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DISASTER COMPLEXITY CASE STUDY

Disaster complexity and the Santiago de Compostela train derailment

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ABSTRACT

This disaster complexity case study examines Spain's deadliest train derailment that occurred on July 24, 2013 on the outskirts of Santiago de Compostela, Galicia, Spain. Train derailments are typically survivable. However, in this case, human error was a primary factor as the train driver powered the Alvia train into a left curve at more than twice the posted speed. All 13 cars came off the rails with many of the carriages careening into a concrete barrier lining the curve, leading to exceptional mortality and injury. Among the 224 train occupants, 80 (36%) were killed and all of the remaining 144 (4%) were injured. The official investigative report determined that this crash was completely preventable.

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anthropogenic disaster; complex disaster; complexity science; disaster cascade; human-generated disaster; mass casualty incident; risk landscape; transportation disaster; technological disaster; train derailment

This case study was created by assembling a team of expert co-authors, including a mechanical engineer who is a renowned authority on transportation disasters, a trauma surgeon who directs a vehicle crash research center, and a team of disaster psychologists from Spain, rounded off by specialists in disaster health and complexity sciences. The complementary vantage points of these subject matter experts were blended together to reconstruct the cascading sequence of harmful events that took place. First, the engineer's perspective describes the mechanics of derailment and details the destructive demise of the train. Second, the surgeon tells how the passengers sustained deadly and injurious medical trauma as the carriages overturned, collided, and skidded along the retaining wall. Third, a team of Spanish disaster psychologists who respond to national emergencies explains the rippling psychosocial consequences that expand to affect the train crash survivors, the family members of the injured and deceased, the rescue personnel, the local population, and the citizens of Spain.

This case study presents an interesting contrast to the official crash investigation. Employing simplicity thinking and linear logic, the official findings and the judicial rulings determined that the train driver was "exclusively" responsible for the crash. The analysis presented here applies complex systems thinking both upstream and downstream from the moment of the crash. The expert contributions tell the downstream sequence that began as the train entered the curve at excessive speed: derailment, train rollover and destruction, occupant death and injury, and psychological trauma and loss. Upstream, it was possible to identify a broader latticework of causal factors. This upstream component is particularly useful when searching for a more comprehensive set of preventive interventions

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Figure 1. Alvia 13-car train (RENFE Class 130).

that think beyond, supersede, or override human error. Implications for disaster prevention and preparedness are discussed.

Disaster synopsis

At 8:41 PM on the evening of July 24, 2013, an Alvia hybrid high-speed train (Fig. 1), en route from Madrid to Ferrol, Spain, was traveling at 195 km/h (121 mph), and failed to decelerate to negotiate a sharp left curve, with a posted speed of 80 km/h (50 mph), while passing by the hamlet of Angrois, on approach to Santiago de Compostela.[1-6] The entire train - all 13 carriages, including locomotives fore and aft - toppled from the rails (Fig. 2). Multiple cars fell over onto their right sides, skidding with forward momentum as their roofs scraped against an imposing concrete wall erected along the curved tracks. Several passenger coaches went airborne and both a generator car and a passenger coach caught fire.

The train was a member of the Alvia fleet, operated by Spain's national railway network, "RENFE" (*Red Nacional de los Ferrocarriles Españoles*). Although automated accident prevention systems for slowing a speeding train are available throughout many portions of Spain's extensive rail system, this safeguard (the Level 2 European Rail Traffic Management System, "ERTMS") was not available along the curve where the crash occurred.[1,7,8]

The accident resulted in medical trauma of uncommon severity, especially for a train derailment.[9] Among the 224 occupants, all were either killed (80) or injured (144).[2,3] including 140 injured survivors who required medical or surgical treatment. No one escaped alive and unharmed. This was Spain's deadliest rail crash and the first fatality incident since the introduction of the high-speed rail system in 1992.[10]

The derailment occurred on the eve of the Feast of St. James the Apostle, a Spanish national holiday, when thousands of visitors, including pilgrims completing the Walk of St. James (*El Camino de Santiago*), assemble at the Cathedral of Santiago de Compostela to honor the Saint. The train was full with passengers traveling to visit their homes and attend this venerated annual observance that coincides with the peak of the summer holiday season.

Weather and track conditions were optimal and did not contribute to the accident. Visibility was clear. The

Figure 2. Alvia train derailment and crash sequence, July 24, 2015, Santiago de Compostela, Spain.

train was moving along level track so terrain was not a factor. Crash investigators determined that signals and train driver alerts were operational.[2]

The train driver's attention was distracted by repeated mobile phone calls from the railway's inspector in charge of the rail line leading into Santiago de Compostela.[1-3] The last of these calls lasted 1 minute and 42 seconds, sufficient time for the train to travel more than 5.5 km and emerge from the final tunnel before the curve. Just as he terminated the call, the train driver, Mr. Francisco Garzón Amo, realized that the train was entering the arc of the "*A Grandeira*" curve at high velocity. Prior to that moment, he had failed to heed three separate alerts indicating that the train was traveling at excessive speed. In the final seconds, he attempted to apply the brakes but it was too late to avoid the crash. The train vaulted from the rails at 179 km/h (111 mph).[1-3]

Of particular interest is the interplay among the event-specific train crash hazards, the severe and deadly medical injuries sustained by the train occupants, and the psychological experiences of trauma and loss. Psychological impacts were related to the degree of physical proximity and social connection to the event and the volume of media exposure.

Authoring the case study

This case study was developed by purposefully assembling an event-specific expert author team. The saga of the Santiago de Compostela train crash was reconstructed from the complementary vantage points of international experts in transportation engineering, crash injury research, biomechanics, disaster and trauma psychology, complexity sciences, and disaster health. Critical to the process was the involvement of a team of disaster psychologists from Spain. The author contributions have been sequenced to provide a cohesive description of the disaster in a manner that illustrates the complex risks and cascading consequences. This approach to authorship enlarged the discussion by inviting trans-disciplinary expertise onboard a single publication.

Distinguishing features of the Santiago de Compostela train derailment

In the taxonomy of extreme events, this incident can be classified as a *non-intentional, human-generated (anthropogenic) technological/transportation disaster*.[11,12] The Santiago de Compostela passenger train derailment was selected as a disaster complexity case study because this event clearly illustrates both the "upstream" pre-crash risk landscape and the "downstream" cascades of harm that began at the moment of derailment.[13-19] This transportation disaster was also chosen for ease of story-telling because it was a discrete incident that was bounded in time and place.

Distinguishing features of this disaster included: human error as a primary contributor to a preventable event, absence of automated safety engineering to slow the speeding train, excessive velocity, extreme wreckage, and co-occurring medical and psychological trauma (Table 1). The observed 100% rate of death or injury as an outcome of a train derailment represents a true anomaly in the history of rail crashes.[9] The psychological effects were most acute for the crash survivors but extended outward to encompass the family members of the injured and deceased; the professional rescue and hospital personnel who performed a tactical mass casualty response under duress; and the heroic community volunteers from the village of Angrois (where the train derailed) who were first on-scene to offer assistance. The citizens of Santiago de Compostela were also strongly affected. The entire national population of Spain was initially barraged with graphic and potentially traumatizing media coverage at the time of the crash. Thereafter, the nation waited a full year for the completion and public release of the investigative report, followed by another year before the criminal charges were announced. The trial is still pending.

The official story: the train driver was "exclusively" responsible

Consensus was evident. The dominant media stories at the time of the incident, the Spanish Ministry of Development's investigative report, and the judge's rulings all place blame squarely and solely on the train driver.

July 2013 media accounts

In the immediate aftermath, the "breaking news" storyline that was carried in the media was straightforward: the train driver's attention was distracted as he talked on his phone and he failed to slow the speeding train as it approached a sharp curve. The entire train derailed, killing or injuring all train occupants, and the driver was likely to be charged with a capital

Table 1. Distinguishing Features of the Santiago de Compostela Train Derailment Galicia, Spain, July 24, 2013.

Defining characteristics	
1	Deadliest rail crash in Spain's history (80 deaths)
2	One of the deadliest train *derailment* accidents in world history
3	First fatality crash involving Spain's high-speed rail system
4	Derailment of a fully-operational train traveling under optimal conditions (good weather, visibility, and track conditions; no other trains in the vicinity)
5	Derailment due to excessive speed on a curve (more than twice the posted speed)
Human-generated component	
6	Official government determination: completely preventable disaster
7	Official government determination: Train driver was distracted, talking on the company cell phone, and failed to slow the train
8	Official government position: the train driver bears "exclusive" responsibility
9	Judicial rulings: Train driver charged with 80 counts of reckless manslaughter and 144 counts of reckless injury
Exceptional rates of death and injury for a train derailment	
10	Death or injury for 100%: 224 of 224 occupants were either killed or injured
11	High mortality rate (36.0%): 80 of 224 occupants died in the crash
12	High injury rate (64.0%): 144 of 224 occupants survived; all 144 were injured
Important system safeguards were not available	
13	The Level 2 European Rail Traffic Management System (ERTMS) accident prevention systems for automatically slowing a speeding train were not activated on the curve where the train derailed
14	Driver was distracted by a company cell phone call from railway controller
15	Official government investigation downplayed systemic contributions to risk

crime. This made-for-media depiction contained the elements of a preventable tragedy, victims to mourn, a villain to blame, and a search for justice.

July 2014 Railway Accident Investigation Commission investigative report

One year after the date of the crash, the initial media stories were echoed, in substance and simplicity, when Spain's Railway Accident Investigation Commission (CIAF), Ministry of Development, released its official report. The CIAF report described the Santiago de Compostela crash as completely preventable.

The 266-page document opens with a terse distillate of the event: the crash was due to excessive speed that caused the train to derail on a sharp curve.[1] The driver was engaged in a conversation with the track agent using the company's mobile phone and he failed to attend to his driving duties as the train sped toward Santiago de Compostela, several minutes behind schedule. The driver was cited for breaches of protocol for failing to brake the train safely and was reported to face criminal charges including one count of "homicide by professional recklessness" for each fatality.[20]

Consistent with placing primary blame on train driver error, the CIAF report prescribed a series of engineering modifications and administrative processes to prevent future incidents, primarily by diminishing the chances for human negligence as a precipitating factor.[1] Suggested remedies included posting speed limit signs, implementing audio and video surveillance inside the driver's cab, developing secure communication systems that decrease the chances for driver distraction, establishing committees to identify potential crash risks, and installing automated speed reduction equipment along more sections of the national railways.

October 2015 judicial ruling

On October 6, 2015, the train driver, Mr. Garzón Amo, was formally charged. The case against him as the culpable party whose negligence caused the derailment was released publicly in a 22-page judicial ruling.[2,3] Concluding the two-year investigation, a judge charged the driver with 80 counts of reckless manslaughter, one charge for each death, and 144 counts of reckless injury. Mr. Garzón Amo will stand trial. The judge's case both references and resembles the CIAF findings, rendered in concise legal prose and condensed into 22 pages.

The ruling outlined the judicial case that the crash was caused by excessive speed and that Mr. Garzón Amo, described as a veteran engineer who had personally driven this route, round-trip, on 59 previous occasions, bears "exclusive" responsibility for the deadly derailment.[2,3] Alternative foci for blame were mentioned, including the absence of an automated ERTMS safety system on the *A Grandeira* curve, but their importance is systematically discounted. In addition to charges stemming from the crash-associated mortality and morbidity, the cost estimate for damages to track and railway infrastructure was placed at €1.4 million. No cost estimate was provided for the destruction of the 13-car Alvia train (RENFE Class 130 manufactured by Bombardier Transportation, Germany).

Simplicity thinking and linear logic

There is considerable appeal to the simple and consistent story that was told in multiple installments delivered at one-year intervals. The real-time media accounts at the time of the crash in 2013,[4-7,10,20-22] the CIAF investigative report in 2014,[1] and the judicial rulings in 2015,[2,3] all fault the driver as "exclusively" responsible for the derailment. In each case, the media reporters, the CIAF investigators, and the judge who filed the ruling, all employed "linear logic."

When diagrammed, the elements literally "line up" – driver inattention, excessive speed, derailment and crash, catastrophic destruction of the train, and fatal or injurious medical trauma (Fig. 3). Consistent with the linear logic employed, the proposed solutions focus on increasing the surveillance and supervision of train drivers.

The simple story creates a package that is clear, concise, and aligns well with a disaster episode that was so tightly constrained in time and place.

Time

The Santiago de Compostela derailment happened very fast. Once off the tracks, frictional forces rapidly brought the derailed train cars to complete standstill in a matter of several seconds.

Place

Trains glide along rails, coupled together, at least until they derail. The physical destruction of the 13-car Alvia train was geographically limited to the immediate vicinity of the *A Grandeira* curve, a half-kilometer-long semicircle of track (Fig. 4). The derailing train collided with a reinforced concrete wall that restricted the scattering of the wreckage and prevented the coaches from tumbling into nearby residential neighborhoods.

Captured on film by a trackside closed-circuit camera, the brief duration and the circumscribed physical footprint can be visually confirmed.[23] These particular realities of the event are amenable to description in a simple manner.

Simplicity is also reflected in the fact that the CIAF report and judicial rulings present almost no information regarding the human health and societal consequences of the crash. Apart from tabulating the numbers of passengers who were killed or injured – the basis for bringing charges – no detail was presented on the patterns of mortality and injury. No mention was made of psychological trauma, loss, grief, and bereavement experienced by passengers who were injured but survived, and the family members of surviving and the deceased train occupants. Psychosocial effects on the community of Angrois, the city of Santiago de Compostela, or the larger citizenry of Spain were beyond the scope of inquiry. It is important to note that no other ministry or government agency examined the health and social impacts of the train crash.

Dissenting viewpoints from the victims

The surviving passengers, and the family members of the train occupants (both those who lived and died),

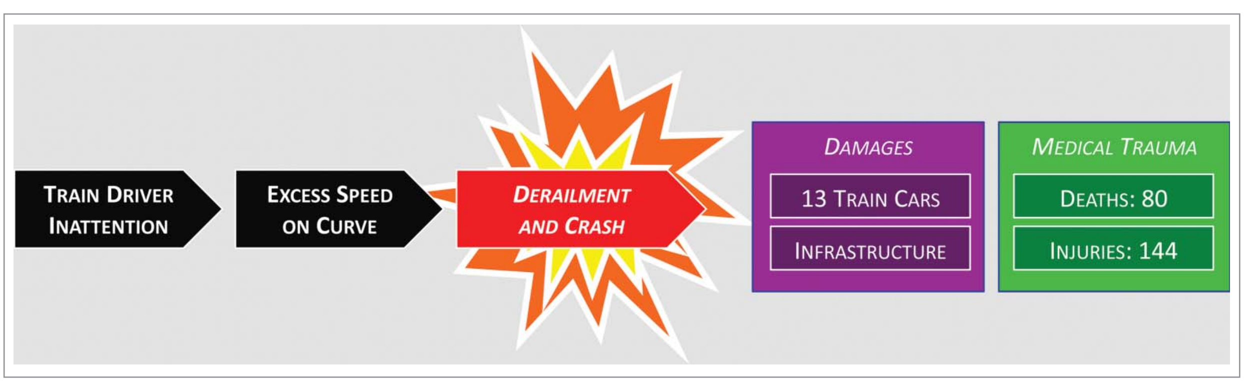

Figure 3. Simplicity thinking and linear causation: Santiago de Compostela train edrailment, Galicia, Spain, July 24, 2013.

Figure 4. The *A Grandeira* curve where the crash occurred shortly after the train emerged from the tunnel (see the label "Ourense") on approach to Santiago de Compostela.

do not subscribe to the government's official version of the crash saga. They have come together, creating an organization (Asociación de Perjudicados por el Accidente Ferroviario del Alvia de Santiago de Compostela - APAFAS) to share information and advocate for a just settlement (http://www.apafas.es). Upon the release of the 2015 judicial rulings, APAFAS President González Rabadán wrote a letter to Justice Alberto Ruiz Gallardón, expressing the victims' consensus that, "the unique cause was not the train driver."

The victims are distressed and vocal about the official conclusions. Indeed, the CIAF report is limited in scope and is understandably restricted by the agency's purview and agenda.[1] One potential motive for concluding that the driver is solely to blame, as raised by the victims, may have been to deflect blame away from the national railway system. As noted, the CIAF report carefully aligns the evidence and constructs a detailed case to establish the centrality of human error and the culpability of the train driver. The judicial rulings follow suit.

These dissenting viewpoints of the victims and their advocates have legal and liability implications that are beyond the scope of this paper. However, from the standpoint of considering the cascade of consequences it is important to mention here that psychological issues of importance include the prolonged secondary victimization that occurs when investigations and legal proceedings take years to conclude. The Santiago de Compostela tragedy remains vivid in the minds of victims, and unresolved. Victims and their family members have experienced life-changing injuries, loss of loved ones who were killed in the derailment, and psychological distress and disorders. Their search for "justice" and acknowledgment of the harm they have sustained has strong psychological overtones.

Complex systems thinking and non-linear causation

While the train derailment appears simple on the surface, there is more to the story. Neither the CIAF report nor the judicial rulings contemplate interacting risks or cascading consequences. The structure of these reports represents the antithesis of complex systems thinking.[1-3] The apparent simplicity of what transpired, as conveyed in the government's case, belies the underlying complexity. As with most disasters, there is rarely a singular cause.

The analysis presented hereafter provides an alternative perspective on the Santiago de Compostela train derailment. Disasters occur in the context of a complex risk "landscape" leading to "cascades" of consequences when a disaster strikes and extending into the aftermath. As a disaster event unfolds, situations frequently go from bad to worse, sometimes in the blink of an eye. The event gains momentum. Hazards compound[13,14] and negative consequences proliferate and amplify the harm sustained by disaster-affected citizens and their communities. This is because many disasters, including this train derailment, evolve from the interactions among multiple, interdependent risks.[15-19]

The current analysis applies complex systems thinking in two directions. First, a "downstream" examination of the disaster consequence cascade focuses on the expanding ripples of harm to individual and population health from the moment of derailment forward. Second, we then move back "upstream" to take a broader look at the pre-crash risk landscape in search of possible points of intervention. Dissecting the tragedy on the tracks leading into Santiago de Compostela at a finer level of detail – both downstream and upstream - may provide additional clues for how to prevent a future reenactment of the horribly damaging crash that occurred on the eve of the Festival of St. James, July 24, 2013.

Looking downstream: a cascade of disaster consequences

In the case of a train derailment, there is a literal "tipping point" as the train loses contact with the rails. When this happens, a cascade of outcomes unfolds rapidly and unstoppably. The Santiago de Compostela derailment presents a useful case study for examining the interrelationships among 1) train crash mechanics, 2) medical injury, and 3) multiple levels of psychosocial consequences (Fig. 5). This extensive "downstream" exploration of disaster consequence "cascades" is provided by a succession of our expert co-authors: explaining how trains crash, describing mechanisms of passenger injury in a rollover derailment, and defining how physical harm translates into psychological distress and disorders.

How trains crash

Railway crash expert, Dr. George Bibel, provides the explanation of how trains crash, with specific applications to the derailment that occurred near Santiago de Compostela. Train crashes still occur more or less the same way they did 100 years ago: they collide or derail (fly off the tracks).[9] While most train collisions result from human error, train derailments are usually

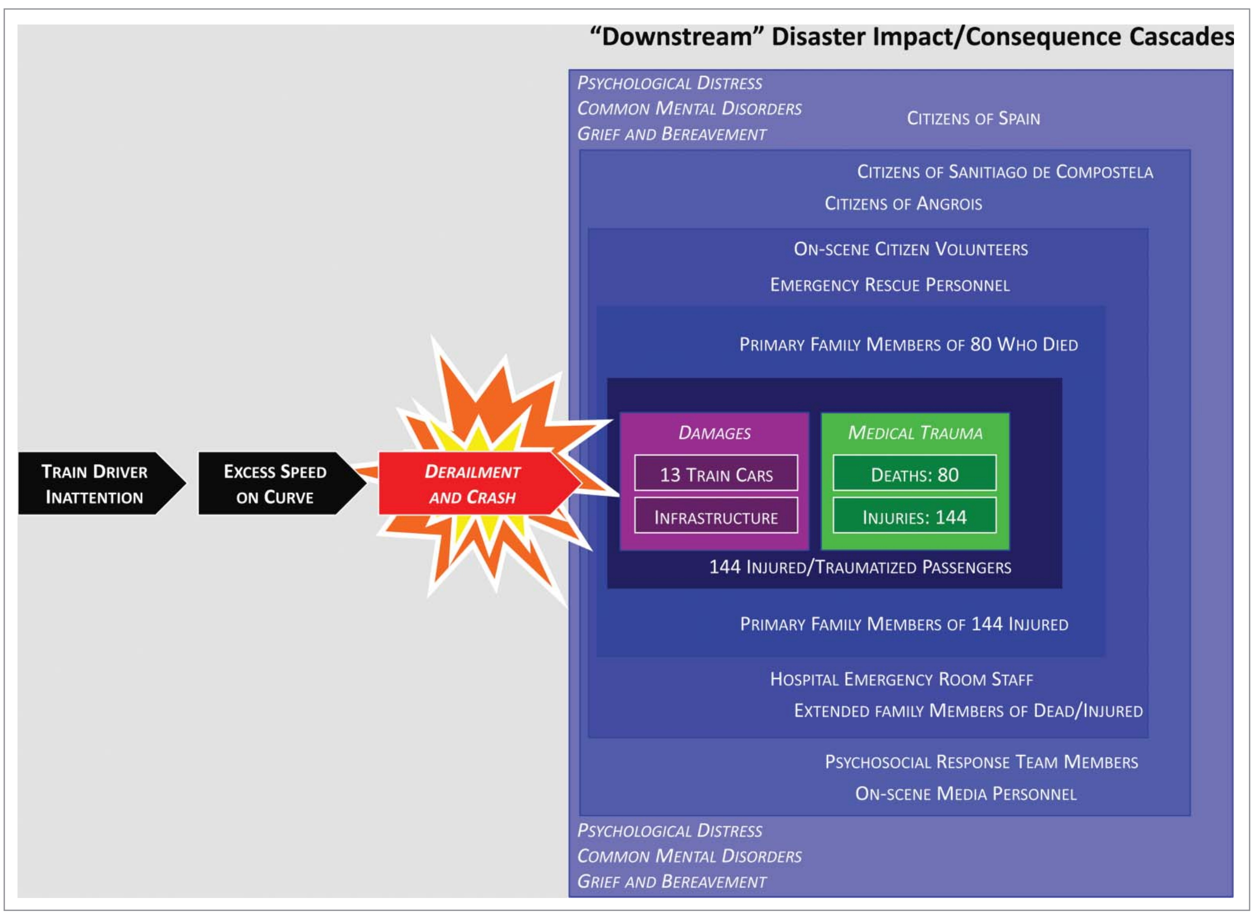

Figure 5. Complex systems thinking: Downstream cascade of disaster consequences: derailment, damages, medical trauma, psychosocial consequences. Santiago de Compostela Train Derailment, Galicia, Spain, July 24, 2013.

related to equipment failure (e.g. damaged or shifted track; broken wheels, axles, or bearings), shifted load, or environmental factors such as high winds or rock slides.[9] As the rare exception, the Santiago de Compostela tragedy involved the derailment of a fully-functional train that was traveling in daylight, on the level, with optimal weather and track conditions. A single passenger train was involved so no collision occurred.

Passenger trains are protected from overturning on a curve by the driver's attentiveness and a healthy margin of error between the (lower) posted speed limit and the (higher) overturning speed.[9] Many railways have installed electronic speed-monitoring devices that automatically intervene to slow a train that is traveling at excessive speed while approaching a tight curve (such as the ERTMS system previously described). Although RENFE has proactively installed such devices along many segments of Spain's national railway system, unfortunately such protections were not implemented along the *A Grandeira* curve.

Most derailments are surprisingly survivable, even at high speed and few result in high fatality rates.[9] Deadly exceptions tend to be memorable incidents such as when a train plummets off a mountain pass or plunges into water, resulting in significant loss of life. The 2013 crash of the Alvia express train on approach to Santiago de Compostela was especially deadly (36% fatality rate) and injurious (6% injury rate, representing 100% of those who were not killed) because the derailment occurred at high speed along the *A Grandeira* curve, whose entire outer perimeter is bordered by an imposing concrete retaining wall. Unable to hold the tracks at high speed, the inertial forces slammed the train into this immovable barrier. The forward momentum caused some of the derailing train cars to skid along the wall, as the car siding was ripped, sheared, and peeled by the extreme impact forces. The fact that derailment occurred while the train was traveling at high velocity in an arc around a tight left curve created extreme overturning loads that caused some of the cars to twist and violently tip over (Table 2).

The symmetrical 13-car Alvia configuration contributed to the severity of outcomes (Fig. 1).[1] Front to back, the train was composed of a forward locomotive ("power car") coupled to an electric generator car (that includes passenger seating), followed by a set of eight passenger carriages (or "coaches") and one dining car, and finally a trailing, rear-facing generator car and locomotive.[1] While the passenger coaches are relatively short and light, the locomotive and generator cars fore and aft are larger, longer, and heavier.

A track-side closed-circuit television camera captured the derailment on video.[23] During the crash, the forward power car toppled from the tracks and slithered savagely along the ground on its right side, its roof grazing the retaining wall. As this engine and its generator car slid to a halt, the rear of the train maintained its forward momentum. Lighter-weight passenger carriages, located between the heavier locomotives at either end of the train, were compressed. The momentum of the rear power/generator cars had the potential to cause passenger carriages to collapse in an accordion-like fashion and smash into each other sideways, possibly crushing the passengers. The camera showed the second or third car behind the locomotive coming off the tracks and slamming into the front of the concrete abutment alongside the tracks, apparently the most violent component of this accident. Consistent with this description, the rear generator and power cars were the last two cars to derail and come to rest (Fig. 6).

Several passenger carriages overturned, wedged upward, and even went airborne (Fig. 6). During a train crash, if adjacent cars are jammed together, end-to-end, the front of the trailing car does not typically impact uniformly into the back of preceding car. Instead, the impact is somewhat misaligned for a variety of reasons. This causes the stronger undercarriage of the impacting car to ride up onto the undercarriage of the impacted car and slice through the weaker sidewalls. The impacted car crushes and forms a ramp that may catapult the impacting car upward, sending it airborne for a distance before crashing into other derailed cars, as occurred in Santiago de Compostela.[9] All of these elements of train destruction happened, start-to-finish, and literally, front-to-back, within the span of about eight seconds.[23] As described by Dr. Bibel, the derailment triggered a complex process involving rotational forces in the tumbling carriages, mechanical interactions among the coupled cars, and a jangling collision of metal against an immovable concrete barrier.

How passengers are injured in a train derailment

Trauma surgeon, Dr. Carl Schulman, Director of the William Lehman Injury Research Center at the University of Miami Miller School of Medicine's Ryder Trauma Center and his colleague, George Bahouth,

Table 2. Profile of the Santiago de Compostela Train Derailment Galicia, Spain, July 24, 2013.

Event Description	
Type of Event	High-speed passenger train derailment into a concrete retaining wall on a sharp left curve (the *A Grandeira* curve).
Disaster Classification	Non-intentional, human-generated (anthropogenic) technological (transportation) disaster.
Possible Causal Factors	Train traveling at twice the posted speed for the curve. Train driver distraction/inattention/error.
Date and Time	24 July 2013 20:41 CEST (UTC+02:00)
Location	Angrois, Santiago de Compostela, Galicia, Spain 2 mi (3.2 km) southeast from Santiago de Compostela
Train Description	
Rail Line	Madrid – Ferrol route. Iberian gauge track.
Train Operator	Renfe
Train Description	Renfe Class S130H/S730: a special hybrid version of the Alvia train with both electric and diesel power, allowing the train to operate on high-speed and non-high-speed segments of the Spanish railway system. Built by Talgo and Bombardier (Germany). Two locomotives ("power cars") at either end of train using MTU 12 V 4000 R43L engines (1.8MW each).
Train Configuration	13 car "set" in symmetrical formation: Locomotive ("power car"), generator/passenger car, 9 passenger carriages (including one dining car), generator passenger car, locomotive.
Train Specifications	
Train length	183 m (600 ft 4.7 in)
Car length	20 m (65 ft 7.4 in) (power car) 13.14 m (43 ft 1.3 in) (passenger car)
Width	2.96 m (9 ft 8.54 in) (power car)
Height	4 m (13 ft 1.48 in) (power car)
Maximum speed	Overhead electrification – high-speed - mode: 260 km/h (160 mph) (standard gauge lines) 220 km/h (140 mph) (Iberian gauge lines) Diesel mode: 180 km/h (110 mph)
Derailment Description	
Speed at Time of Derailment	250 m before the curve: 195 km/h (121 mph): black box confirmed 179 km/h (111 mph) at moment of derailment Posted speed on curve: 80 km/h (50 mph)
Derailment of Entire Train	All 13 vehicles derailed: 2 power cars and the 2 adjacent generator cars (with diesel tanks) at the front and back of the train 9 intermediate carriages (8 passenger coaches, 1 dining car)
Derailment Sequence	1) front generator car 2) leading passenger coaches 3) front power car 4) remaining passenger coaches 5) rear generator car 6) rear power car
Damage to cars	4 cars overturned 3 passenger cars torn apart 1 passenger car caught fire due to leaking diesel fuel Rear generator car caught fire
Mechanisms of Injury and Death / Types of Survivable Injuries	
Mechanisms of Injury and Death	Bodies thrown forward (due to abrupt deceleration) Bodies thrown to the right side of the cars (due to the inertial forces of derailment on a sharp left curve) Bodies tossed around inside overturning cars Compression and constriction of "livable volume" in damaged cars Entrapment in crushed spaces Burn injuries in cars that caught fire Sudden changes in momentum Collision with retaining wall Laceration from shredded/torn metal parts
Types of Injuries in Treated Survivors	Blunt trauma, impalement, crush injuries, lacerations, fractures, amputating injuries, burn injuries, paralyzing injuries, head trauma, internal injuries due to sudden changes in momentum

Founder of Impact Research LLC, an expert in crash biomechanics, describe how medical trauma occurs in a rollover accident.

Most transportation injury research is dedicated to the understanding of the biomechanics and injury patterns in passenger vehicle crashes.[24-27] There are well-founded relationships between common crash configurations occurring in the real world that provide the context for discussion of the mechanisms of injury during passenger train crashes.

Figure 6. The final section of the train showing the rear-facing locomotive, the burned generator car, and upended carriages.

During a train crash - collision or derailment - loss of "livable volume" is the most dangerous condition for train occupants.[9] Research conducted at the Volpe National Transportation Systems Center focused on the secondary impact for train collision passengers and the various interventions for preventing head and chest trauma.[28] In frontal train-to-train collisions, the telescoping of adjacent cars compresses the available livable space. Head and chest traumas are especially common, with passengers striking a seat, table, or object located directly in front of them.[9,28,29] In contrast, train derailment produces a different pattern of injuries from that seen in a train collision, according to the limited research on derailment incidents.[9,28,29]

Lessons learned from the investigation of motor vehicle accidents can be extrapolated to train crash scenarios. The types and severities of injuries sustained in rollover automobile crashes vary based on occupant restraint status, airbag deployment, roof strength, and crash severity. Digges and colleagues

Figure 7. Rescue operations in process to extricate occupants from a derailed passenger coach.

Figure 8. Forward section of the derailed train with cars lying on their right sides. The village of Angrois is visible on the hillside.

studied the various injury patterns in rollovers in relation to crash severity and established that unbelted – and non-ejected - occupants typically experience multiple injuries to the same body region and organs.[25,26] For occupants who remain within the vehicle during rollover, the majority of the "serious" injuries, classified on the "Abbreviated Injury Scale" as severity level 3,[30] involve extremities, followed by head, trunk and spine. The majority of the "critical" and "severe" injuries (severity levels 4 and 5) involve the head, followed by the trunk and spine. While some passenger car rollover crashes occur with a high roll rate about the vehicle's longitudinal (roll) axis, most rollover events are relatively slow, similar to what was observed in the Santiago de Compostela train derailment (Fig. 7).

Train crash injuries frequently result from impact with interior surfaces not designed for occupant contact. Furthermore, these injuries are exacerbated during a "farside roll", where the first quarter turn of the rollover occurs on the side of the vehicle opposite from where occupants are seated. In the case of the Santiago de Compostela crash, the curve was to the left. While negotiating the curve at high speed, the left wheels lost contact first as the coaches pivoted upward on their right wheels and rolled over the right rail, landing on their sides (Fig. 8). Unrestrained occupants seated on the left sides of the passenger carriages were at highest risk for becoming human projectiles as they were flung across the vehicle during the rollover.

Secondary impacts are also problematic. That is, after first slamming against a solid surface inside the passenger carriage, the occupants continue to spin and tumble. The human body is oblong in shape and, much like a football, will "bounce" in an unpredictable manner when hurled about the passenger compartment. During the crash, flailing passengers, perhaps rendered unconscious after being launched across the compartment or colliding with a hard object, may have sustained repeated head and neck injuries, fallen out of windows, or been speared by a protruding object. Luggage that had been placed untethered on overhead racks became airborne and dangerous.

Some train crashes, including the Santiago de Compostela derailment, involve multiple cars that impact each other before and after derailment. Research reveals that multiple-car rollover crashes have double the injury rate compared with single-car rollovers. Moreover, vehicle crash physics indicates that injury severity is a function of the train's initial speed and the rate of change in velocity occurring during extreme deceleration as the speeding train comes abruptly to a halt. High-speed trains travel at higher than normal automobile velocities so medical trauma severity is increased. In this case the derailment speed was 179 km/h (111 mph). Additionally, it has been shown, as occurred in the Santiago de Compostela crash, that the impact of the train against a fixed object (the concrete retaining wall) magnifies the risk and lethality of injury.

Recent technological advances have created engineering systems to override the train driver's control when a speeding train is exceeding a safe velocity. Spain has deployed the ERTMS along many segments of its extensive rail system. Had ERTMS been available along the approach to the *A Grandeira* curve, this tragedy might have been averted.[8] Unfortunately, the section of track at the accident site did not have ERTMS installed and activated. Instead, the older-generation signaling system notified the train driver that he was approaching a restricted speed zone, but could not "commandeer" the speed controls.

Vehicle crash research has recently incorporated the design of safer seating configurations and interior passenger environments, including improvements to occupant restraint systems, for the purpose of reducing fatal head and chest injuries during collision or derailment. The design concept of compartmentalization, or arranging seats or restraining barriers to form a protection zone around occupants, can be as effective as lap belts for minimizing fatalities.

How physical harm and a community disaster translate into psychological distress and disorder

Three Spanish disaster psychologists, Drs. Maria Paz Garcia-Vera, Clara Gesteira Santos, and Jesús Sanz Fernández from the Universidad Complutense de Madrid, provide the in-country, on-scene perspective. Physical and psychological harm interact in an iterative, reciprocal fashion. For some disaster survivors, the combination of physical and psychological trauma magnifies the risk of progression to posttraumatic stress disorder (PTSD) and depression. Intensity of psychological trauma exposure is a strong predictor of acute distress during disaster impact and progression to PTSD or depression in the aftermath.[31-35] For direct victims, the severity of exposure to the traumatizing event, the perception of threat to life, the loss of loved ones, and the experience of personal physical injury represent powerful and interacting determinants of adverse psychological outcomes.[31-34] Research also indicates that PTSD rates vary in relation to both severity of exposure and social connectedness to the victims (Table 3).[31-34,36,37]

Elevated psychological risks in anthropogenic events

Systematic reviews have indicated that, particularly in developed nations, prevalence rates for posttraumatic stress disorder (PTSD) are higher for human-caused ("anthropogenic") disasters than for natural disasters.[31,33,34] The Santiago de Compostela train crash was a human-generated event and it was officially alleged that human error (a distracted driver) propelled human technology (a hurtling train) beyond the limits of performance, causing the derailment.[1-3]

However, the victims represented by APAFAS believe the rail system should also be held accountable for this anthropogenic disaster particularly for permitting calls from the controller to an on-duty train driver and for not installing and activating ERTMS on the sharp *A Grandeir* curve. They are angered by the official assertion that the train driver is "exclusively" responsible. APAFAS believes this to be a gross injustice that may be shielding the government from liability. These understandable reactions add to the psychological stress and distress experienced by direct victims and their family members.

Injury-related distress and compounding risks for crash survivors

There were 218 passengers and six railway staff onboard at the time of derailment. Railway personnel included two drivers, a controller, a security officer, and two cafeteria and customer service staff. All of these 224 occupants can be considered to be direct victims, including the 80 who were killed (78 passengers and the two cafeteria/service staff). All 144 survivors of the crash (140 passengers, two drivers, controller, and security officer) were physically injured with 140 of the injured requiring medical or surgical treatment.

Pain is a psychic stressor, and disaster-related physical injury is frequently a precursor to acute psychological distress with possible progression to common mental disorders.[38,39] In fact, physical injury is an independent risk factor for psychopathology as underscored by active research on "injury-related distress" (IRD).[40] Acute and chronic presentations of IRD include symptoms of posttraumatic stress, depression, anxiety, and pain.[41,42] Assessment of IRD is recommended during the early phase of hospitalization for injury in anticipation of the potential for subsequent psychological effects.[43]

Table 3. Psychological Stressors/Risk Factors by Subpopulation of Affected Persons, Santiago de Compostela Train Derailment, Galicia, Spain, July 24, 2013.

Subpopulation by Degree of Exposure	Estimated Number	Psychological Stressors Risk Factors
Direct victims: Passengers (78) and crew (2) who died in the train crash	80	Not applicable: deceased
Direct victims: Passengers who survived the train crash	140 (all surviving passengers were injured)	Stressors/Risk Factors: Felt direct threat to life (fear of imminent death); Physical injury (including life-changing injury); Physical pain, disability, disfigurement; Witnessing serious injury to others; Witnessing death and dead bodies; Witnessing grotesque scenes, body parts; Entrapment or delayed rescue; Special stressors associated with: amputating injury, brain injury, head/facial injury, paralyzing injury; Loss of family member(s); Loss of close friend(s); Survivor guilt; Loss of functional capacities; Possible job loss due to injury; Financial impact of injury/rehabilitation/life change; Prolonged legal processes (secondary victimization); Human culpability (not exclusively the driver); Human negligence; Exposure to media coverage of the crash
Crew members who survived the crash)	4 (all 4 surviving crew members were injured)	Stressors/Risk factors: For crew: All of the above for injured passengers; Sense of personal guilt, culpability; Legal liability/criminal prosecution; Public perception of guilt of train driver; Official government report/judicial rulings blaming the train driver
Primary family members of passengers killed in the crash	∼300–400 (assume 4–5 primary family members for each of 80 deaths)	Stressors/Risk factors: Traumatic bereavement; Delayed notification of death of loved one; Stressors of body identification, traumatic memory; Premature loss of loved one(s); Financial consequences of loss of provider; Exposure to media coverage of the crash; Survivor guilt for those who survived but lost loved ones and/or friends; Legal processes (secondary victimization)
Primary family members of passengers injured in the crash	∼500–700 (assume 4–5 primary family members for each of 143 surviving passengers)	Stressors/Risk factors: Witnessing severely injured family member; Witnessing life-changing injury, burn disfigurement, disability to family member; Witnessing the pain/discomfort during rehabilitation; Dealing with the stressors specific to type of injury (e.g. amputation, brain injury); Financial consequences of injury to family; Prolonged legal processes; Exposure to media coverage of the crash
Professional emergency rescue workers and hospital personnel	Hundreds	Stressors/Risk factors: Witnessing extreme harm on a mass scale; Witnessing severe injury to others; Witnessing severe harm to children; Witnessing mass death and dead bodies; Witnessing grotesque scenes, body parts; Inability to save some lives; Inability to rescue some trapped passengers; Sensory and occupational overwhelm; Being injured during the rescue (∼50 rescuers); Exposure to media coverage of the crash
Citizen emergency volunteers who came to scene	Hundreds	Stressors/Risk factors: Witnessing extreme harm on a mass scale; Witnessing severe injury to others; Witnessing severe harm to children; Witnessing mass death and dead bodies; Witnessing grotesque scenes, body parts; Inability to rescue/save some passengers'; Sensory overwhelm; Exposure to media coverage of the crash
Extended family members and friends of the killed and injured	1,000s	Stressors/Risk factors: Premature loss of extended family members; Repeated exposure to media coverage of the crash
Citizens of the Angrois neighborhood and surroundings (Angrois-Canteiras-Ponte Marsan)	∼200–300	Stressors/Risk factors: Witnessing extreme harm on a mass scale; Witnessing mass death and dead bodies; Witnessing grotesque scenes; Exposure to media coverage of the crash
Citizens of Santiago de Compostela and nearby areas in Galicia	City population: 96,041	Stressors/Risk factors: Exposure to media coverage of the crash; Impact on Feast of St. James observance
Citizens of Spain	National population: 47,129,783	Stressors/Risk factors: Exposure to media coverage of the crash

During disasters, injured survivors are subjected to physical and psychological trauma, a combination that confers elevated risk for PTSD.[44-49] Zatzick determined that 10% to 40% of hospitalized injured adolescent and adult survivors develop symptoms compatible with a diagnosis of PTSD.[49-57] Depression[56-59] and medically-unexplained complaints[60-62] are common co-morbidities.

The need for mental health treatment is particularly compelling for limb-loss victims whose risks for psychological impairment exceed those of other disaster survivors: 35% of traumatic limb loss survivors meet criteria for major depression.[63] Limb-loss early in life predicts major depression and other mental disorders in subsequent years.[64,65] Amputation following accidental injury is associated with increased PTSD prevalence.[66] Achieving optimal reintegration for amputees requires a combination of effective prosthetics and multi-faceted treatment that encompasses physical, psychological, and social needs.[67,68]

In addition to suffering varying degrees of physical injury, the 144 surviving occupants experienced other potentially traumatizing exposures. They shared the life-threating environment with people around them in the same carriage, and, in many cases, with their own family members. Some who remained conscious

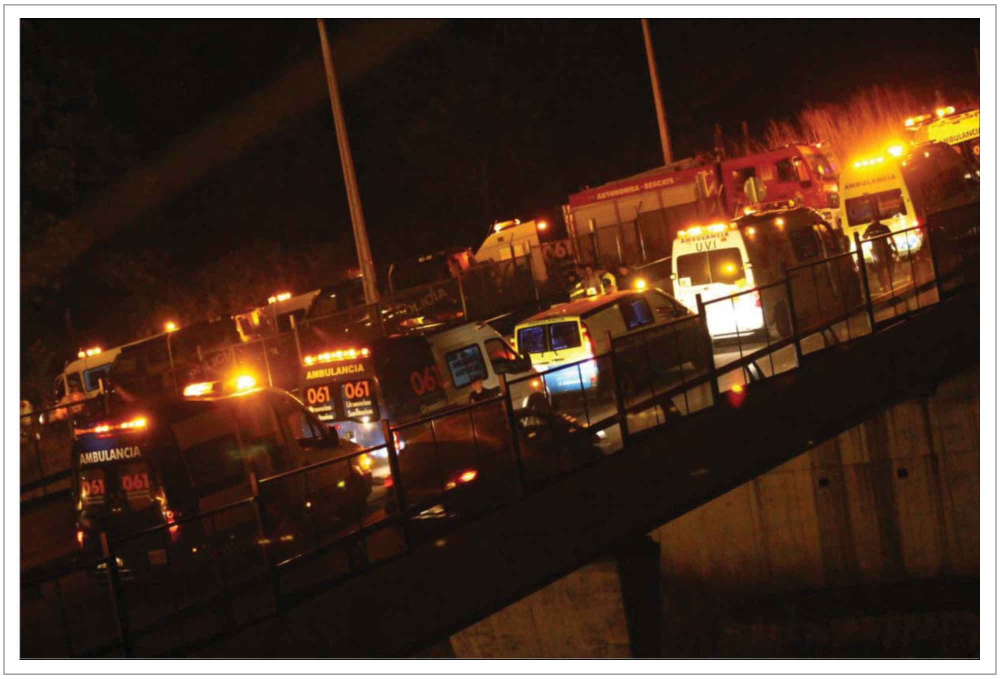

Figure 9. Rescue and ambulance personnel transporting injured passengers to nearby hospitals and trauma centers.

witnessed the moment of death or severe harm to others, including loved ones. Their senses were confronted by an array of grotesque sights, sounds, and smells. Some were entrapped and required the assistance of rescue personnel to extricate them. Those with minor injuries assisted others in escaping from the mangled cars or providing support for the more critically wounded.

Taken together, many of the survivors experienced multiple risk factors for psychological distress and disorders including real and/or perceived threat to life, life-changing physical injury, pain, entrapment, immobilization, and delayed rescue.

Psychological impact extending to indirect victims

Disasters also create psychological repercussions for "indirect victims," including family members and close friends of the direct victims, emergency professionals, volunteers, people living in close proximity to the scene, and the general population of the affected communities.[31,69]

Family members of crash casualties

Although news coverage of the crash was immediately broadcast internationally and the derailment was the top news story in Spain, notification of family members of the injured and deceased passengers was delayed until positive body identification could be made. Even as news of the accident was dominating the news cycles, the family members were forced to wait with agonizing uncertainty for information regarding the fate of their relatives: dead or alive, and if alive, whether their injuries were life-changing. For families of the 80 victims who died, many are likely to have experienced complicated grief or traumatic bereavement. These deaths were sudden, premature, and unanticipated.

Emergency personnel and local volunteer helpers

During the rescue phase of the response, emergency personnel worked long hours in hazardous conditions under high stress (Figs. 7, 9). Fifty rescuers were physically injured and all first responders were exposed to mass death and gruesome injury. Many rescue professionals and local volunteers assisted on-scene during the rescue phase for time periods ranging from several hours to several days.

Other professionals, including psychologists, forensics experts, and mortuary personnel who work with preservation and identification of human remains, had prolonged exposures to the crash scene, extending into the recovery phase (Fig. 10).

Local and national citizens of Spain

Citizens from the hamlet of Angrois rushed to the scene spontaneously to assist. Untrained, these volunteers

Figure 10. Rescue and disaster mortuary personnel work with the cadavers of the deceased and the identification of human remains.

witnessed their neighborhood suddenly transformed by a mass casualty incident. In the following days, they also organized memorials for those who died (Fig. 11).

Extensive media coverage of the crash certainly elevated distress among the crash survivors and the family members and friends of occupants who were injured and killed. Focused, repetitious viewing of media coverage of a disaster or extreme event increases the probability of suffering acute distress and posttraumatic stress symptoms, even for those

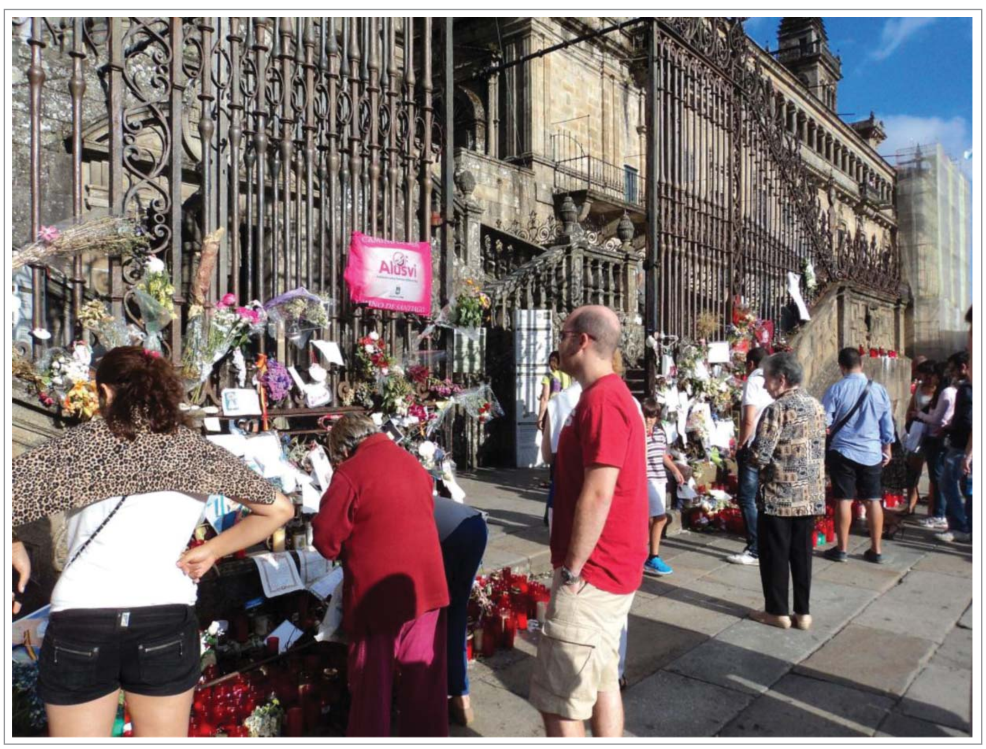

Figure 11. The community of Angrois provided volunteer support on the night of the crash and memorials for the train occupants who died.

who are only indirectly exposed to the event through the media.[70,71] Although media coverage was most intense in Galicia, and most especially in Santiago de Compostela, the train crash was also the top news story throughout Spain for weeks. Stories included the somber visits of government officials and dignitaries who came to pay their respects.

Looking upstream: examining the pre-crash risk landscape

Having examined the cascade of downstream consequences once the derailment was in motion, including the total destruction of all 13 cars comprising the Alvia train, severe physical harm or death for all train occupants, and rippling psychosocial impacts for survivors, family members, rescuers, local communities, and the citizenry of Spain, it is worthwhile to consider whether and how this tragic derailment could have been prevented. What critical elements comprised the "risk landscape" that preceded the event? Based on these observations, what are the most important preventive interventions that can be implemented to forestall future deadly derailments?

Episodes of inattention and distracted driving will invariably happen again in the future as train drivers log hundreds of thousands of hours annually. The need for redundant safety systems is well established. Indeed, the absence of an activated ERTMS system on the *A Grandeira* curve to override driver error was noted immediately in the international press[10] and reinforced in comments from the railway employees union in Spain's national newspaper, *El Pais*, the day following the crash.[72]

There was unanimous agreement in the press and all investigative reports that excess speed on a curve caused the train to overturn. This finding was self-evident; tipping over when taking a turn too fast and too tight on a wheeled vehicle is a universally understood childhood lesson. In this case, excess speed was related to driver distraction and failure to slow the train. Given the otherwise optimal conditions, had the driver been alert and focused, the derailment would not have occurred.

However, the risk landscape is a bit more complex. As noted by the victims' advocacy organization, APAFAS, perhaps if railway personnel had not distracted the driver's attention with multiple cellular calls during a critical part of the journey, the driver would have reacted to the speed alerts and averted the crash. Furthermore, even under the circumstance where the driver was not paying attention, an activated ERTMS system would have decelerated the train to a safe speed, and again, the tragedy would have been avoided.

Given the wide range of possible recommendations to address the multi-dimensional risk landscape, it is interesting to note that the official CIAF investigative report opted for a relatively limited set of remedies:[1]

1. Mandate the posting of speed limit signs.
2. Reinforce established safety management system procedures.
3. Extend safety procedures to all railway companies via the National Railway Safety Authority.
4. Reestablish a Traffic Committee with representatives of all railway companies to analyze risks involving the lines, vehicles, and roadways.
5. Analyze route-specific risks when developing new rail lines.
6. Develop secure communication systems for train personnel that diminish risks for distraction.
7. Implement audio/video recording and surveillance of the driver's cabin.
8. Integrate digital systems to allow for rapid reduction of train speed

Rather than championing the creation of multiple layers of prevention, redundant safety systems, and a proactive safety culture, the solutions tend to focus on driver behavior. Missing from consideration are recommendations for improving safety features of the passenger compartments (e.g. installation of passenger restraint systems, better securement of luggage, etc.) and considering how to cushion potential impact points such as the concrete retaining wall along the *A Grandeira* curve that contributed significantly to the severity of the injuries (Fig. 12). Missing also are opportunities for public education on passenger safety precautions and how to survive a crash.

As an interesting counterpoint, another deadly train derailment occurred in the same month, July 2013; an unmanned runaway oil train rolled downhill over a distance of 11 km (7 miles), derailed on a curve in downtown Lac-Mégantic, Quebec, Canada, and erupted into an explosive inferno. Forty-seven townspeople were killed in the two-day conflagration. The crash investigation report[73] and

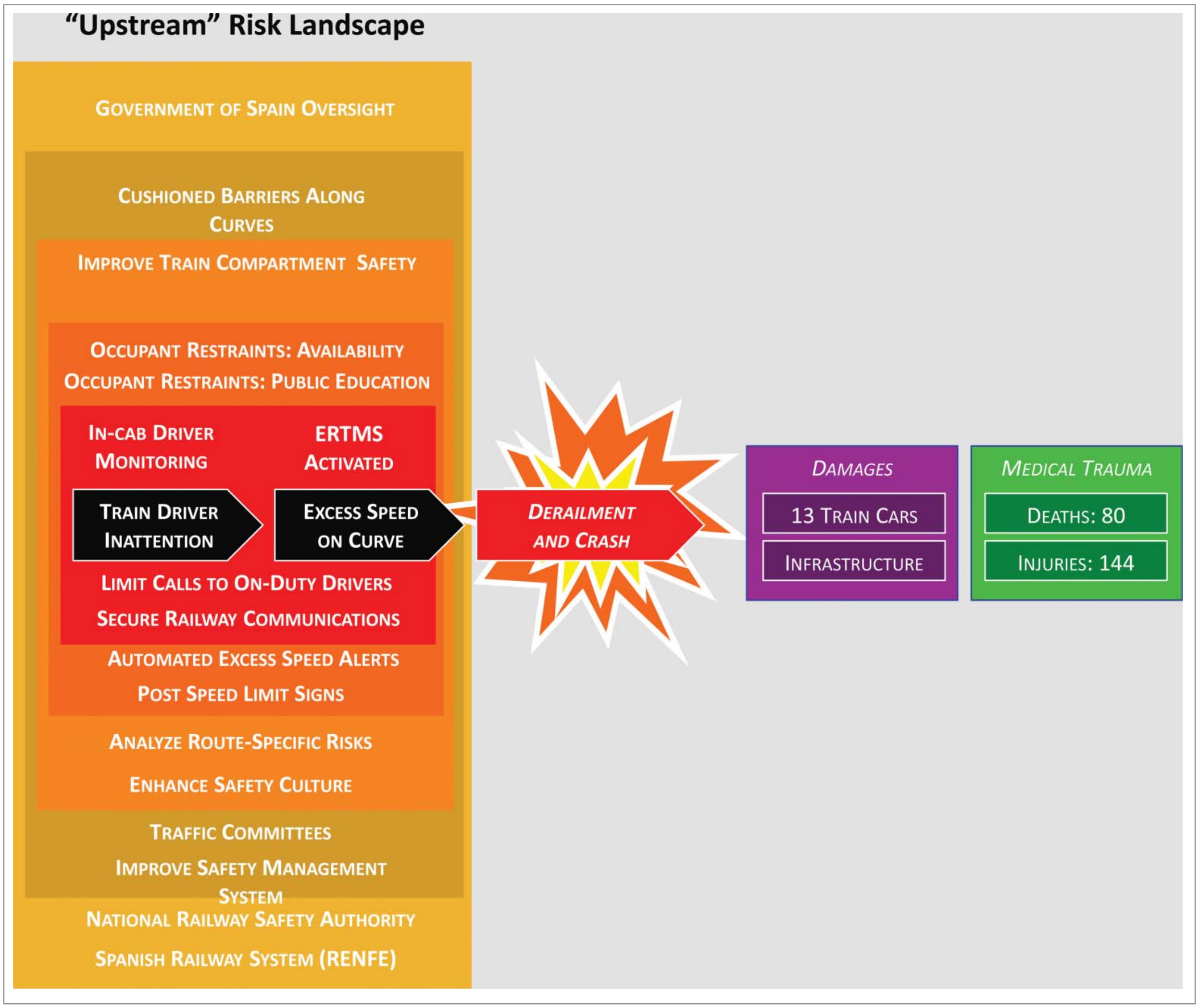

Figure 12. Complex systems thinking: Upstream risk landscape to identify possible causal factors and points for future intervention.

policy analysis[74] describe the complex intricacies of causation. The detailed analysis implicated all levels of oversight from national (Transport Canada), to the Montreal, Maine, & Atlantic Railway, to flawed locomotive maintenance, to inadequate "securement" on the part of the engineer when the train was parked for the night. The report specified dozens of points for decreasing risks and effectively preventing future recurrences. The contrast between the crash investigation reports in Spain and Canada is noteworthy.

Concluding comments

The train derailment and crash near Santiago de Compostela happened so suddenly that within a span of just eight seconds, all 224 occupants onboard were injured, dead, or dying. This transportation disaster was officially declared to be a "preventable" tragedy with blame focused solely on train driver error.

Using a complex systems perspective, the anatomy of this extreme rail accident has been examined from multiple vantage points to better understand the mechanics of the crash, the translation of a train derailment (usually associated with minor injuries) into severe and deadly medical trauma, and the further transformation of the event into psychological impact for surviving train occupants, family members, emergency responders, local residents, and the national population. The disaster health consequences were more severe and pervasive than described in government accounts of the incident, particularly when considering the spectrum of socio-psychological effects. This presentation of the downstream disaster

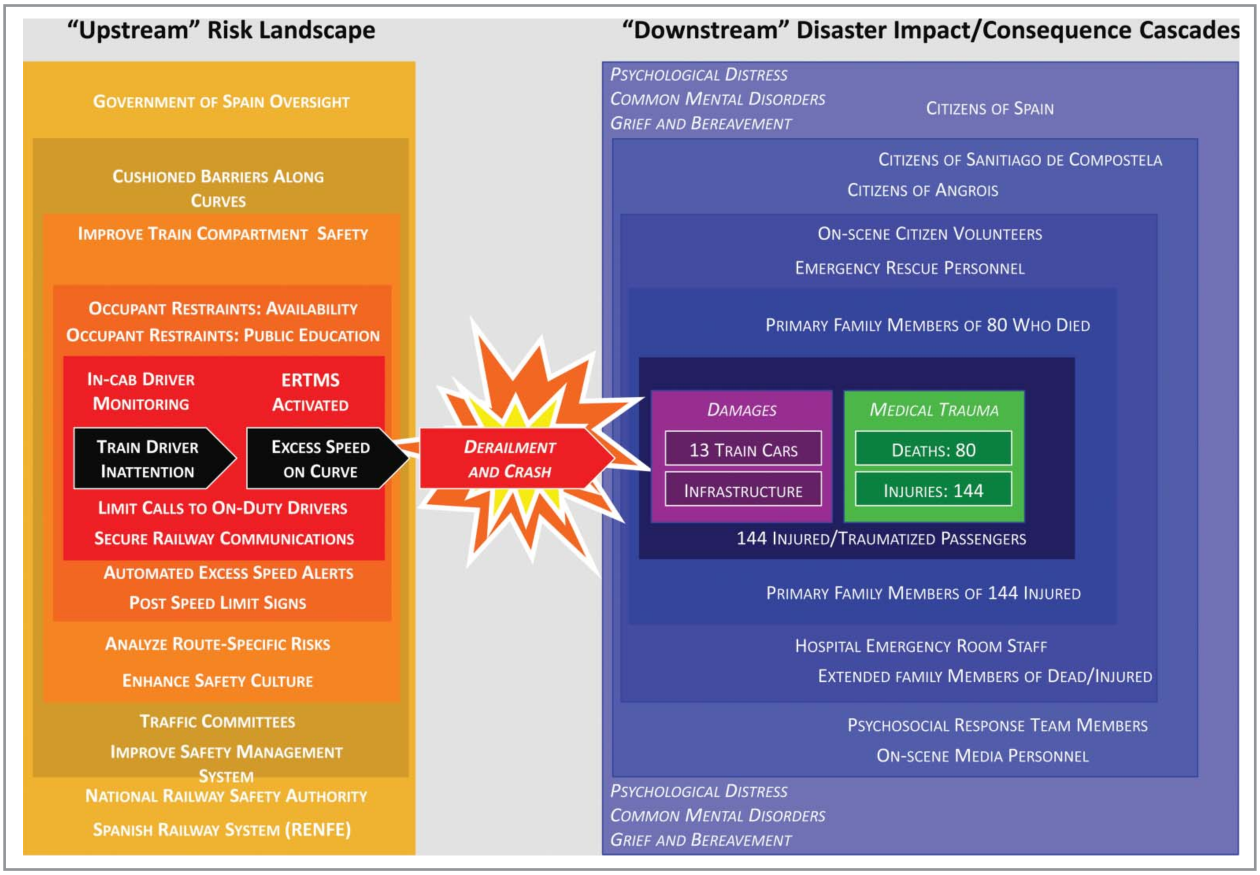

Figure 13. Complex systems thinking: Upstream risk landscape and downstream disaster consequence cascades.

consequence "cascade" relied upon the collaboration from experts in the areas of transportation disasters, medical crash trauma, disaster psychology, complexity sciences, and disaster health (Fig. 13).

When looking back upstream at the disaster risk landscape, it seems clear that this disaster was preventable - at multiple levels (Fig. 13). Had available protections been activated, including automated systems that can override driver error and slow a speeding train, it is possible that the accident could have been averted.

Crash investigators labeled this event to be wholly preventable, yet the derailment did occur with calamitous consequences. So, a fundamental question is how to actually prevent what is deemed to be preventable. The simplicity thinking and linear logic of the investigative reports and judicial rulings were compared with analyses based on complex systems thinking. The identification and implementation of future remedies for safeguarding rail passengers will be significantly different depending upon the perspectives brought to the decision process. Complexity thinking adds layers of protections.

A complementary finding is that when disasters do occur, the psychological ramifications greatly amplify the number of persons who are affected and the duration of significant health and mental health consequences. Currently, preparedness for psychological consequences tends to be omitted or receives low priority in the planning process. As part of future disaster planning, preparations should optimally include capabilities for early psychological assessment and support of direct victims - and first responders (a key element of "force protection") - in the immediate aftermath, monitoring of persons who have sustained life-changing injuries or have lost a loved one or have experienced significant psychological trauma, and provision of evidence-based interventions for victims and family members whose symptoms progress to the level of diagnosable mental disorders.

As illustrated with this case study, the application of complex systems thinking may help guide disaster planners and risk reduction professionals in the selection of optimal prevention and preparedness measures.

Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

References

1. Railway Accident Investigation Commission (CIAF), Ministry of Development. Final Report of the Grave Railway Accident No. 0054/2013 that Occurred on July 24, 2013 in the Proximity of the Compostela Station. Comisión de Investigación de Accidentes Ferroviarios, Ministerio de Fomento. Informe Final sobre el Accidente Grave Ferroviario No. 0054/2013 occurrido el día 24.07.2013 en las Proximaidades de la Estación de Compostela (a Coruña). Available at: http://www.fomento.gob.es/nr/rdonlyres/0ade7f17-84bb-4cbd-9451-c750ede06170/125127/if24071-3200514ciaf.pdf
2. Court order of Instruction No. 3 of Santiago de Compostela. Preliminary Proceedings No. 4069/2013, October 6, 2015. Juzgado de Instrucción No. 3 de Santiago: Diliengias Previas No. 4069/2013. Available at: https://assets.documentcloud.org/documents/2451309/auto-pa-4069-2013-alvia.pdf
3. The Spain Report. Judge Charges Train Driver With 80 Counts Of Reckless Manslaughter for 2013 Santiago Train Crash. October 7, 2015. Available at: https://www.thespainreport.com/articles/236-151007165707-judge-charges-train-driver-with-80-counts-of-reckless-manslaughter-for-2013-santiago-train-crash
4. Cedrón M. Accidente en Santiago: La caja negra confirma que el tren iba a más de 190 km/h" [Accident in Santiago: The black box confirms that the train was going over 190 km / h]. La Voz de Galicia. Available at:http://www.lavozdegalicia.es/noticia/santiago/2013/07/24/maquinista-tren-descarrilado-santiago-reconoce-iba-190-hora/00031374692270721158120.htm
5. Gómez J. Ochenta y siete heridos continúan ingresados, 33 en estado crítico [Eighty seven injured victims continue to be hospitalized, 33 in critical condition]Available at:http://www.lavozdegalicia.es/noticia/santiago/2013/07/25/noventa-cinco-heridos-continuan-ingresados-36-estado-critico/0003_2013-071374755918280648.htm
6. Peck T, Sharkey L, Roberts M. Spanish train crash mystery: Investigators examine why driver was travelling at twice recommended speed, as 13 bodies remain unidentified. Independent July 26, 2013. Available at: http://goo.gl/cgH1lv
7. Burgen S. Spanish railway safety under review after Galicia crash, say bosses. Guardian. 8 August 2013. Available at: http://www.theguardian.com/world/2013/aug/08/spanish-railway-safety-review
8. Fernando P. ETCS: a crucial factor in Santiago accident inquiry International Railway Journal. Available at: http://www.railjournal.com/index.php/signalling/etcs-a-crucial-factor-in-santiago-accident-inquiry.html
9. Bibel G. Train Wreck: The Forensics of Rail Disasters. John Hopkins University Press 2012.
10. Laursen L. Spanish high-speed train crash offers safety-system lessons. Scientific American. 26 July 2013. Available at: https://www.scientificamerican.com/article.cfm?id=ish-high-speed-train-crash.; PMID:23729061
11. Shultz JM, Espinel Z, Galea S, Reissman DE. Disaster Ecology: Implications for Disaster Psychiatry. In: Ursano RJ, Fullerton CS, Weisaeth L, Raphael B (eds.), Textbook of Disaster Psychiatry. Cambridge, UK: Cambridge University Press, 2007, pp. 69-96.
12. Shultz JM, Espinel Z, Flynn BW, Hoffman Y, Cohen RE. DEEP PREP: All-Hazards Disaster Behavioral Health Training. Disaster Life Support Publishing, Tampa, Florida, 2007.
13. Lorenz J, Battiston S, Schweitzer F. Systemic risk in a unifying framework for cascading processes on networks. Eur Phys J B 2009; 71(4):441-460.
14. Buldyrev SV, Parshani R, Paul G, Stanley HE, Havlin S. Catastrophic cascade of failures in interdependent networks. Nature 2010; 464:1025-1028 ; PMID:20393559
15. Helbing D. Globally networked risks and how to respond. Nature 2013; 497:51-59; PMID:23636396
16. Ramalingam B, Jones H, Toussainte R, Young J. Working Paper 285: Exploring the Science of Complexity. Ideas and Implications for Development and Humanitarian Efforts. 2nd Edition. London: Overseas Development Institute, 2008.
17. Cavallo A. Risk Management in Complex Projects. An Exploratory Study to Managing Unknown Unknowns in Uncertain Environments. Saarbruecken, Germany: Lambert Academic Publishing. 2010.
18. Cavallo A, Ireland V. Preparing for complex interdependent risks: A System of Systems approach to building disaster resilience. Int J Disaster Risk Reduction 2014; 9:181-193
19. Cavallo A. Integrating disaster preparedness and resilience: A complex approach using System of Systems. Aust J Emerg Management 2014; 29(3):46-51
20. Rucinski T. Spanish train driver Francisco Garzon charged with 79 counts of homicide. Reuters/The Huffington Post. 28 July 28 2013. Available at: http://www.huffingtonpost.com/2013/07/28/spanish-train-driver-charged_n_3668167.html
21. Associated Press. Spanish train crash: Investigators say driver got three speed warnings. The Guardian. 2 August 2013. Available at: http://www.theguardian.com/world/2013/aug/02/spanish-train-crash-driver-warnings.
22. Hooper J. Spanish train's black boxes reveal driver was on phone to rail firm. Guardian. 30 July 2013. Available at: http://www.theguardian.com/world/2013/jul/30/spanish-train-crash-black-boxes
23. The Guardian. Santiago de Compostela train crash: CCTV captures moment of derailment – video. Available at: http://www.theguardian.com/world/video/2013/jul/25/santiago-de-compostela-train-crash-cctv-video.
24. Digges K, Eigen AM, Dahdah S. Injury patterns in rollovers by crash severity. 19th International Technical Conference on the Enhanced Safety of Vehicles 2005.
25. Digges K, Eigen AM. Crash attributes that influence the severity of rollover crashes. Progress Technol 2004; 101:299-308.
26. Eichler RC. The causes of injury in rollover accidents. Accid Reconstr J 2003; Jan/Feb:1-17.
27. Eigen AM. Rollover crash mechanisms and injury outcomes for restrained occupants. National Highway Traffic Safety Administration. No. HS-809 894. 2005.

28. Tyrell DC, Severson KJ, Marquis BP. Analysis of occupant protection strategies in train collisions. ASME International Mechanical Engineering Congress and Exposition 1995.
29. Fothergill NJ, Ebbs SR, Reese A, Partridge RJ, Mowbray M, Southcott RDC, Hashemi K. The Purley train crash mechanism: injuries and prevention. Arch Emerg Med 1992; 9:125-129.; PMID:1388485
30. Civil ID, Schwab CW. The Abbreviated Injury Scale, 1985 revision: A condensed chart for clinical use. J Trauma 1988; 28(1):87-90.; PMID:3339667
31. Galea S, Nandi A, Vlahov D. The epidemiology of post-traumatic stress disorder after disasters. Epidemiol Rev 2005; 27:78-91.; PMID:15958429
32. Shultz JM, Neria Y, Allen A, Espinel Z. Psychological Impacts of Natural Disasters. In: Bobrowsky, P. (ed.), Encyclopedia of Natural Hazards. Dordrecht, Heidelberg, London, New York: Springer Publishing, 2013. pp. 779-791.
33. Norris FH, Friedman MJ, Watson PJ, Byrne CM, Diaz E, Kaniasty K: 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981–2001. Psychiatry 2002; 65(3):207-239.; PMID:12405079.
34. Norris FH, Friedman MJ, Watson PJ: 60,000 disaster victims speak: Part II. Summary and implications of the disaster mental health research. Psychiatry 2002; 65 (3):240-260.; PMID:12405080.
35. Shultz JM. Perspectives on disaster public health and disaster behavioral health integration. Disaster Health 2014; 2(2):69–74.
36. Galea S, Boscarino J, Resnick H, Vlahov D. Mental health in New York City after the September 11 terrorist attacks: results from two population surveys. In Manderscheid RW, Henderson MH. (eds.) Mental Health, United States, 2002. Washington, DC: US Govt Print Office 2003:83-91
37. Ozer EJ, Best SR, Lipsey TL, Weiss DS. Predictors of post-traumatic stress disorder and symptoms in adults: A meta-analysis. Psych Bull 2003; 129(1); 52-73
38. Rundell JR. Psychiatric issues in medical-surgical disaster casualties: A consultation-liaison approach. Psychiatr Q 2000; 71:245-258.; PMID:10934748
39. Rundell JR. Assessment and Management of Medical-Surgical Disaster Casualties. In: Ursano RJ, Fulerton CS, Weisaeth L, Raphael B (eds.) Textbook of Disaster Psychiatry. Cambridge, UK: Cambridge University Press 2007:164-189.
40. Victorson D, Farmer L, Burnett K, Ouellette A, Barocas J. Maladaptive coping strategies and injury-related distress following traumatic physical injury. Rehabil Psychol 2005; 50(4):408-415.
41. Geisser ME, Roth RS, Bachman JE, Eckert TA. The relationship between symptoms of post-traumatic stress disorder and pain, affective disturbance and disability among patients with accident and non-accident related pain. Pain 1996; 66:207-214.; PMID:8880842
42. Maes M, Mylle J, Delmeire L, Altamura C. Psychiatric morbidity and comorbidity following accidental man-made traumatic events: Incidence and risk factors. Eur Arch Psychiatry Clin Neurosci 2000; 250:156-162.; PMID:10941992
43. Richmond TS, Kauder D: Predictors of psychological distress following serious injury. J Trauma Stress 2000; 13:681-692.; PMID:11109239
44. Helzer JE, Robins LN, McEvoy L: Post-traumatic stress disorder in the general population. Findings of the epidemiological catchment area survey. N Engl J Med 1987; 317:1630-1634.; PMID:3683502
45. Abenheim L, Dab W, Salmi LR. Study of civilian victims of terrorist attacks (France 1982–1987). J Clin Epidemiol 1992; 45:103-109.; PMID:1573426
46. Green BL. Identifying survivors at risk. In: Wilson JP, Raphael B (eds.) International Handbook of Traumatic Stress Syndromes. New York: Plenum Press 1993.
47. Hoge CW, Castro CA, Messer SC, McGurk D, Cotting DI, Koffman RL. Combat duty in Iraq and Afghanistan, mental health problems and barriers to care. N Engl J Med 2004; 351(1):13-22.; PMID:15229303
48. Koren D, Norman D, Cohen A, Berman J, Klein EM. Increased PTSD risk with combat-related injury: A matched comparison study of injured and uninjured soldiers experiencing the same combat events. Am J Psychiatry 2005;162:276-282.; PMID:15677591
49. Zatzick D. Interventions for acutely injured survivors of individual and mass trauma. In: Ursano RJ, Fulerton CS, Weisaeth L, Raphael B (eds.) Textbook of Disaster Psychiatry. Cambridge, UK: Cambridge University Press 2007:190-205.
50. Michaels AJ, Michaels CE, Moon CH, Smith JS, Zimmerman MA, Taheri PA, Peterson C. Posttraumatic stress disorder after injury: Impact on general health outcome and early risk assessment. J Trauma 1999; 47:460-467.; PMID:10498298
51. Ursano RJ, Fullertion CS, Epstein RS, Crowley B, Kao T, Vance K, Craig KJ, Dougall AL, Baum A. Acute and chronic posttraumatic stress disorder in motor vehicle accident victims. Am J Psychiatry 1999; 156;589-595.; PMID:10200739
52. Holbrook TL, Hoyt DB, Stein MB, Sieber WJ. Perceived threat to life predicts posttraumatic stress disorder after major trauma: risk factors and functional outcome. J Trauma 2001; 51:287-293.; PMID:11493786
53. Marshall GN, Schell TL. Reappraising the link between peritraumatic dissociation and PTSD symptom severity: Evidence from a longitudinal study of community violence survivors. J Abnorm Psychol 2002; 111:626-636.; PMID:12428776
54. Zatzick DF, Jurkovich GJ, Gentilello LM, Wisner DH, Rivara FP: Posttraumatic stress, problem drinking, and functioning 1 year after injury. Arch Surg 2002; 137:200-205.; PMID:11822960
55. Zatzick DF, Kang SM, Muller HG, Russo JE, Rivara FP, Katon W, Jurkovich GJ, Roy B. Predicting posttraumatic distress in hospitalized trauma survivors with acute injuries. Am J Psychiatry 2002; 159:941-946.; PMID:12042181
56. Zatzick DF, Jurkovich G, Russo J, Roy-Byrne P, Katon W, Wagner A, Dunn C, Uehara E, Wisner D, Rivara F. Post-traumatic

distress, alcohol disorders, and recurrent trauma across level 1 trauma centers. J Trauma 2004; 57:360-366.; PMID:15345986

57. Zatzick DF, Russo J, Grossman DC, Jurkovich G, Sabin J, Berliner L, Rivara F. Posttraumatic stress and depressive symptoms, alcohol use, and recurrent traumatic events in a representative sample of hospitalized injured adolescents and their parents. J Pediatric Psychol 2006; 31:377-387.
58. Shalev AY, Freedman S, Peri T, Brandes D, Sahar T, Orr SP, Pitman RK. Prospective study of posttraumatic stress disorder and depression following trauma. Am J Psychiatry 1998; 155:630-637.; PMID:9585714
59. O'Donnell ML, Creamer M, Pattison P. Posttraumatic stress disorder and depression following trauma: Understanding comorbidity. Am J Psychiatry 2004; 161:1390-1396.
60. Engel CC, Liu X, McCarthy BD, Miller RF, Ursano RJ. Relationship of physical symptoms to posttraumatic stress disorder among veterans seeking care for Gulf War-related health concerns. Psychosom Med 2000; 62:739-745.; PMID:11138991
61. Katon W, Sullivan M, Walker E. Medical symptoms without identified pathology: Relationship to psychiatric disorders, childhood and adult trauma, and personality traits. Ann Intern Med 2001; 134:917-925.; PMID:11346329
62. Zatzick DF, Russo J, Katon W. Somatic, posttraumatic stress and depressive symptoms among injured patients treated in trauma surgery. Psychosomatics 2003; 44:479-484.; PMID:14597682
63. Cansever A, Uzon O, Yuldiz C, Ates A, Atesalp AS: Depression in men with traumatic lower part amputation: A comparison to men with surgical lower part amputation. Mil Med 2003; 168(2):106-109.; PMID:12636136
64. Singh R, Ripley D, Pentland B, Todd I, Hunter J, Hutton L, Philip A: Depression and anxiety symptoms after lower limb amputation: The rise and fall. Clin Rehabil 2009; 23:281-286.; PMID:19218302
65. Cavanagh SR, Shin LM, Karamouz N, Rauch S: Psychiatric and emotional sequelae of surgical amputation. Psychomatics 2006; 47(6):459-64.
66. Frank R, Kashani J, Kashani S, Wonderlich S, Umlauf R, Ashkanazi G:. Psychological response to amputation as a function of age and time since amputation. Br J Psychiatry 1984; 144:493-497.; PMID:6733373
67. Horgan O, MacLachlan M: Psychosocial adjustment to lower-limb amputation: a review. Disabil Rehabil 2004; 26 (14–15):837-50.; PMID:15497913
68. Ferguson AD, Richie BS, Gomez MJ: Psychological factors after traumatic amputation in landmine survivors: the bridge between physical healing and full recovery. Disabil Rehabil 2004; 26(14–15):931-8.
69. García-Vera MP, Sanz J. Psychopathological consequences of terrorism: the prevalence of post-traumatic stress disorder in victims of terrorist attacks. In Del Real Alcalá JA (Ed.), Fundamental rights and vulnerable groups. Sharjah, UAE: Bentham Science Publishers, 2015.
70. Holman EA, Garfin DR, Silver RC. Media's role in broadcasting acute stress following the Boston Marathon bombings. PNAS 2014 111: 93-98.; PMID:24324161
71. Silver RC, Holman EA, Andersen JP, Poulin M, McIntosh DN, Gil-Rivas V. Mental- and physical-health effects of acute exposure to media images of the September 11, 2001, attacks and the Iraq War. Psych Sci 2013; 1623-1634.; PMID:23907546
72. Muñoz R, Reinero, D. La seguridad del tramo no era la del AVE. Available at: http://ccaa.elpais.com/ccaa/2013/07/25/galicia/1374754693_288688.html
73. Transportation Safety Board of Canada, Railway Investigation Report R13D0054 Runaway. Runaway and Main-Track Derailment, Montreal, Maine, & Atlantic Railway, Freight Train MMA-002, Mile 0.23, Sherbrooke Subdivision Lac-Megantive, Quebec, 06 July 2013. Minister of Public Works and Government Services Canada 2014 Cat. No. TU3-6/13-0054E. ISBN 978-1-100-24860-8, 181 pp.
74. Bruce Campbell. The Lac-Mégantic Disaster: Where Does the Buck Stop? Canadian Centre for Policy Alternatives. October, 2013. ISBN 978-1-77125-088-7, 56 pp. Available at: https://www.policyalternatives.ca/publications/reports/lac-mégantic-disaster