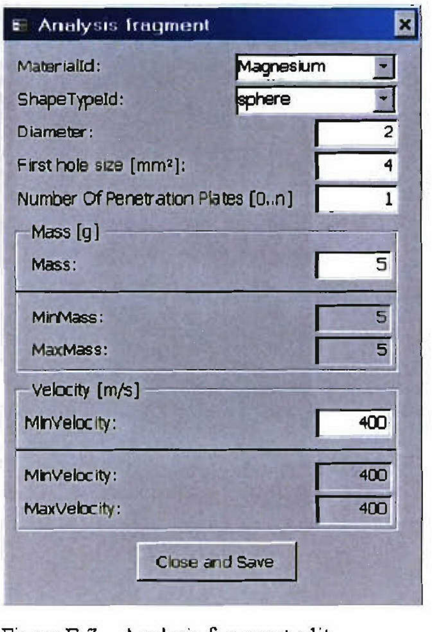


Figure E.7 Analysis fragment edit.

Before you can analyse the fragment profiles, you have to select a witness pack that matches the one used during the experiment. Usually this witness pack was created in the designer during the first phase. If this was the last configuration used in the designer, this witness pack will be loaded automatically. To check the current witness pack you can use the 'witness pack-configuration'-button in the analysis window. If you want to change the configuration, you can use the load-button in this interface to select another configuration.

If you are sure that you are using the correct witness pack, use the analysis-button to determine the possible fragments that penetrated the witness pack. After the analysis is done, you can review the result by selecting a fragment-description and clicking the 'Show NOPP-graph' button. A graph like Figure E.8 will show up. In this NOPP (Number Of Penetrated Plates) graph you can see at what plate a fragment is stopped at different velocities. If the weight is also a range, then you can select a specific weight within the mass control form.

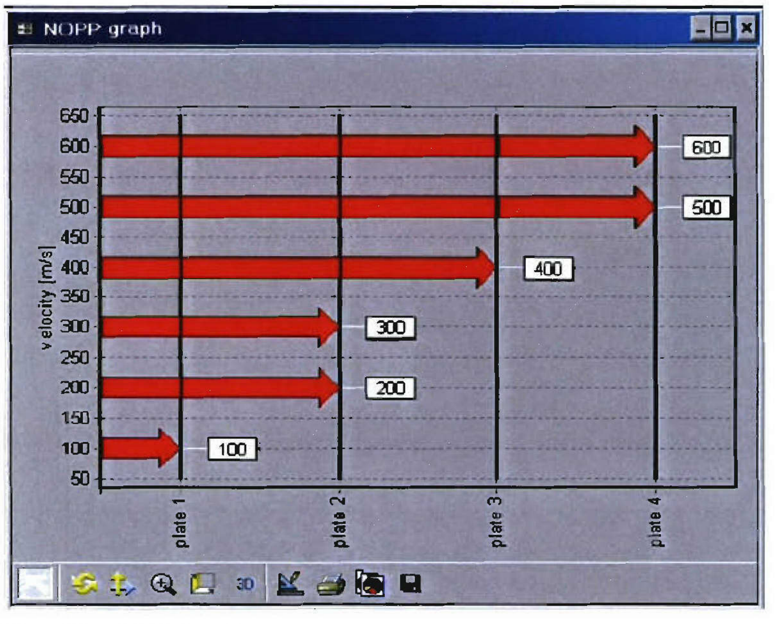


Figure E.8 NOPP graph.

In the analyser you are also able to save or load fragment profiles. Use the load and save buttons in the bottom to do so. This will save or load fragment-definitions in the analyser. To save the analyser results, you have to use the export-button. The results saved to this file can be used in the assessment-module.

E.3 Assessment

In this third module you can determine the effect of any fragment (from the experiment) and determine what its effect would be on a human being. In this module you can load data from the analysis-module or define your own fragment. The last analysis you have run, will be loaded automatically. When the module starts, you will see the WitnessMan in 3D, sliders to adjust his orientation and controls to select or enter a fragment (Figure E.9).

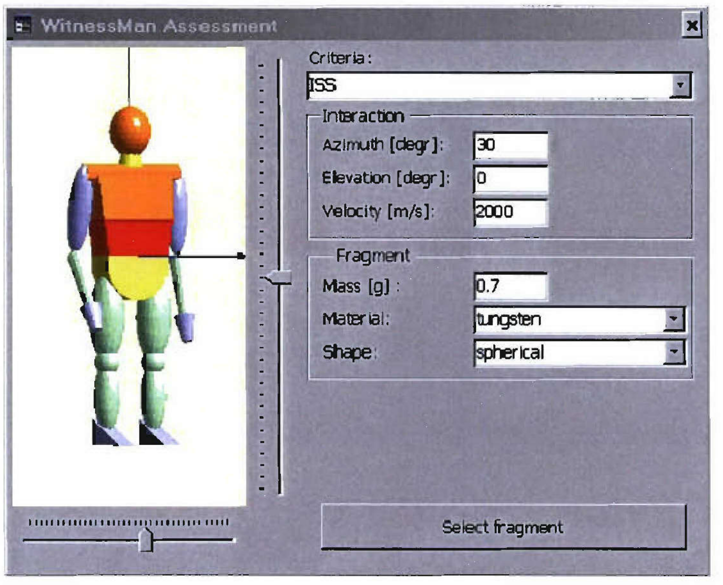
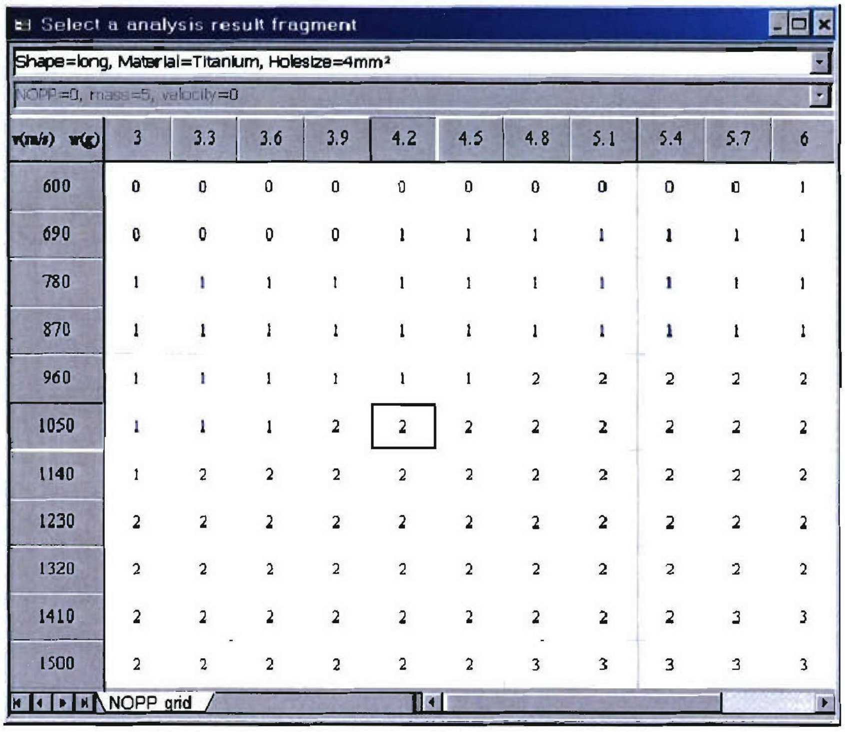


Figure E.9 WitnessMan main window.

If you would like to define your own fragment, you have to specify some fragment properties:

- velocity;
- mass;
- material;
- shape.

If you wish to select a fragment from the analyser you can use the 'select fragment'-button in the main window. Here you can load results from the analyser and select specific fragments from the profiles. If the profile contained no ranges, you can simple select the profile and go back to the WitnessMan main window. If the fragment-profile has a velocity range and a specific weight value (same applies for calculated mass values), you can choose a velocity/mass combination from the selection box below the fragment-profiles. If a profile has both a mass as a velocity range, options will be displayed in a grid (Figure E.10). The grid shows velocity against the mass of the fragments. The cells at the conjunction contain a value that represents the number of penetrated plates by the fragment. Select one of the cells and return to the main window.



v(m/s) w(g)	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6
600	0	0	0	0	0	0	0	0	0	0	1
690	0	0	0	0	1	1	1	1	1	1	1
780	1	1	1	1	1	1	1	1	1	1	1
870	1	1	1	1	1	1	1	1	1	1	1
960	1	1	1	1	1	1	2	2	2	2	2
1050	1	1	1	2	2	2	2	2	2	2	2
1140	1	2	2	2	2	2	2	2	2	2	2
1230	2	2	2	2	2	2	2	2	2	2	2
1320	2	2	2	2	2	2	2	2	2	2	2
1410	2	2	2	2	2	2	2	2	2	3	3
1500	2	2	2	2	2	2	3	3	3	3	3

Figure E.10 Analyser results.

In the top-right of the main window you can select a criterion for determining injuries. These are the currently available criteria:

- AIS = Abbreviated Injury Scale.
- ISS = Injury Severity Score.
- Ps = Survivability Probability (according to ISS).
- Ps Ap = Survivability Probability (according to Anatomical Profile).
- Pk = Kill Probability.
- Pk RIM = Kill Probability (according to the Rapid Incapacitation Model).

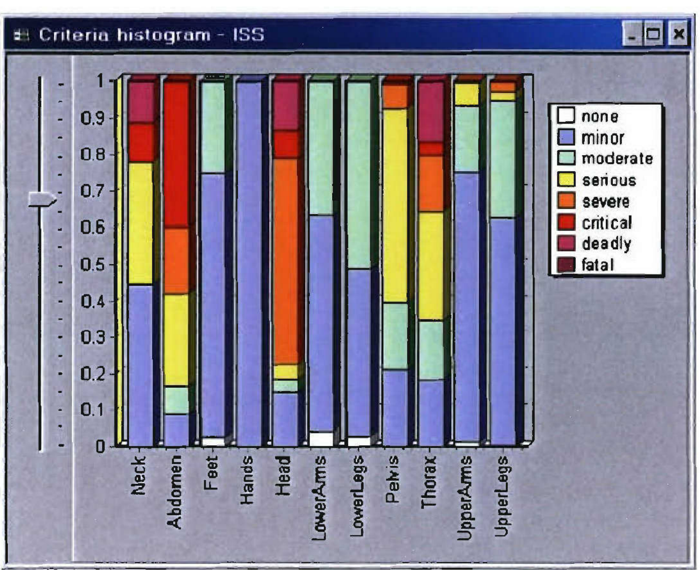


Figure E.11 Criteria histogram.

When you select a criterion, you will see that the colours of the 3D-WitnessMan are updated according to the current state of body parts shown in the histogram next to the main window (Figure E.11). Results are shown at the level of body parts and are pre-calculated with the ComputerMan program. Within this program all tissues and organs were involved in the calculation. Below each bar you can see what it refers to and on the right of the histogram you can see the legend. On the left there is a slide-bar that you can adjust. Zero gives the best case scenario and one the worst. In the future it will be possible to apply protection to body parts and see its results on the severity of the injuries.

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WitnessMan. The software tool to design, analyse and assess a witness pack with respect to military and medical effects on an (un)protected (dis)mounted soldier

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

Witness packs are widely used to enable the characterization of fragments generated during ballistic experiments. To assess the effect of fragment impact on an exposed (dis)mounted soldier a follow-up Vul-nerability/Lethality (V/L) simulation is essential. The overall process is elaborative and time consuming. This paper presents a 'proof of concept' of WitnessMan, an integrated software tool to support:

- the design of the witness pack, including experimental conditions and restrictions, V/L assessment demands and financial aspects;
- the in-the-field 'real-time' analysis of the exposed witness pack for a first characterisation of the fragment cloud;
- the in-the-field 'real-time' human V/L assessment in terms of the military and medical effects on an exposed, (un)protected soldier.

WitnessMan incorporates knowledge of many different fields of TNO research and enables the ability to adapt the witness pack configuration during the experiments to improve the fragment discrimination and thus improve the overall value of experimental research.

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