TRAINSAFE: SAFE VEHICLE INTERIORS

Workshop 28 – 29 April 2004
The Belfry, West Midlands

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PROFILES OF PRESENTERS

Peter Matthews

Company, AEA Technology Rail: Thirty years in the Rail Industry

Relevant Experience:

Formally head of interiors engineering for Regional Railways. Led a small team attending the site of rail accidents to gain information on the link between passenger injury and train interior furniture. Helped to compile the ATOC standards regarding vehicle interior crashworthiness, fire and evacuation.

Dr A R Payne

No profile available.

Jaap Horst

AEA Technology Rail BV for 6 years.

Relevant Experience:
In all of the projects based on my experience with plastics and rubbers, fire tests became an important part. This evolved to fire safety studies, and finally to more general safety issues.

Bernadette Stanley

Bernadette Stanley, Beng, Ceng, MIEE has been working in the field of Vehicle Crashworthiness for Occupant Safety for the past 10 years. Within this time she has supported numerous projects for the automotive, rail, and aviation sectors.

She is an expert MADYMO 3D user, and has successfully lead and completed projects which have included the following:

- Evaluation of vehicle crashworthiness
- Assessment of structural behaviour and its influence on occupant injury
- Optimisation of both vehicle structure and interiors for occupant safety
- Integration of test and simulation for effective system development

- The utilisation of Design of Experiment Techniques for robust design solutions

As a Senior Consultant, Bernadette now leads the Design and Simulation Crashworthiness team and takes technical responsibility for the commercial projects undertaken by that team.

She has also carried out numerous research programmes associated with occupant safety and as a result has been published as the main author at the ESV, SAE and TNO MADYMO conferences, aswell as co authoring and supporting a number of other articles/papers.

Nick Swift

Nick Swift BEng Hons in Mechanical Engineering, MIMechE
I have worked for HSBC Rail (UK) Ltd for 7 years, and prior to that worked for Thames Trains and the BRB.

I have been involved with crashworthiness and train evacuation issues for the last five years. During this time I have built the award winning Coach Roll Over Rig (used for evacuation research, training and exercises) and I have developed the K.Tex window egress system, for which I am the patent holder.

Jorge Ambrosio

Jorge Ambrosio, Ph.D. in Mechanical Engineering by the University of Arizona in 1990, Professor at the Technical University of Lisbon in the areas of Computational Methods, Computational Dynamics, Optimization and Solid Mechanics. Has been associated to different international projects in Railway Crashworthiness (TRAINCOL and TRAINSAFE) in Railway Dynamics (PEDIP - Dynamic Studies of Railway Vehicles), Road vehicle crashworthiness (APROSYS) and in Biomechanics. He has directed several international conferences in Crashworthiness, including NATO-ASI on Crashworthiness of Transportation Systems (1997), CISM Advanced course in Crashworthiness (2000), IRCOBI Conference (2003) and AAAM Conference (2003). He is the Editor of the journal Multibody System Dynamics and member of the editorial board of the International Journal of Crashworthiness.

PETER MATTHEWS

OCCUPANT DYNAMNICS

TRAINSAFE - Safe Vehicle Interiors

Subtitle: Occupant Dynamics.

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Abstract:

From the examination of vehicles involved in past collisions it became apparent that passengers were being killed and injured as result of the loss of the integrity of the vehicle structure. Recently, improvements into vehicle structural crashworthiness have been researched and implemented that combat this issue. Energy absorbing vehicle structures and anti-overriding devices are now part of the requirements of train structures throughout Europe. Passenger survival space has been improved, however it could be argued that the in order to achieve this improvement the conditions for survival have been worsened for the remaining passengers.

Is this a real issue of concern and if so how do we mitigate this concern?

Is it possible and reasonable to expect that designers and suppliers of train interior furniture to foresee collision conditions and ensure that their products are as safe as reasonably practicable when considering passenger impact?

Unfortunately in the UK there has been a number of train collisions. Consequentially there has been a move to improve the injury outcomes of seated passengers in trains under accelerations derived from the collision performance of crashworthy vehicle structures. Dynamic testing is now required to demonstrate the structural integrity of the seat/table and vehicle interface; additionally there are requirements for the allowable passenger injury. This paper seeks to demonstrate the rationale applied in the UK and some of the testing undertaken on vehicle furniture to date.

Introduction

The Association of Train Operating Companies (ATOC) and the Rail Safety and Standards Board (RSSB) have produced a code of practice concerning vehicle interior crashworthiness AV/ST9001. For interior furniture the standard considers the structural integrity of the item in the vehicle and the ability of the furniture to harm the occupants. Dynamic testing of the furniture is now required. The following section details the history of interior crashworthiness in the UK and some recent developments

Vehicle interior crashworthiness in the UK

Following the rail disaster at Clapham in 1989, Anthony Hidden QC recommended (Clapham Inquiry - Hidden 56) that British Rail conduct research in order to improve (train) interior furniture under conditions of passenger impact. His work was conducted in two parallel fields, one to improve the vehicle structure and define the conditions of acceleration that could be expected in the passenger saloon and the other to use this information to try and improve the interior of the vehicle.

This work concluded in 1996 and the element that concerns the vehicle interiors was published as a code of practice (BR/BCT609). This code sought to identify conditions which would improve the survivability of passengers in impact situations. The code based requirements on the outcomes of research and observations from investigations into rail accidents conducted in the late 1980's and mid 1990's.

The work assumes the premise that it would be reasonable to limit the excursion of the passenger during an impact and to protect the passenger, as far as it is reasonably practicable, from objects in the vehicle interior (such as luggage) as they become unrestrained and missiles under conditions of acceleration.

When considering passenger protection, it seemed reasonable to use the information available and describe features that promote safe vehicle interior design. Dynamic testing has shown the effectiveness of features such as longitudinal dividers within the length of the luggage racks to reduce the acceleration of un-restrained luggage and the likelihood of the luggage on racks falling onto passengers. The inclusion and spacing of such devices is recommended in the code. It was also considered reasonable that passengers should be protected from the effect of broken glass within the vehicle saloons. The performance of glass should be cognisant of the tendency for toughened glass to dice in crashes and the potential for this to be injurious in acceleration conditions. Additionally, where glass is used to support or retain luggage, then it would seem reasonable that this structural need should be retained after the glass has fractured, again to protect the passenger form the effect of diced glass and accelerating heavy objects. It would also seem reasonable, when considering the tendency for door systems to jam following an accident, to design such systems to contain passengers if the vehicle rolls on its side (in the case of external doors). Additionally for internal doors to provide for the need of passengers to escape through a jammed door or to design the system in such a way that it would prevent the door from jamming. The code does not mention the requirements for bodyside glazing, as they are a matter of mandatory requirements prescribed now by the Rail Safety and Standards Board. However, it again seems reasonable that the bodyside glazing system should offer as much protection to the passenger as possible to retain them within the vehicle in an accident and help to protect them from the uncontrolled events which are happening on the vehicle exterior. It should be noted that these principals have been re-enforced by investigations and recommendations following subsequent rail crashes.

When considering passenger excursion in a vehicle following a crash it is reasonable to foresee that the passenger will impact on that which is in their immediate vicinity. Crash investigation showed that over a period of time significant injury was caused by passenger seating and tables.

It is important to understand that the conditions in an impact situation are not the same in all modes of transport. What is true and understood in an automotive environment is not necessarily true or transferable to a rail environment. What happens to a passenger in a rail environment will be heavily modified by the vehicle collision pulse, the passenger orientation to the vehicle and furniture and how this has effect on passenger kinematics. It is however reasonable to use the same tools to improve the collision performance of rail vehicle interiors as used by the automotive industry where these can be proved to be beneficial and validated.

If it is possible to derive an acceleration profile that relates to that of a crashworthy vehicle structure under conditions of impact it is reasonable to use this on a component level to improve rail vehicle seat and table design. This philosophy is being used in the UK to in current research commissioned by Rail Safety and Standards Board. In the USA currently there is work being undertaken by the Volpe Institute for the Federal Railroad Administration, this work also seeks to manage the energy involved in a vehicle collision and describe vehicle interiors for the benefit of the survivability of the passenger. The work on vehicle structures has produced collision pulses that are very similar. Those of Safetrain and that used in the UK are very similar and are comparable to that used in the USA

The testing of vehicle interiors has been undertaken in the UK and in the USA using the standard forward facing crash test dummy used in the automotive industry, the hybrid 111 ATD. It would seem reasonable that train manufacturers and component suppliers use this information and codes of practice when designing vehicle interior furniture and the fixing of the furniture to rail vehicles. This would provide for some significant identifiable gains in terms of passenger survivability and would arguably form that which is the minimum the passenger could reasonably expect.

Currently work is continuing to improve the crashworthiness of train furniture in the USA and in the UK. In both countries the performance of the standard crash test dummy for rail use has led to some concern. The performance of the standard hybrid 111 dummy when considering injury to the lower thorax can be deceiving and the device inserted into the abdomen to record abdominal intrusion is quite basic and does not give the quality of information required. It has been noted that the bio-fidelity of the hybrid 111 dummy could also be improved.

In the UK the research sponsored by RSSB has led to the development of a new variant dummy known as the hybrid 111RS (the RS dummy). This dummy is more bio-fidelic than the standard hybrid 111 and has improved instrumentation in the thorax and in the abdomen. The dummy is in the course of development and validation in the rail environment. It is based heavily on instrumentation developed for THOR the latest dummy being developed for the automotive industry. Within the last few months Volpe has conducted tests for FRA in the USA where the RS dummy has been subjected to full scale vehicle testing. These tests would seem to indicate that the RS dummy has better bio-fidelic characteristics than the standard hybrid 111 and that the information gathered is more accurate.

It is hoped that the development of better tools will enable better designed vehicle interior furniture to be developed and evaluated. During the researching of these matters it should be acknowledged that there is a desire to share information and address common problems and that the FRA and RSSB are developing a memorandum of understanding in order to do this.

DR ANTHONY PAYNE

INJURY CRITERIA FOR RAIL INTERIOR CRASHWORTHINESS

TRAINSAFE – Injury Criteria for Rail Interior Crashworthiness

Subtitle: Injury Criteria Options for Assessing Occupant Protection in Rail Vehicle Interiors

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Abstract:

Injury Criteria, with their associated tolerance levels, have been successfully used, in conjunction with anthropomorphic test devices or crash test dummies, in car crashworthiness and restraint system design and assessment for the past two decades. However do these injury criteria represent the most appropriate for the design and assessment of rail vehicle interiors? The following paper looks at the development of automotive injury criteria and how these have been applied in the UK ATOC standard AV/ST9001. It then considers the options facing the rail industry, in terms of which injury criteria would be the most appropriate for unrestrained rail occupants, and their associated tolerance levels.

Introduction – What are 'Injury Criteria'

' *An injury criterion is a mathematical relationship, based on empirical observation, which formally describes a relationship between some measurable physical parameter interacting with a test subject and the occurrence of that injury that directly results from that interaction'*

S.W. Rouhana 1993

Injury criteria are the tools for linking actual physical injuries sustained by a person as a result of an accident or impact with an object, with an engineering appraisal of that accident or impact. These are then used to design and optimise the characteristic of that object to reduce or eliminate those physical injuries. Therefore in order to design or improve the characteristics of that object the injury criteria must be in 'engineering units' such as forces, accelerations, velocities and displacements.

The main method of deriving injury criteria is to conduct actual dynamic physical tests on biological specimens, which vary from full cadaver tests with humans or surrogate animals to body part components. Large numbers of tests are undertaken where the test specimen is analysed to assess the type and level of potential injury, which is then linked to a physical input parameter of the test. The injury criterion is that physical parameter which most closely simulates the injury mechanism and the potential level of injury. For example the mechanism and physical parameter that best simulates bone fracture will be a force or bending moment, while for internal soft tissue injuries acceleration based parameter are more applicable.

It is important to state that a lot physical parameters used as injury criteria are not directly related to a specified injury or type of injury mechanism but purely a method for assessing the probability of a level of injury. The acceleration based Head Injury Criteria is an example of this, where the occurrence and level of many different types of head and brain injuries, ranging from skull fracture to diffuse axonal injury, are assessed using just one injury criteria. In fact for diffuse axonal injury, a better physical parameter would be head rotational acceleration, which although can be measured using rotational accelerometers, is not used as it would very difficult to design to as it is so impact orientation sensitive.

A critical factor in defining injury criteria is specifying an assessment technique. The anthropomorphic test device (ATD) or crash test dummy is the preferred physical assessment tool where instrumentation within the device measures the injury criteria physical parameter at the correct location. Femur load cell for femur fracture, or triaxial accelerometers at the head centre of gravity for brain injury. However injury criteria can also be assessed on component level dynamic tests such as free-flight or pendulum head form impactors and even in dynamic computer models such as MADYMO or DYNA3D.

'The tolerance to injury can be defined as the value of some know injury criterion that delineates a non-injurious event from an injurious event. Or, phrased another way, the tolerance is the minimum dose associated with a specified probability of producing injury of a specified severity.'

S.W. Rouhana 1993

With an applicable assessment technique then tolerance levels can be established to predict, in a specific impact, whether an injury has occurred, or the potential level of an injury. There are two types of injury criteria tolerance levels:-

- Absolute tolerances level that is the value of the injury criteria physical parameter where an injury or a specified level of an injury will occur.

- Benchmarking tolerance levels that can be used to compare the injury levels between different impact objects and occupant restraint systems in order to improve their design or set compliance standards.

With both injury criterion and, particularly, tolerance levels these vary dependent on the age, stature and size of the occupant. For tolerance levels size has been addressed using scaling factors backed some biomechanical testing. However age and stature is more difficult and there is a distinct lack of biomechanical data for children and the very old where injury patterns and mechanisms are very different from the rest of the population.

Development of Injury Criteria in the Automotive Industry

The majority of currently used injury criteria where devised in the 1960's to 1980's for the automotive industry. They were the result of a considerable amount of biomechanical testing and research from which both injury criteria and the present range of crash test dummies where developed. As such they were very much concerned with the injuries caused in car accidents and techniques for improving car crashworthiness and occupant restraint systems. Therefore the injury criteria where developed for the main occupant fatality and life threatening injury impact areas: -

- Head - Impact with steering wheels, instrument panels and windscreens.
- Chest - Impact with steering wheels, instrument panels and seat belt loads.
- Femur – Impact with lower dashboard.

In order to assess car crashworthiness performance crash test dummies were developed, and culminated in the HIII frontal ATD, which is now globally accepted for all legislative standards. As with the injury criteria the dummy was made biofidelic, human dynamic impact response, for the car occupant impact areas, specifically for head, chest and knee impacts.

As car restraint systems improve, especially with the introduction of airbags, the injury criteria and tolerance levels have been changed to accommodate these. For example in the 1980's considerable research was conducted to devise a suitable facial injury criterion and assessment technique for impacts with steering wheels, but with the elimination of facial impacts with the installation of airbags, an internationally recognised facial injury criterion was never agreed or implemented. However with increase in potentially fatal neck injuries produced in out of position occupants the new NIJ injury criteria have been implemented in the latest Federal Frontal Vehicle crashworthiness legislation.

Application of Injury Criteria for Rail Interiors

Both the aerospace and rail industries have looked to the advances made in occupant restraint systems from the automotive industry in order to improve their own occupant protection. Due to its proven performance in improving occupant protection the HIII frontal ATD being adopted as the main assessment technique with many of its associated injury criteria. Research sled tests conducted in the 1990's using the HIII in rail interior configurations proved that it was an applicable assessment tool for unrestrained seated occupants in unidirectional seating. The tolerance levels for the main injury criteria where reduced to try and reflect the injury mechanisms and requirements for the rail interior environment. In certain impact areas, such as the abdomen to table edge, where established automotive injury criteria did not exist, research injury criterion and assessment techniques, namely the frangible abdomen, were applied.

The researches lead to the implementation of the ATOC Vehicle Interior crashworthiness standard AV/ST9001 which is now being used to assess and gain approval for all new train interiors and train interior refurbishments in the United Kingdom. AV/ST9001 has certainly drawn attention to the importance of rail vehicle interior crashworthiness and rail interior seat and table design have been significantly improved for occupant protection.

Further research is now being conducted by the Rail Safety Standards Board looking at occupant injury criteria and assessment techniques, particularly crash test dummies for the rail interior environment.

Conclusions – Options for Injury Criteria for Rail Interiors

There are many advantages and disadvantages in adopting automotive developed injury criteria for rail interiors. Their experience has improved car structural and occupant restraint system crashworthiness but is their approach best for the rail industry?

- Injury criteria have been based on car interior occupant impacts and restraint system loading mechanisms. Not for unrestrained occupants impacting seats, tables and other interior hard objects such as partition walls and grab poles. Injury criteria for the legs have been based around indirect loading, as experienced in foot-well intrusion and not direct impacts on seat bases and under frames. There are no injury criteria for the upper extremities (arms/hands) or face. Occupant kinematics and injury mechanisms for standing occupants may be different than those seated and also have not been addressed in the automotive industry.

- Injury criteria have used to just assess occupant fatality and serious injury and not minor injuries, which could lead to disability, disfigurement and compromise ability of egress. Most car accidents involve a limited number of people (4 – 8), in serious accidents the vehicle may have to be 'cut' apart to extract the occupants. Rail accidents potentially involve hundreds of people, in which minor injuries could effect egress from a rail vehicle and slow down rescuers in reaching and treating the seriously injured.

- Benchmarking tolerance levels are generally used to provide achievable targets for car manufacturers that have been lowered as car crashworthiness and restraint systems have been improved. In the rail industry absolute tolerance levels may be more applicable to predict actual injury limits, even if some of the levels may be very difficult to achieve. Also more biomechanical research and testing may be required to better clarify tolerance levels.

- Automotive Injury Criteria have been based around the crash test dummy as the assessment technique. Could injury criteria based on component level tests or dynamic computer models are more applicable to the rail environment?

Therefore the main questions which need to be addressed and resolved concerning the application of injury criteria and associated tolerance levels for the rail industry are:-

- Should Injury Criteria that better simulate the injury types and mechanisms for unrestrained occupants in rail accidents are used even if this means more research and biomechanical testing? Are the currently used automotive injury criteria acceptable at present even if they many need to be modified or added to in the future? Experience has show us that once injury criteria and tolerance levels are put in legislative standards it is very difficult to revoke them as people are unwilling to question the judgement or premise or the original authors.

- Should Injury criteria tolerance levels be based on benchmarking or absolute injury levels, even if absolute levels may be very difficult to achieve? Should there be different levels of protection for different occupant locations? Higher targets for seated occupants than standing.

- Should injury criteria and tolerance levels represent the whole of the rail travelling public? Both in terms of occupant size, age and stature and also location within the vehicle; seated, out of position and standing.

- Is the crash test dummy be the only assessment tool for injury criteria? Are there better component level dynamic tests or computer models?

In all these questions the element of cost and liability are an important factors. As the objective of rail vehicle crashworthiness design is to provide the 'highest level of occupant protection at an affordable price'.

The highest level of protection may have mean that certain injury criterion have absolute tolerance levels which have to met, if they concern the risk of life threatening injuries, while injury criteria concerned with the persons ability of egress will have target or benchmarking tolerance levels.

In terms of affordable price certain injury criterion tolerance levels may be unachievable and as such should a ‘cost benefit analysis’ or ‘as low as reasonably possible’ approach be adopted.

Liability is also another factor that needs consideration. Although public outcry following an accident is often short lived, it invokes a process that could lead to severe fines and criminal sentences, as had been proved following a number of recent rail accidents. It is therefore essential that at all these issues are at least considered and resolved.

REFERENCES:

***ROUDANA S.W.**..: Biomechanics of Abdominal Trauma. In Accidental Injury - Biomechanics and Prevention, 1995*

BERNADETTE STANLEY

OCCUPANT KINEMATICS IN RAIL CRASHES AND THE SUBSEQUENT CRASHWORTHY PERFORMANCE OF THE INTERIORS

TRAINSAFE – Occupant Kinematics in Rail Crashes and the Subsequent Crashworthy Performance of the Interiors

Subtitle: Safe Vehicle Interiors.

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Abstract

This paper addresses occupant kinematics in a rail crash scenario. The different seating and standing layouts are considered and safety issues highlighted. Currently there are many different interior layouts and when coupled with the different sized passengers and a variety of possible crash configurations, it is difficult to design a robust crashworthy interior. As passengers are not actively restrained, it is difficult to ensure control of their kinematics and subsequent safety. The resulting debris can also hamper evacuation after an impact. The ATOC AV/ST9001 document outlines test procedures to evaluate the crashworthy performance of the vehicle interior, but the crash pulse used does not allow for any lateral or rollover components, and is therefore not always representative of 'real life'.

After consideration of the issues highlighted in this paper the following question must be asked – ''Is passive safety in trains a realistic option?''

A simple active safety device such as a seat belt would negate a lot of the kinematic problems, and allow the passengers to be restrained in a more controlled manner. In particular it would present a robust solution, which could be effective in all of the seating scenarios. A similar solution could be developed for the standing occupant (a standing belt?).

Future research should be aimed at reducing the effect of layout, passenger size and crash pulse variability as these are the factors that reduce the crashworthy performance of the rail interiors.

Introduction

The objective of this paper is to highlight the effects of a rail crash on the passengers and to provide a low level explanation of the mechanisms involved. The issues are heavily dependant on the crash scenario itself, but this paper will concentrate on the issues associated with occupant safety and rail interiors design. At this point it is important to note that the crash scenario used for the following explanations is a zero degree longitudinal impact with no consideration of a lateral component. Although this is not realistic, it allows the mechanisms to be simplified and provides a good basis for discussion on this subject area.

The assumptions and statements made in this paper are based on 10 years of experience in the simulation and prediction of occupant injury and interior design optimisation projects for various rail crash scenarios.

The conclusion details possible ways forward and highlights potential issues to be aware of when designing a rail carriage interior.

Rail Interiors – What are the issues?

Modelling techniques have been used, and still are used to enable a good understanding of the mechanisms that occur during a rail crash. These same techniques can be used to formulate design solutions for safer train interiors. Simulation is a more efficient and cost effective way of progressing a design solution mainly because it removes the need for multiple iterations of prototype builds and subsequent destructive testing. The content of this paper is mainly based on simulation studies that have been carried out over the last 10 years.

Before detailing the effects of a rail crash on the train occupant it is important to clarify the potential fatality risks and compare them with other modes of transport. A HSE report (www.hse.gov.uk/railways/howsafe.htm) states that since 1995 there have been 69 fatalities in rail crashes, 74 in bus crashes and 192 in air crashes. However, in car crashes there have been over 10,000 fatalities. This same report states that rail travel is 6 times safer than private car travel. This report may lead one to the conclusion that rail travel is the safest mode of travel, but in truth, the figures for serious and minor injuries also need to be taken into account before this can be proven. Even if rail travel can be assumed to be relatively safe when compared to other forms of transportation, efforts should still be made to reduce injuries in a crash situation, as any fatality is unacceptable.

The following sections detail different seating/standing scenarios and highlight the potential issues associated with those positions. For the benefit of this paper the different occupant positions were simulated using the ATOC AV/ST9001 crash pulse. This pulse can be seen in figure 1.

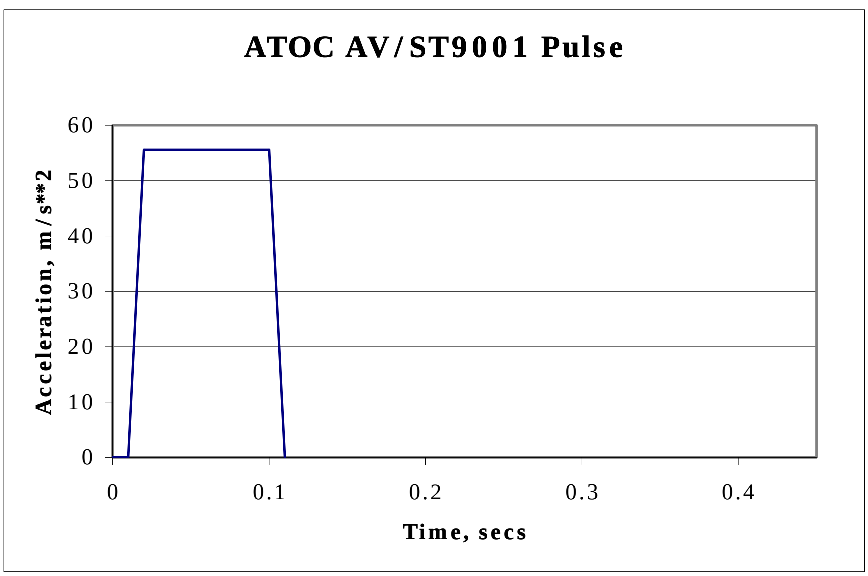

Fig. 1 ATOC AV/ST9001 Pulse

Also for the benefit of this paper, only the 50th %ile occupant is considered. But it should be noted that different sized occupants can be subjected to different injury mechanisms and risks.

UNI-DIRECTIONAL SEATING ARRANGEMENT

The uni-directional seating arrangement can be seen in figure 2.

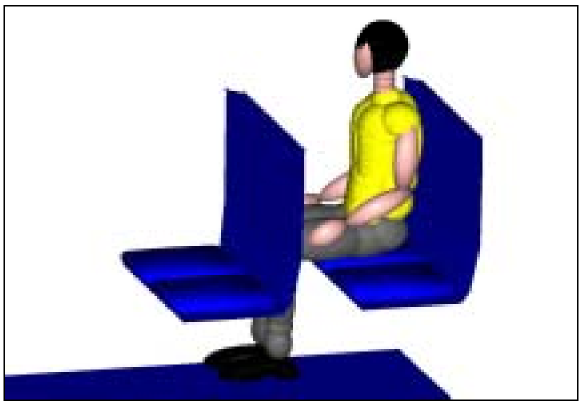

Fig. 2 Uni-directional seating arrangement

For the uni-directional seating arrangement, the seat pitch varies from train to train and can have a bearing on the injuries induced by an impact. Further to this the impact can be either in the forward or rearward direction causing different kinds of injuries to be sustained, and causing the seats to undergo quite different loading mechanisms.

In a forward impact the occupant generally slides forwards in the seat until the knees impact the seat in front. At this point the upper body will rotate, and dependant on the geometry of the front seat the chest and/or head will impact the seat back. The severity of this impact is controlled by the local stiffness of the front seat back and the load at which the front seat back will deform. The geometric point at which the seat back will deform will also affect the overall injury results. Finally, in an ideal case, after being restrained by the front seat the occupant will return to its original seating position.

The occupant kinematics seen in this scenario make this position the easiest to optimise for improved safety. However, in reality, the pulse experienced is likely to have a lateral component at the very least, and this may cause the occupant not to return to the initial seating position. If the occupant is not restrained such that it returns to its initial seating position – the kinematics are now considered uncontrolled, and this is where ensuring safety becomes a greater challenge.

With different seat pitches, and occupant sizes the problem is escalated with robust solutions being more difficult to achieve without considerable compromises. A different sized occupant will load the front seat differently and in different geometric areas.

In a rear impact, and if the seat back does not fail, a solution is possible. But this assumes no seat back failure (regardless of occupant loading forces) and also no lateral component.

In short, without the addition of an active restraint system, such as seat belts, the confidence in the ability to adequately restrain the occupant with the seat itself is flawed.

BAY SEATING ARRANGEMENT

The bay seating arrangement can be seen in figure 3.

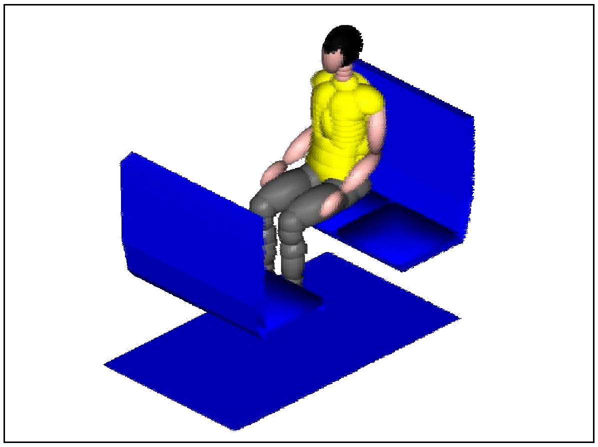

Fig. 3 Bay seating arrangement

For the bay seating arrangement, the seat pitch varies from train to train and can have a bearing on the injuries induced by an impact. Further to this the impact can be either in the forward or rearward direction causing different kinds of injuries to be sustained, and causing the seats to undergo quite different loading mechanisms. The bay seating arrangement can also include the addition of a table between the seats, which can dramatically change the occupant kinematics.

In an impact, as with the uni-directional seating, the occupant will slide forwards until the knees impact the opposite seat base. At this point the occupants upper body will rotate to impact the upper part of the seat. This assumes that the opposite seat does not have an occupant sitting in it. If this is the case, the two occupants will collide. In a rear impact the opposite will occur, unless both seats are not occupied. In this case the occupant will load the seat as in the uni-directional rearward impact case.

When a table is introduced, the forward moving occupant will move towards the table until it's abdominal region impacts it. The table edge is significantly stiff and can cause serious abdominal injuries.

As with the uni-directional seating the pitch between seats and different sized occupants together with the likely lateral component make a safe solution difficult to realise.

It may be possible to use smart materials when designing the table in order to reduce abdominal loading, but this is made more difficult when the need for anti-vandalism solutions also need to be considered.

In short, without the addition of an active restraint system, such as seat belts, the occupant may either impact the opposite seat, a table, or another occupant. Due to the way the trains operate neither case can be pre-determined.

EXPOSED SEATING ARRANGEMENT

The exposed seating arrangement can be seen in figure 4.

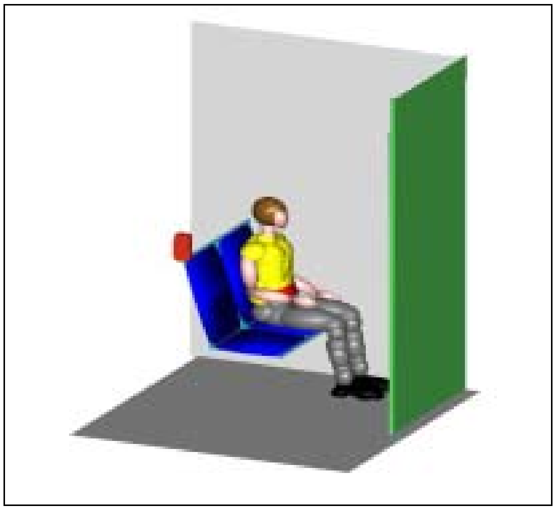

Fig. 4 Exposed seating arrangement

For the exposed seating arrangement, the seat pitch varies from train to train and can have a bearing on the injuries induced by an impact. Further to this the impact can be either in the forward or rearward direction causing different kinds of injuries to be sustained, and causing the seats to undergo quite different loading mechanisms. In a rearward impact the occupant loads the seat as with the uni-directional seat configuration. However in a frontal impact the occupant does not load the seat. Instead it moves forward until the partition is impacted. The geometry and stiffness of this partition will be dependant on the function that it performs. As with the other seating configurations, occupant size and seat pitch does affect the injuries sustained, although the variation would be less in this case if the partition were 'flat'. Generally the greater the seat pitch, the greater the injuries sustained. As with the other seating scenarios, the introduction of a lateral component can cause the occupant kinematics to be uncontrolled.

An active restraint system would alleviate the occupant to partition impact.

SIDE FACING SEATING ARRANGEMENT

The side facing seating arrangement can be seen in figure 5.

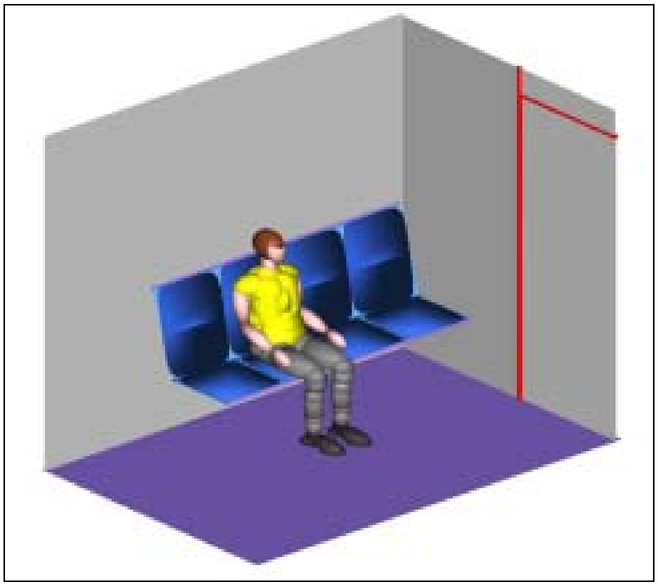

Fig. 5 Side facing seating arrangement

For the side facing scenario, the impact surface will be dependant on the internal geometry within the carriage. It could be a partition wall, or a vertical pole or an armrest of some sort. There is also the risk of occupant to occupant impacts when several occupants are moving towards the same rigid surface. As with the other seating scenarios, the introduction of a lateral component to the crash pulse could effectively cause the occupants to be totally unrestrained and in free flight.

Occupant to Occupant impacts will be worsened when the occupant sizes are not compatible.

As with the exposed seating arrangement the occupants receive greater injuries the further away they are from the point of impact.

If occupants seated in this position were actively restrained, their movements would be more controlled.

STANDING ARRANGEMENT

Possible standing arrangements can be seen in figure 6. However, in reality, the occupants can stand just about anywhere in a train.

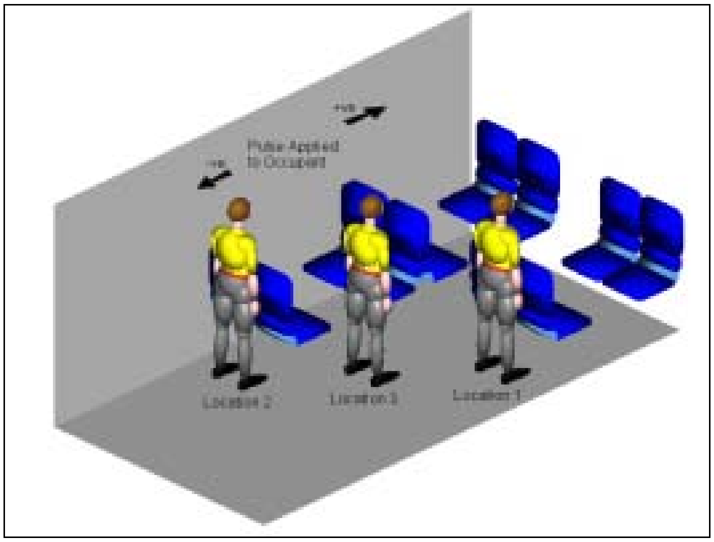

Fig. 6 Standing arrangement (figure from Safe tram Report 0465013)

As with the seating scenarios occupant size can vary as can the pulse direction. As trains do not actively prevent passengers from standing anywhere, it is possible for any surface within the carriage to be impacted by the standing occupant. Effectively the standing occupant is totally unrestrained and during a crash is in free flight, free to impact any surface or other occupant.

Generally the longer the distance between the standing occupant and the impacted surface the greater the injury sustained. This is the case for both a forward or rearward pulse.

Conclusion

In conclusion the occupant positional explanations taking from historic research have highlighted the following points and questions:

1. With regard to occupant safety in trains, and taking into consideration the variety of positions available and that in an impact the pulse is likely to consist of longitudinal, lateral, and rollover components, without active restraints there is a high risk of uncontrolled occupant kinematics.
2. The design of interior components (seats, tables etc) is confounded by the high number of possible loading conditions due to unrestrained occupants. It is difficult to design energy absorbing furniture that is also capable of withstanding vandal damage.
3. Due to the variation in size of occupants it is difficult to generate robust design solutions that will benefit all.
4. The standard used to support the design and development of interior components does not allow for lateral or rollover crash pulses and assumes a longitudinal pulse only. This is not realistic when we consider real life crash scenarios.
5. Is passive safety in trains a realistic option? A simple active safety device such as a seat belt would negate a lot of the issues highlighted in this paper. In particular it would present a robust solution, which could be effective in many of the seating scenarios. A similar solution could be developed for the standing occupant (a standing belt?)

6. To introduce an active safety system onto a train would be costly, but it would allow one seat design to cater for all seating positions. Seatbelts are one active safety option, but there may be others. Planes and coaches have already gone down the seatbelt route. However legislation has helped to force this and this means that the added cost is the same for all manufacturers.
7. Future research should concentrate on finding a robust solution for occupant safety in the event of a train crash – this may be passive, but is more likely to be active. This research should also take into account:

   a. How would an active system be implemented and policed.

   b. Allow for evacuation procedures when considering active safety devices. If all occupants were restrained, would there be less ‘furniture’ damage, allowing for easier evacuation?

   c. Consider the implications of having standing occupants.

   d. Consider robust design solutions for interior furniture such that one design can be used for all seating layouts.

   e. If an active restraint system was to be successfully implemented (effectively keeping occupants in one position), would this mean that supplementary furniture such as tables partition walls etc could have more simplified designs, as they would not need to absorb occupant impact loads?

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JAAP HORST

EVACUATION IN CASE OF AN EMERGENCY

TRAINSAFE – Evacuation in case of an emergency
Safe Vehicle Interiors.

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Abstract:
Emergency situations in trains will always exist, and this implies that measures for evacuating the passengers will always be necessary. There are a lot of aspects related to the evacuation of trains, and very different circumstances or scenario's that may be applicable. First of all the decision if an emergency situation exists or not. This is not always obvious. Who makes the decision, where does he get the information from which he needs? If the situation is not critical, it is safer to remain on the train, especially in countries where a 3rd rail is used for the power supply. Plans and procedures should be available, and the train staff should be trained to use them.
If the train can not continue to the next station, the evacuation should take place in an orderly fashion, the train staff and their training is all important for this. Logically the train itself must be thus equipped that the evacuation is made possible, also under difficult conditions like complete darkness, smoke and/or carriages laying on their side! In some cases there wll be no supervision, passengers must try to escape from the train on their own. Design of the interior should be thus, that escape is not hindered, additionally special escape devices may be provided.

Introduction

To begin with I want to give you a few examples of emergencies and things that have occurred. Not too many details are given.

- In a metro fire in Asia, the train personnel fled from the train to bring themselves to safety, without opening the doors for the passengers first. In another example the driver was KO from a collision, and could not open the doors. Thus the passengers were unable to leave the train.
- As the consequence of a derailment of an AMTRAK passenger train in 1997, the electrical systems underneath the train were damaged. As a result, the emergency lighting failed to function, making escape much more difficult.

- During a recent train fire, the train was evacuated and the fire in one compartment finally extinguished. Afterwards one lady in a nearby compartment (not directly affected by the fire) was found suffocated from the fumes. She presumably was asleep, and had not heard any calls.

- Window-rubbers in some Netherland's trains were provided with a handle, so the rubber, and thus the window, could be removed in case of an emergency. During maintenance it turned out that most handles broke off, without removing the rubber.

- During egress tests with test persons leaving a train in an orderly fashion, the carriage was empty in 2 minutes. The test was repeated, with the promise that the person first to leave the train would receive 100 pounds. Evacuation now lasted 5 minutes

- In the Kaprun disaster, people at first could not get out of the train. After breaking the windows, the fire for many blocked the way down the tunnel, forcing them to go up, only to be killed by the smoke.

These examples show that in case of any emergency or accident, both technical as well as human factors are of importance.

Points that come to mind are:

Technical: Design of carriages (width of passage, number of doors, emergency exits or windows, detrainment devices), emergency lighting, emergency brakes / alarm systems.

Human: Communication to / from train personnel, personnel training, evacuation procedures and plans, capability to avoid panic situations.

Evacuation / Escape

Important is the difference between *evacuation* and *escape*. Evacuation is generally considered to be the controlled, supervised egress, while escape is regarded as the unsupervised egress. In case of evacuation, the train or carriage from which the passengers have to leave generally is in a good state and normal position, in the ideal situation at a platform, but it can also be in any other location. In case of escape, there generally has been an accident of some sort, with the train remaining on the accident location, possibly damage to the carriages and these may be in strange positions, maybe on the side or otherwise.

Requirements as to Evacuation can be in two forms: On the one hand design rules, where dimensions of passageways, number of doors and emergency exits etc. are given.

As an example, the Dutch document dated 1988 on fire safety contains a chapter on escape routes, where positions of doors are prescribed, as well as the width of doors in relation to the number of passengers. Also prescribed is that doors should remain functional, regardless of the state of the vehicle, and that emergency opening of these doors should be always possible, both from the inside and the outside.

On the other hand Performance Requirements can be stated. Some standards use a mix of both, see for example the ATOC AV/ST9002. In this standard a normalised method is given to evaluate evacuation in a real situation. The UK is at this moment at the forefront of developing standards for evacuation and escape, following Lord Cullen´s report of the Ladbroke Grove accident, where 31 people were killed.

In case of an emergency where there is no supervision to egress, the passengers must be able to escape. The main scenario where rapid escape from a train is required, is in the case of fire. In most other scenario's, e.g. a collision or derailment, passengers can mostly remain in the train.

It is much more difficult to test the performance in case of an escape situation, especially if different circumstances must be evaluated, like fire and smoke (with low visibility) or a carriage on it's side. For this reason, for the escape possibilities of a carriage design rules are of greater importance than performance requirements. Especially important in this case is the position and number of escape openings, lighting and passenger knowledge about escape equipment, signing etcetera. Practical tests especially with carriages on the side can make clear the difficulties encountered in this situation, and how the interior design can be altered to make escape easier. Passageway doors can be major obstructions, reaching one compartment from another may be almost impossible. The presence of escape hatches in roof or floor may be helpful in these cases but may present hazards in normal operation which outweigh any advantage in escape. In the Netherlands, hammers to break the windows in case of an emergency were provided in each compartment. However, these hammers were stolen so often, that they now have been removed from all trains.

Another aspect is the time necessary for escape or evacuation. Especially in the case of fire, the time available for escape may be highly increased by using the right firesafe materials in the construction of the interior, or by the use of either fixed or mobile extinguishing systems. In case of a fire, escape or evacuation may be first to a place of relative safety (for example another coach), enabling the train to stop at a place where evacuation can be done easier. The conditions in which to escape can be further improved by using a dedicated ventilation system, designed to provide the passengers with fresh air, meanwhile removing the smoke.

Communication

From the examples given in the introduction the importance of good communication is clear. Communication is necessary from the passengers to the driver and other train staff, between members of the staff, from the staff to the passengers and from staff to the train movement control centre or emergency services. Added to this may be fire detection systems or derailment detection systems, which are aimed at giving the driver an early warning or increased insight in the situation.

The main concern is that the driver and other staff know exactly what the severity of an emergency situation is, so that a well-founded decision can be made as to the actions to be taken. In most cases it would be preferable to drive the train to the nearest station or location where evacuation can take place safely. A recent study by the Railway Safety and Standards Board in the UK shows that only on a rapidly escalating fire on a diesel train it is preferable to evacuate passengers rather than leave them on the train (This because of the risks of falling from the high level of the train to ground level, the risk of being hit by a train on the other track, or the risk of touching live wires or third rail). Especially in the case of fire it should be avoided to stop in tunnels. In the Netherlands' situation, where increasingly tunnels or over-roofed sections are being built, an overriding system on the emergency brake is being fitted to some classes of trains. This to enable the driver to leave a tunnel if a passenger pulled the emergency brake. Use of alarm systems instead of emergency brakes is being considered. These systems should include a communication system to enable passengers to make clear to the driver what the situation is.

Using the information received, the driver must decide as to how to act. In the ideal situation, the driver can refer to plans and standard procedures established for different scenario's, and is trained in how to use them in an emergency situation.

Once the driver has decided what action to take, the passengers should be informed as to what is expected of them. Information systems are important, but as was shown in one of the examples, it is not always certain that all people are reached this way.

In case of an escape situation, it is presumed that there will be no communication possible between driver and passengers. Passengers will have to escape, using the information provided in the carriage or information they have retained from previous experience. Signs are of importance, as may be information leaflets to inform passengers before an incident, as to how to escape in case of an emergency, location of escape possibilities etc. The working of escape devices should be clearly indicated in the vicinity of the device.

Evacuation or escape does not end at the door of the carriage; in fact the different situations the train can be in (tunnels, bridges, crowded stations) should be considered in the plans to be made. It is clear that the driver should take different actions when his train is in a tunnel or on a bridge. For the high situation, escape chutes can be an option, see Fig.1. These are long textile tubes, enabling vertical evacuation in a safe manner.

Fig. 1 Zephinie Escape Chute, as proposed for a monorail.

Fig. 2 Metro detrainment device.

Conclusion

Principally, evacuation and escape are aimed at minimising any further risk to the passengers and staff on the train.
Standards should aim to assure this, taking into account different possible circumstances or scenario's, and preferably not hindering technical innovation. A combination of design rules and performance requirements seem to be a logical step how to assure this. The question is if performance requirements should be standard, or should depend on situations a particular train may be in.

Standardizing escape equipment in Europe would make it clearer to a passenger how to act in case of an emergency, also more effort could be put into the development of better systems.

Approaching the safety of a train as a system, can enable to ensure optimum safety in the most cost/effective and efficient way: minimizing the risk while at the meantime avoiding to take measures at high cost with little of no positive effect.

Priorities for research can be identified at the workshop, some ideas are: Testing the escape possibilities of a train on its side in order to achieve design rules for easier escape, development of information for passengers and the development of low cost escape devices, which are not prone to vandalism.

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NICK SWIFT

TRAIN EGRESS AND EVACUATION

TRAINSAFE – Train Egress & Evacuation
Subtitle: A Common Approach?

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Abstract: Three models for an approach to train safety are proposed and compared. The need for common standards and the application of these to each model is then discussed.

Introduction

Train egress is a complex and emotive issue. When everything has gone wrong in a major way, how the railway deals with its customers (or how the customers deal with the railway that they are suddenly faced with) can have a major effect on the public's perception of safety.

Main Text

In considering egress and passive safety I think our approach can fall into one of three different models:

Scientific Model

The first model I have named the scientific approach. Developed from the aircraft industry's 90 second evacuation trials, it assumes that immediate egress is desirable and that we can engineer the post incident environment to deliver it. Specifications are written around the concept that provided the length of time to fully evacuate the vehicle is shorter than the minimum time for the risk to arise, the vehicle is safe. It assumes that occupants will behave rationally, read instruction labels and perform in a manner that can be modelled and measured by evacuation trials. The Americans generally follow this approach to rail vehicle safety.

But is evacuation the safe option? Can we expect passengers to behave rationally?

Risk Model

My second model is the risk model. The creation of a range of accident scenarios, an assessment on the risk to the individual from what to do next, and a comparison with historic information leads to the conclusion that in most situations it is safer to stay on the train. Whilst advocates of this model rarely propose the removal of all means of escape, making egress “difficult” is seen as a way of reducing overall risk after the incident. This approach places a heavy dependence upon communicating information to passengers and our ability to control the post incident environment. The “Train Evacuation Risk Model” developed recently for RSSB have supports this approach.

But will passengers believe what they are told?

Human Model

My last model I have called the Human model. It starts from the presumption that people will generally make the right decisions for themselves in any particular situation. Our task is simply to provide them with the right tools to carry through that decision. These “tools” may be information, the presence of light, or devices to aid egress. In this model we do not assume that we know best or that we can control the environment in which passengers find themselves. We delegate. As Engineers we may have difficulty with this approach, but there is often support for it from others.

But should we “encourage” something that we believe may increase personal risk? How do we write standards around may have become a chaotic environment that we find difficulty in predicting? Should only Engineers be making these decisions?

Conclusions

Where are we? In the UK the responsibility for deciding which model to adopt is split. More than 20 different train operators, a couple of manufactures and, to a certain extent, the train leasing companies, all have a hand in deciding which way to go. It is therefore not surprising that different policies are adopted for different fleets, often operating over the same routes. On many occasions, including at most Public Inquiries following major accidents, a call has been made for common standards: similarity between vehicles and procedures to improve public safety.

But, do we really want common standards? Prescription can stifle innovation and prevents any account being taken of local conditions. We do not have common standard passengers.

If the three models I have outlined above are valid, how do common standards apply to each and ultimately which one should we **all** agree to adopt?

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JORG AMBROSIO

OCCUPANT MODELLING FOR IMPACT BIOMECHANICS

OCCUPANT MODELLING FOR IMPACT BIOMECHANICS
Injury Prediction in Railway Vehicles.

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Abstract:

This work presents an overview of the modelling strategies of transportation vehicles' occupants for application to the biomechanics of impact, including injury prediction. Based on the fact that almost all modelling software used today for the design and analysis of biomechanical models of occupants are based on multi-body dynamics methodologies, the fundamental characteristics of their corresponding models are reviewed. Many of the features of the occupant models currently available have been developed with the automotive industry in mind and adapted afterwards to applications to other type of vehicles. Therefore their predictive capabilities focus the important parameters required in the design of the road vehicles and not necessarily reflect the needs of the type of simulation required for the railway and aerospace vehicle occupants. In what the occupants positioning is concerned the road and aerospace vehicles share in common the fact that the occupants are restrained during their normal operation, being the occupants' kinematics guided in case of impact. The occupants of railway vehicles are mostly unrestrained, it is common to have front and side facing seats and the existence of standing passengers is general. Another distinctive feature in railway vehicles is the design of their interiors that generally includes poles, rails and tables. As the current measures of injury, such as the HIC or the SI, are being questioned today concerning their biofidelity it can also be questioned if the distinctive features of the rail vehicle interior on other injury indexes should also have an influence. Furthermore, a train crash is generally preceded by signs that let the passengers predict its occurrence and take defensive measures that reflect in the voluntary muscle contraction, with the objective of stiffening the body. The current biomechanical models either do not include muscle actions or, at the most, include a reflexive muscle contraction. It is suggested here that for the case of standing passengers it is important to include in the biomechanical models muscle models that allow for the representation of the muscle voluntary contractions and joint stiffening. It is also suggested that the evaluation of the models leading to the identification of such actions can be done by using techniques similar to those used in the evaluation of muscle force sharing in different human motions.

Introduction

The safety of occupants and their potential survival in crash events of transportation systems involve topics as different as interior trimming of the passenger compartment, structural crashworthiness, or restraint systems efficiency. The analysis of such aspects is currently done during the initial design stages. Current design methodologies entail the use of different computer simulations of increasing complexity ranging from simplified lumped mass models (Kamal, 1970), multi-body models (Ambrósio, 1996) to complex geometric and material nonlinear finite element based representations of occupant (King, 1991) and vehicle structures (Haug, 1988). Some well-known simulation programs are now available: PAM CRASH (Haug, 1988), WHAMS-3D (Belytschko, 1988) and DYNA 3D (Halquist, 1982) for structural impact and CAL3D (Fleck, 1981) and MADYMO (1986) for occupant dynamics. These programs are able to simulate with relative detail frontal, rear and side impact scenarios. However, in most cases, the structural impact and the occupant dynamics are treated separately. The structural crash analysis provides the relevant accelerations pulses, which are used in the occupant analysis phase. The injury indices such as HIC and chest accelerations (MVSS, 1988; Viano, 1988) can then be evaluated to access design performances.

The dynamic analysis of the vehicle occupants require that the initial conditions for the biomechanical models are supplied for the simulations. In road vehicles it is rather predictable what the passenger positions are, and consequently the different safety systems, such as restraints and air-bags, are 'easily' tuned to control the occupant kinematics and to minimize the injury risk. In this sense, postures such as those shown in Figure 1 are called, in road vehicles, out-of-position because the devices that are designed to mitigate injury are not set to have their optimal operation for such conditions. However, for the normal occupants posture in trains there is no sense in defining out-of-position postures because no restraints are used to guide the occupants in case of a crash.

Fig. 1 Out-of-Position occupants for road vehicles

The biomechanical models developed with the numerical tools outlined in the next section are set for the type of kinematics experienced by the normal vehicle occupants. The road vehicle simulations that lead to passenger kinematics closer to that observed by a railway vehicle occupant are those of unbelted passengers in general and rollovers with ejection, such as that shown in Figure 2, in particular. In this type of events the impact events take a relatively long time, the occupant can react to the perception of the accident and any injury mitigating system, such as the airbag, is bound not to be efficient.

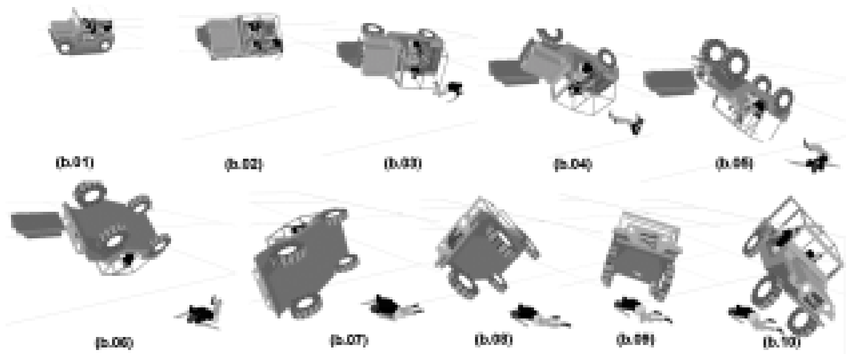


Fig. 2 Large motion of an unrestrained vehicle occupant during a rollover accident

In order to identify strategies that can be efficient for the modelling of railway vehicle occupants and for the prediction of their potential for injury, this work will first review the main features of the current biomechanical models used for passenger simulation. Next their shortcomings in the representation of the railway passengers will be identified. Based on the state-of-art a list of features required for the biomechanical models of unbelted passengers in general, and of railway occupants in particular is identified. Special attention is paid to the need for these models to include biofidelic muscle actions. In order to identify the typical postures of the railway passengers and the reflexive and controlled muscle actions and joints stiffening several numerical and experimental procedures are proposed.

Current Features of Biomechanical Models

Most of the methodologies applied to the representation of a three-dimensional, whole body response, biomechanical model of the human body suitable for impact simulations are based on multi-body dynamics (Laananen, 1983). These models are general and accept data for any individual. The information required for the programs to assemble the equations of motion of the models include the mass and inertia of the biomechanical segments, their lengths, location of the body-fixed coordinate frames and the geometry of the potential contact surfaces, as pictured in Figure 3.

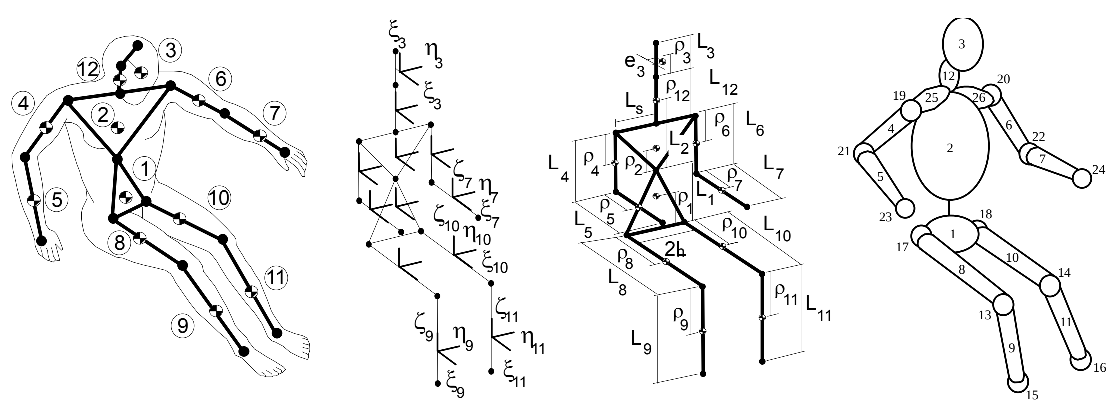


Fig. 3 Three-dimensional biomechanical model for impact: (a) actual model; (b) local referentials; (c) dimensions of the biomechanical segments; (d) contact surfaces

In contact/impact simulations the relative kinematics of the head-neck and torso are important to the correct evaluation of the loads transmitted to the human body. Consequently, the head and neck are modeled as separate bodies and the torso is divided in two bodies. The hands and feet do not play a significant role in this type of problems and consequently very often they are not modeled. The whole body models are generally described using 12 or 16 rigid bodies. In the biomechanical model, no active muscle forces are generally considered but the muscle passive behavior is represented by joint resistance torques. Applying a set of penalty torques when adjacent segments of the biomechanical model reach the limit of their relative range of motion prevents physically unacceptable positions of the body segments. A viscous torsional damper and a non-linear torsional spring, located in each kinematic joint, describe such joint torques. Take the elbow of the model, for instance, represented in Figure 4 where the range for the relative rotation of the lower and upper arm is represented

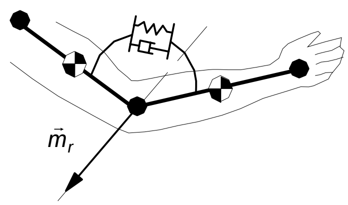


Fig. 4 Joint resistance torque modeled with a spring and damper torsional element.

A set of contact surfaces is defined for the calculation of the external forces exerted on the model when the bodies contact other objects or different body segments. These surfaces are generally ellipsoids and cylinders with the form depicted by Figure 3(d). When contact between components of the biomechanical model are detected a contact forces are applied to such components in the points of contact. Friction forces are also applied to the contact surfaces using Coulomb friction. It must be noted that the characterization of the surfaces in contact is important for general applications of the biomechanical model.

Biomechanical models such as the ones described, both for human subjects and for dummies, have been validated experimentally and are now used as virtual testing devices in many design and analysis situations. However, these models cannot provide biofidelic responses in many situations, such as for low speed impact, large deformations of the spinal column or anytime that the muscle activity plays a role. Some important efforts have been developed to overcome such problems and to provide detailed mathematical models, as the one represented in Figure 5 for the cervical spine (de Jager, 1994). Besides having a anatomical correct representation of the geometry of the vertebras this model includes the intervertebral discs, the ligaments, the contact between the facets of the vertebras and the reflexive muscle activity during impact.

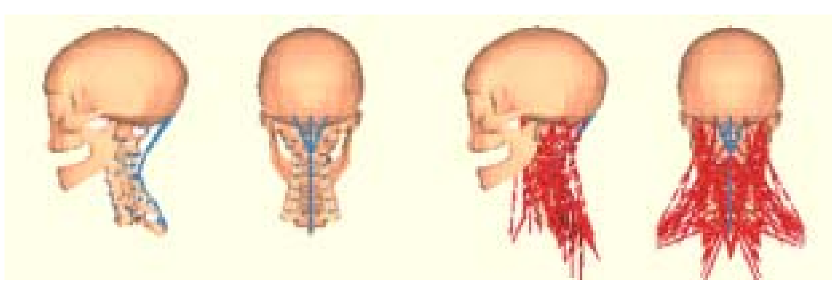


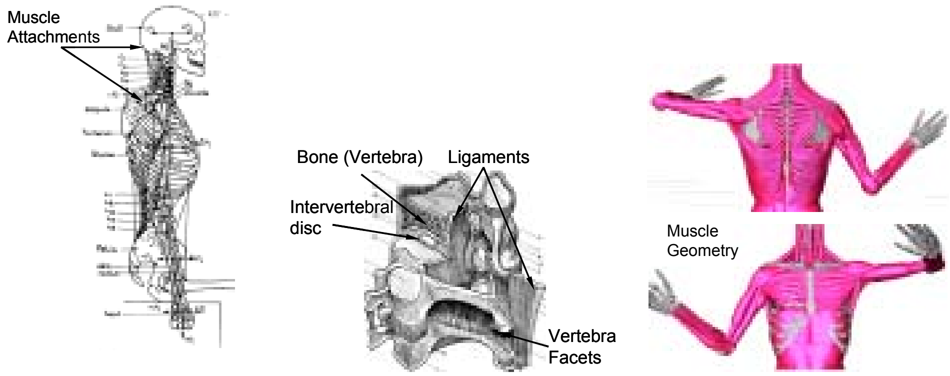
Fig. 5 Detailed head-neck model by de Jager (1994).

Along the line of development of this type of models other efforts are currently under way, such as the FP5 European project HUMOS II or the FP6 Integrated project APROSYS, to supply new and more advanced biomechanical models for injury assessment. Together with the development of new knowledge on injury mechanisms and corresponding injury criteria and tolerance levels that will result from the use of these new generation models and of the testing programs that are in place the new mathematical tools are predicted to have a major impact on the design of vehicles interiors. The issue of the safety of more vulnerable users, such as children and the elderly, or of more complex scenarios will certainly be better addressed by these models.

Advanced Modelling Features for Railway Occupants

One of the particular features of the use of the railway vehicles by the passengers is the mobility that they experience while travelling. Much of this mobility is possible because of the wide volumes for the motion of the occupants, the lack of any enforced use of restraining devices, such as seat belts, the different areas inside the trains and the furniture in the vehicle interiors that invite a more 'comfortable' posture and a better access to the entrance and exit of the vehicle. The simulations of particular postures and the different seating and standing positions of the railway vehicle occupants are not as biofidelic as for the occupants of road vehicles because: the kinematics of the occupant are not guided; the front and side facing occupants lead to body to body impact that is not the type of impact for which the biomechanical models have been developed; the lag of time between the warning signs that develop before the collision and the impact that follows allow for the passengers to take defensive measures; the muscle activity in the standing passengers modifies considerably the post-impact kinematics.

The investigation of more biofidelic biomechanical models for railway occupant representations requires that some effort is put on the identification of the aspects that differentiate the posture of the typical railway passenger from that of the occupant of other types of transportation. The non-guided kinematics of the railway vehicle occupant and the multiple postures that can be taken require that the models used for the design of the vehicle interiors are more detailed than those used for road vehicles. In particular, a more detailed model for the spine and for the torax, as for instance that implied by Figure 6(b), can be of major importance. Models of the different anatomical elements of the spine, including the vertebras, discs and ligaments, as presented in Figure 6(b), is required if the correct representation of the posture is of importance. Finally, the detailed representation of the skeletal-muscle system, such as that implied by Figure 6(c) is fundamental if the biomechanics of impact for low and medium velocities is to be accurately evaluated and if the muscle actions are to be included in the biomechanical response of the occupants models.



a) b) c)

Fig. 6 Advanced features for occupant biomechanical models: (a) elements of the trunk (Seireg, 1989); (b) detail of the spine (Kapandji, 1974); (c) Detailed representation fo the muscles (Murial, 1999)

Several questions will have to be addressed before more biofidelic models are developed, especially if they are to include the features listed before. There are ongoing efforts, as for instance the European Projects HUMOS II and APROSYS, to identify detailed data and models for the human body with high potential to be used in railway crashworthiness. However, it is not clear how issues such as age, size and gender will be handled in such models. The identification of the muscle reflexive actions has been addressed by several researchers, especially when applied to the head-neck muscles (De Jager, 1994). However, it is not clear how such activity will be evaluated for other muscle groups or how the voluntary muscle activity will be handled. Finally, the identification of the typical postures for railway passengers has still to be made.

Prediction of the Muscle Activity

The existence of muscle activity and the standing postures in a very significant number of impact cases is a distinctive feature of the railway occupants biomechanics. The identification of the typical postures adopted by the passengers can be achieved using standard videogrammetric techniques, such as those used for motion analysis and depicted in Figure 7. Due to the large volumes existing in the railway vehicle it is feasible to devise a suitable experimental program with which the kinematic and force data associated to different passenger postures and to post-impact motion can be identified.

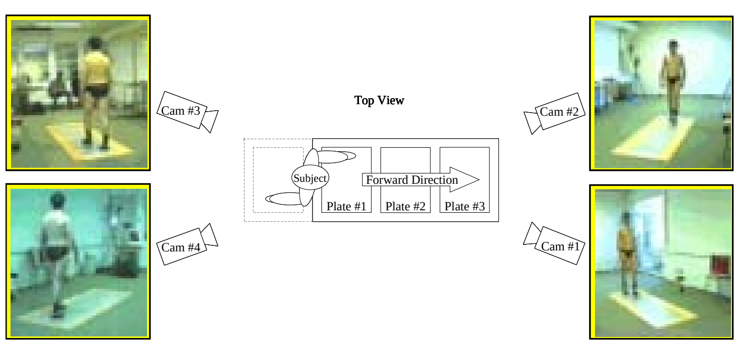


Fig. 7 Kinetic and kinematic data acquisition in a typical gait study (Silva, 2002)

The problem of identifying the muscle forces requires that a detailed description of the most important muscles and muscle groups is done. The anatomical data existing today ensures that the important data required for the development of such models, including the PCSA, location of the insertion points, maximum force, geometry and physiology is available, at least for the normal adult. The data for the reflexive muscle forces, developed due to the high extension rate experienced by the muscle during the impact, can also be obtained. The major problem is to identify the muscle forces developed during the voluntary contractions, as those observed for the standing passenger. The combined use of detailed muscle models, inverse dynamics analysis of biomechanical models and suitable optimization procedures provides solutions for this type of problem, already applied in many human activities such as gait analysis, exemplified in Figure 8, and different athletic activities.

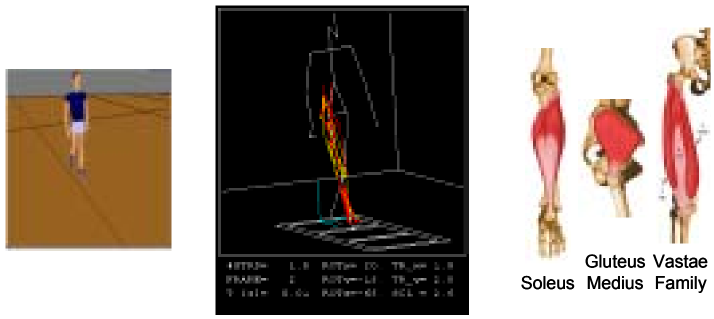


Fig. 8 Evaluation of the muscle force sharing in gait analysis(Silva, 2003)

It is suggested here that the same techniques are used here for the identification of the voluntary muscle actions of the standing passenger and for the analysis of the joint stiffening during the crash events. As the crash event is generally very short, an experimental program supported by proper biomechanical models can be devised to obtain the most relevant pre-crash muscle data and body postures, without involving the actual crash event.

Conclusion

The biomechanical models for occupants of railway vehicles to be used in crashworthiness have requirements that surpass those used for road vehicles or for aerospace applications. Besides the normal seating positions of unbelted passengers, similar to those experienced in road vehicles, in particular buses, these models must allow for the simulation of front and side facing passengers and for the study of contact with the interior of the vehicle, including tables, poles and rails. What is in road vehicles designated by out-of-position passengers is the norm with railway occupants because these can be in almost any possible position when an impact takes place. An important case of the occupant impact biomechanics particular to railway vehicles is the standing passenger for which the muscle activity may play an important role. The actual biomechanics models for whole body response neither account for the voluntary muscle activity that leads to the stiffening of the joints nor are they suitable for passenger posture studies. Some of the developments that are required in the biomechanical models to increase their biofidelity for application to railway passive safety design include the more detailed description of the anatomical segments, a more realistic representation of the geometrical and material properties of the body segments, improved models for the neck and trunk including the bony structures, ligaments, intervertebral discs and anatomical joints, and biofidelic muscle models that include reflexive and voluntary contraction. Other issues that should be addressed in the future concern with the improvement of the correlation between the injury indexes for the different parts of the human body and the biomechanics of injury observed in real life cases, especially in face of the particular design of the railway vehicle interiors. To achieve a satisfactory response to these issues a testing program for railway vehicle occupants able to identify voluntary joint stiffening and muscle contraction must be devised and a better description of the geometrical and material characteristics of the vehicle interiors, specially in what their energy absorbing characteristics is concerned.

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APPENDIX

A OCCUPANT DYNAMICS – PRESENTATION NOT AVAILABLE

B INJURY CRITERIA FOR RAIL INTERIOR CRASHWORTHINESS

C OCCUPANT KINEMATICS IN RAIL CRASHES AND THE SUBSEQUENT CRASHWORTHY PERFORMANCE OF THE INTERIORS

D EVACUATION IN CASE OF AN EMERGENCY

E TRAIN EGRESS & EVACUATION

F OCCUPANT MODELLING FOR IMPACT BIOMECHANICS

Injury Criteria Workshop

Workshop Introduction and Scope

Dr A. R. Payne

MIRA Ltd

Injury Criteria Workshop

- What are 'Injury Criteria'?
- Where did 'Injury Criteria' come from?
- How are 'Injury Criteria' currently used?
- How 'injury Criteria' be applied to Rail Interiors?
- Injury Criteria Options for Rail Interiors

What are 'Injury Criteria'?

'An injury criteria is a mathematical relationship, based on empirical observation, which formally describes a relationship between some measurable physical parameter interacting with a test subject and the occurrence of injury that directly results from that interaction.'

S. W. Rouhana 1993

An engineering parameter (acceleration, force, displacement) which mimics an injury causation mechanism, that can be used to assess the potential injury level produced from that mechanism.

Where did 'Injury Criteria' come from?

Mainly the Automotive Industry

- Based on the body part impact areas and mechanisms for seated car occupants with restraint systems

Frontal –	Head, Chest, Femurs
	Neck, Lower Legs
Side -	Head, Chest, Abdomen, Pelvis

- Based on the instrumentation with crash test dummies

Frontal -	HIII (50%, 95%, 5%, 10yr, 6yr, 3yr, 18mth), THOR
Side -	USSID, EuroSID, WorldSID (50%) SIDIIs (5%)

Accelerometers / Potentiometers / Load Cells

How are 'Injury Criteria' currently used?

- **Automotive Industry**
- Tolerance levels for injury criteria are used to 'Benchmark' vehicle injury criteria.
  - Set minimum levels - Legislation (FMVSS208)
  - Compare vehicles - Consumer Tests (EuroNCAP)
- They are not to look at actual injuries or injury levels but to improve vehicle crashworthiness performance.
- As Crashworthiness performance improves tolerance levels lower
- Concerned with fatality and serious disability NOT egress
- **Aerospace**
- Adopted Automotive injury criteria but set tolernace limits to biomechanical levels

How 'Injury Criteria' has been applied to Rail Interiors?

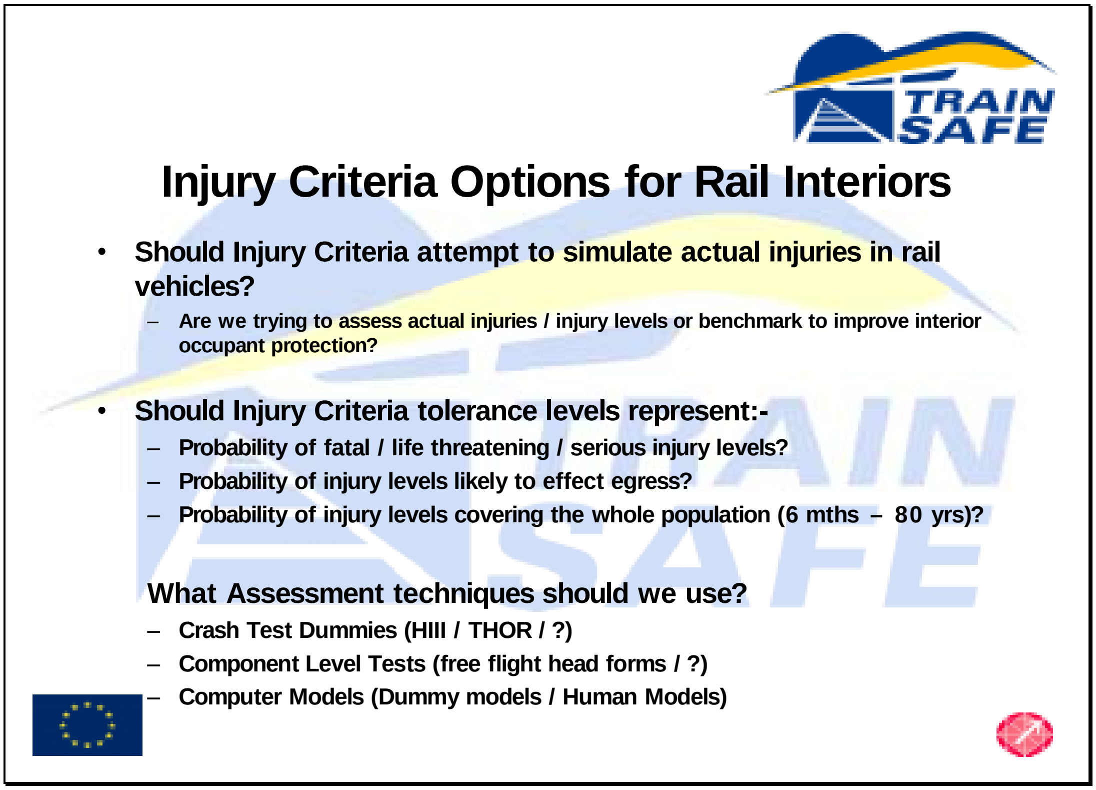
UK Interior Crashworthiness Standard AV/ST9001

- Injury Criteria taken from Automotive Industry as HIII crash test dummy is used as the assessment tool.

Head –	Resultant Acc / Head Injury Criteria (HIC)
Neck –	Resultant Bending Moment
Chest –	Chest deflection (method too crude)
Abdomen –	Intrusion (frangible abdomen not applicable)
Legs –	femur loads / sliding knee / tibia index

- Tolerance Levels based on unrestrained occupant (ECE R80 Coach Seat)

HIC –	500	(5% Life threatening injury)
Chest Deflection -	30mm	(rib fracture)
Abdominal Compression -	40mm	(abdominal injury)
Femur Load -	4Kn	(Femur fracture 6-9Kn – Knee/pelvis injury)
Knee Joint Shear –	12mm	(Cruciate ligament rupture)
Tibia Index –	0.75	(tibia fracture at 1)


TRAIN SAFE
Injury Criteria Options for Rail Interiors
• Should Injury Criteria attempt to simulate actual injuries in rail vehicles?
– Are we trying to assess actual injuries / injury levels or benchmark to improve interior occupant protection?
• Should Injury Criteria tolerance levels represent:-
– Probability of fatal / life threatening / serious injury levels?
– Probability of injury levels likely to effect egress?
– Probability of injury levels covering the whole population (6 mths – 80 yrs)?
What Assessment techniques should we use?
– Crash Test Dummies (HIII / THOR / ?)
– Component Level Tests (free flight head forms / ?)
– Computer Models (Dummy models / Human Models)

Occupant Kinematics in Rail Crashes and the Subsequent Crashworthy Performance of the Interiors

By

Bernadette Stanley Beng Ceng MIEE

MIRA Limited

Should a Robust Solution be Active

- Current interior design depends on passive safety mechanisms
  - Many seating configurations
  - Different 'furniture' designs (Geometry)
  - Other potential hazards eg grab handles, poles etc
  - Inconsistent range of pulses
- Many compromises to be made when designing safe interiors for all scenarios

A Potential Active Device. Seat Belts

- By restraining all occupants in their seats, the seating layout becomes less of an issue
- Table and partition walls etc would not be as hazardous
- Evacuation could be less problematic?
- Issues
  - Vandalism
  - Use
  - Cost
  - Standing Passengers

Evacuation - Escape

Dr. Jaap Horst

AEA Technology Rail BV

Assisted by Peter Matthews, the Engineering Link (also AEAT)

Examples:

- Closed doors
- Failing Emergency lights
- Sleeping during evacuation
- Not-functional escape windows

Evacuation ←→ Escape

Aspects are:

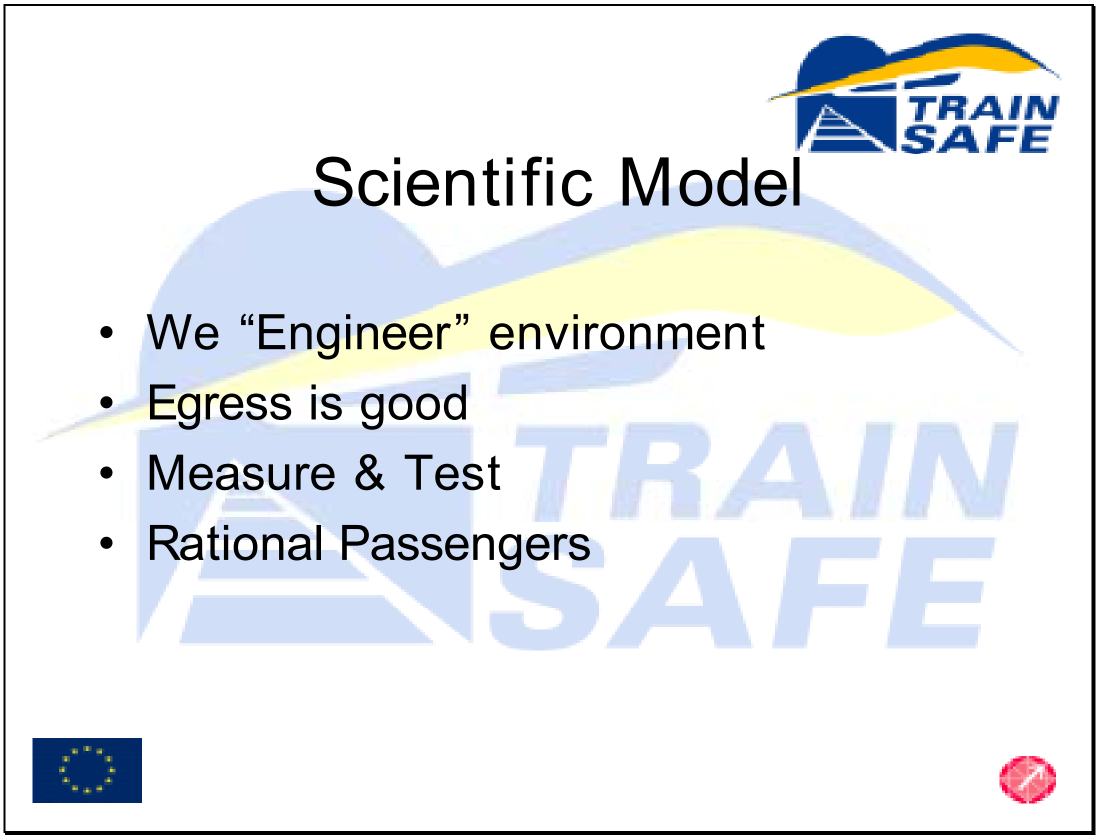
Human	Technical
Communication	Design & construction
Training	Lighting / Signalling
Plans	Emergency Brake / Alarm systems
Procedures	Fire detection and extinguishing
Passengers	

Train Egress & Evacuation

Nick Swift HSBC Rail

Three Models

- Scientific
- Risk
- Human



Scientific Model
We "Engineer" environment
Egress is good
Measure & Test
Rational Passengers

Risk Model

- We "Engineer" environment
- Egress not good - Safer on train
- Rational Passengers

Human Model

- Chaotic Environment
- We provide tools
- Decision delegated - trust the passenger


Common Standards
• Improves public safety?
• Standards vs Innovation?
• Agreed model?

Occupant Modelling for Impact Biomechanics

Injury Prediction in Railway Vehicles

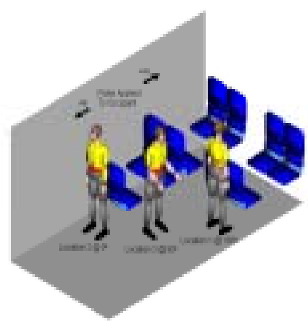
by

Jorge Ambrósio
IDMEC – Instituto Superior Técnico
Lisbon, Portugal

Railway Occupant Biomechanics versus Road Vehicle Occupants

Seating Position:

- Front facing seating positions.
- Side facing seating positions.
- Standing passengers
- Out-of-position occupants (???).



Vehicle Interiors:

- Tables between seats.
- Poles and rails.
- Seats without structural energy absoption.

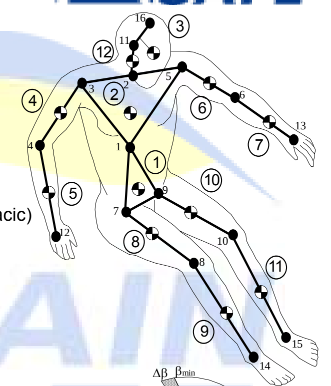
Restraint and Protection Systems:

- No restraint systems are used.
- No devices such as air-bags.
- Seats/furniture without structural energy absoption.

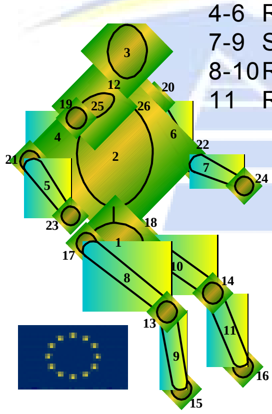
Biomechanical Models for Impact

Biomechanical Characteristics

12 Rigid bodies
29 degrees-of-freedom



Joint	Type	Description
1	Spherical	Back, (12th thoracic and 1st lumbar).
2	Spherical	Torso-Neck (7th cervical + 1st thoracic)
3-5	Spherical	Shoulder.
4-6	Revolute	Elbow.
7-9	Spherical	Hip.
8-10	Revolute	Knee.
11	Revolute	Head-Neck, (at occipital condyles).

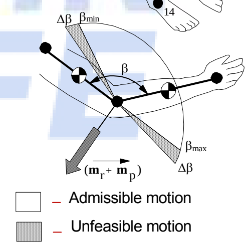


Contact Surfaces

The contact surfaces are used to describe the occurrence of contact.

Contact surfaces are defined by an ellipsoid.

One or more ellipsoids define each segment



Biomechanical Models for Impact

Road Vehicle Applications

- Restrained occupant

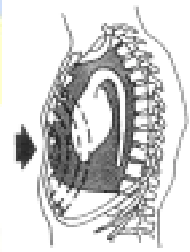
Complex Application Cases

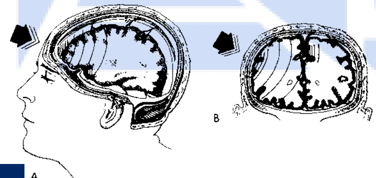
- Pedestrian sidesweep

- Vehicle rollover

Injury Biomechanics

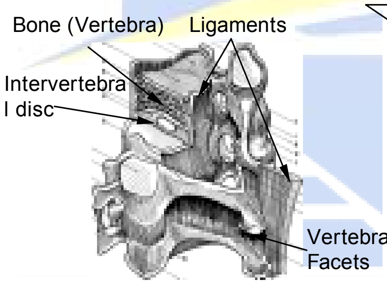
- Response of the brain within the skull to frontal and lateral head impact
- Downward impact on the head can flex or extend the neck with the potential for fracture-dislocation of the vertebrae and damage to the spinal cord
- Compression of the chest or abdomen cause injury if the elastic tolerances are exceeded
- Impulsive shock cause shock waves that may lead to injury if the viscous tolerances are exceeded
- Excessive acceleration leads to tearing of the internal structures





Modeling Requirements for Railway Vehicle Occupants

- Important to model muscle voluntary contraction
- Important to have more detailed human body for injury prediction



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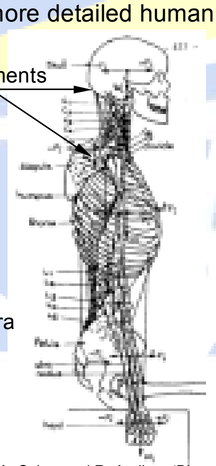

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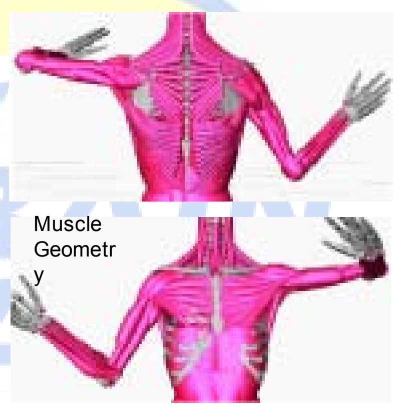

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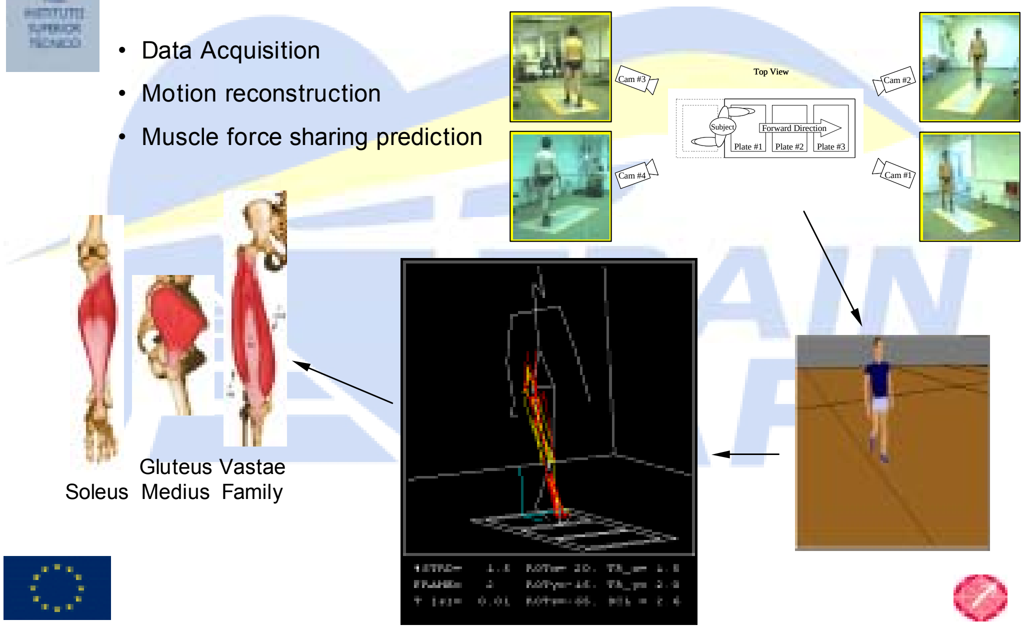
Muscle Forces Prediction

- Data Acquisition
- Motion reconstruction
- Muscle force sharing prediction



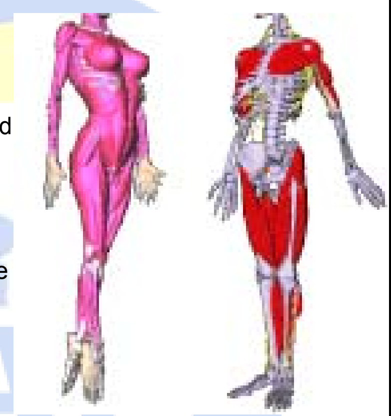
Wish List For Biomechanical Models Features for Railway Passive Safety

Biofidelity:

- Detailed description of the anatomical segments.
- Realistic representation of the geometrical and material features of the body segments.
- Good model for the neck and trunk including bones, ligaments, spinal discs and joints
- Biofidelic muscle models that include reflexive and voluntary contraction.

Others:

- Improved Injury Indexes for the different segments of the human body.
- A testing program for railway vehicle occupants able to identify voluntary joint stiffening and voluntary muscle contraction.
- Better description of the geometrical and material features of the vehicle interiors.



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