# The Role of Night Vision Equipment in Military Incidents and Accidents

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**Abstract.** Night vision devices provide enormous benefits. They enable personnel to carry out operations under conditions that would not otherwise be possible. However, these benefits carry considerable risks. For instance, individuals often become over confident about their ability to use image intensification and infrared devices. In consequence, the use of night vision equipment is an increasingly common factor in military incidents and accidents. For instance, the US Army recently found that there were 7.7 serious incidents per 100,000 hours of daylight flight in their helicopter fleet. The rate rose to 13.9 per 100,000 hours for night flight. Of those, the rate for unaided night operations was 9.3 while 15.8 incidents occurred per 100,000 hours for night operations involving vision enhancement systems. This paper uses an analysis of incident and accident data to identify requirements for the successful deployment of night vision equipment. It is argued that these applications must be integrated more closely with existing navigational systems. Two further factors are required if night vision equipment is to be successfully integrated into many operational environments: adequate risk assessment and team-based training.

## Introduction

There are two main classes of night vision devices. Image intensification ($I^2$) systems enhance the lighting that is available within the existing environment. Infrared (IR) devices, in contrast, will typically use heat emissions to identify objects that cannot otherwise be detected using available light sources. These systems support a wide range of military operations that would not otherwise have been possible. For example, the UK Ministry of Defence (2003) recently identified the ability to use this equipment as a key element of success both for logistics and offensive operations:

> "5.10 The provision of a night vision capability to some soldiers through a Head Mounted Night Vision System and other thermal imaging equipment such as Lion and Sophie improved the ability of our forces to operate at night. The improved shared situational awareness such equipment provided also greatly enhanced their operational effectiveness. These systems were used for surveillance and target acquisition in close combat, and were found to be

> particularly effective in the urban environment. Vehicle commanders and support troops also used this equipment to enable marshalling and logistic manoeuvre to be carried out at night. The majority of these systems were obtained specifically for the Iraq operation through Urgent Operational Requirement (UOR) action following their excellent performance in operations in Afghanistan". (MOD, 2003)

It is important to emphasize that the additional capabilities provided by night vision devices also create new risks. Night operations continue to result in significantly more accidents and incidents than their daytime counterparts (Ruffner et al, 2004). Some of these mishaps can be directly attributed to problems in the design of night vision devices. Others stem from the standard operation procedures and training techniques that are intended to help operators use these systems. Some accidents stem from the problems of coordinating group work when teams of operators must wear these devices during complex nighttime operations. The following pages argue that a detailed analysis of these mishaps must be used to inform the risk assessments that determine whether or not to use night vision equipment in particular operations.

| | Accident Rate | | | | Percentage comparison | | |
|---|---|---|---|---|---|---|---|
| | **2004** | **2003** | **2002** | **2001** | **3-Yr Avg** | **2004 vs. 2003** | **2004 vs. 3 Yr Avg** |
| Flight Class A | 3.371 | 2.248 | 1.126 | .393 | 1.26 | +50.0% | +167.5% |
| Flight Class B | .749 | 1.124 | 2.627 | 1.966 | 1.91 | -33.4% | -60.8% |
| Flight Class C | 4.121 | 6.368 | 4.127 | 9.437 | 6.64 | -35.3% | -37.9% |
| Total | 8.241 | 9.74 | 7.88 | 11.796 | 9.81 | -15.4% | -16.0% |

**Table 1.** Accident rate Per 100,000 hours of US Army Flight (US Army Safety Center, 2004)

We are interested in the role that night vision equipment plays in incidents and accident because many armed forces have faced recent increases in the number and frequency of adverse events. For instance, the number of aviation fatalities from mishaps across all US Department of Defense personnel rose from 65 in 2001 to 82 in 2002. US Army flight operations saw a 75% rise in class A accidents in 2003 compared to 2002. This represented a 125% rise in comparison to the previous three-year average. There was a 233% rise in fatalities compared to 2002 and a 400% rise in comparison to the average over the previous three years. These statistics ignore an increase in risk exposure. US Army operations have changed radically over the last three years. However, Table 1 also shows that US Army aviation accident rates have risen over this period[1].

In May 2003, Defense Secretary Rumsfeld focused concern on these and similar statistics across the US military: "World-class organizations do not tolerate preventable accidents. Our accident rates have increased recently, and we need to turn this situation around" (Gilmore, 2003). He set the challenge to "to reduce the number of mishaps and accident rates by at least 50% in the next two years". Given that approximately 70% of all military accidents occur during the hours of darkness, we are unlikely to achieve such an ambitious target unless we understand and mitigate the risks associated with night vision equipment (Johnson, 2003). The following pages present a number of statistical studies as well as more qualitative investigations into accidents and incidents involving night vision devices. The intention is to show how these adverse events can inform acquisitions, standard operating procedures, training requirements and above all risk assessment for military operations.

A further justification for studying the operational performance of military night vision equipment is that these devices are gradually being approved for civilian applications. On the 29th January 1999, the Federal Aviation Administration issued the first supplemental type certificate to permit the use of Night Vision Goggles by a civilian helicopter Emergency Medical Service. Since then, device manufacturers and distributors have backed a number of initiatives to introduce this equipment into civil applications. Although, many operators remain skeptical about the benefits of night vision technology for commercial aviation.

## A Brief Overview of Night Vision

Before analysing the role of night vision equipment in military mishaps, it is important to review the strengths and weaknesses of the existing technology. Readers who are familiar with the underpinnings of the human perceptual system and with night vision technology are encouraged to skip this section. Military personnel, typically, rely on their visual sense during most operations. For instance, safe flight relies upon good depth perception for landing, good visual acuity is critical if pilots are to identify terrain features. Drivers of land-based vehicles rely on depth perception to judge whether or not they can cross ditches, visual acuity is important in

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[1] Class A mishaps cost $1,000,000 or more and/or destruction of an Army aircraft, missile or spacecraft and/or fatality or permanent total disability. Class B incidents involve damage costs of $200,000 or more, but less than $1,000,000 and/or permanent partial disability and/or three or more people are hospitalized as inpatients. Class C incidents are slightly more complex as the categorization changed in 1992. Prior to that date they were defined to incur damage costs of $10,000 or more, but less than $200,000 and/or non-fatal injury resulting in loss of time from work beyond day/shift when injury occurred and/or non-fatal illness/disability causes loss of time from work. After 1992 this was revised to be damage costs of $20,000 or more, but less than $200,000 and/or non-fatal injury resulting in loss of time from work beyond day/shift when injury occurred and/or non-fatal illness/disability causes loss of time from work.

many aspects of land-based navigation. However, color vision, depth perception, and visual acuity all vary depending on which of the three different types of vision soldiers must rely on in a particular operation. *Photopic vision* occurs with high levels of illumination. The cones concentrated in the center of the fovea are primarily responsible for vision in bright light. High light condition will bleach out the rod cells that support peripheral vision. However, the reliance on cones produces sharp image interpretation and color vision using photopic vision. In contrast, *mesopic vision*, typically occurs at dawn and dusk or under full moonlight. This relies on a combination of rods and cones. Visual acuity steadily decreases with declining light. Color vision degrades as the light level decreases, and the cones become less effective. Mesopic vision is often regarded as the most dangerous if personnel do not adapt to the changing light conditions. As light levels fall, there will be a gradual loss of cone sensitivity. Operators should be trained to rely more on peripheral vision. If personnel fail to recognize the need to change scanning techniques "from central viewing to off-center viewing, incidents may occur" (Department of the Army, 2000). *Scotopic vision* is used under low-light level environments such as partial moonlight and starlight. Cones become ineffective, causing poor resolution of detail. Primary color perception during scotopic vision is shades of black, gray, and white unless the light source is high enough in intensity to stimulate the cones. A central blind spot, known as the night blind spot, also occurs when cone-cell sensitivity is lost. If an object is viewed directly at night, it may not be seen. If the object is detected, it will fade away when stared at for longer than two seconds.

The human eye can adapt to low light. Biochemical reactions increase the level of rhdopsin in the rods. This controls light sensitivity. Individual differences again affect the rate and degree of adaptation. It can take between 30-45 minutes for most people to achieve their maximum acuity under low levels of light. In general, however, the lower the previous light level then the faster the eye will adapt to any subsequent fall in light. Conversely, it can take a further period of time, again up to 45 minutes, for the eye to adapt to higher levels of light. Brief flashes, for instance from strobe lights, have little effect on night vision. However, looking at a flare or searchlight for longer than a second will have an adverse effect on most people. A number of other factors, such as smoking and individual differences, also adversely affect night vision. Night myopia arises from the way in which the visual spectrum is dominated by blue wavelengths of light. Nearsighted individuals viewing blue-green light at night typically experience blurred vision. Even personnel with perfect vision will find that image sharpness decreases as pupil diameter increases. Similarly, "dark focus" occurs because the focusing mechanism of the eye often moves toward a resting position in low light levels. Special corrective lenses can be used to address this problem for individuals who suffer from night myopia.

A number of cues can be used to estimate depth and distance under normal lighting conditions. Binocular cues stem from slight differences in the images that are presented to each of the operator's eyes. Low lighting can make it difficult for personnel to perceive any visible differences. The effect is increased when objects are viewed at a distance. Low light levels also affect a number of monocular cues for depth perception. These include geometric perspective, motion parallax, retinal image size, and aerial perspective. As we shall see, the problems of depth perception play an important role in the causes of incidents and accidents.

**Strategies to Support Night Vision**

A number of training techniques can help maximize any remaining visual resources in low levels of light. The simplest approach is to encourage personnel to identify objects from their shapes or silhouettes. This has considerable limitations; it can be time-consuming to consider a number of different perspectives even for a relatively simple object. Better results can also be obtained if training encourages personnel to maximize those aspects of their vision that are best adapted to low light conditions. For instance, steady fixations of 1-2 seconds have been shown to achieve maximum sensitivity. If an individual stares at an object for longer than this then it can be lost. Such problems can be reduced if individuals are trained to move their eyes from one off-center point to another. This maintains the object in the peripheral field of vision without staring at it for a prolonged period. In particular, it is important to train individuals to avoid the rapid head or eye movements that reduce our ability to assimilate information in low light conditions.

There are also a number of more complex training techniques. As mentioned, the acuity and range of our vision falls after dark. The light-sensitive areas of the retina are unable to perceive images that are in motion. Hence, US Army guidelines recommend a stop-turn-stop-turn procedure (Department of the Army, 2000). Each visual scan of the image area should be followed by a pause. The duration of each stop is based on the degree of detail that is required, but no stop should last more than 2-3 seconds. When moving from one viewing point to the next, individuals should overlap the previous field of view by approximately 10 degrees. These guidelines can be summarized by the Canadian Army's (2004) rules for night observation:

1. **Aim-off with the eyes** - Never look directly at what is to be seen. For example, if the eye looks directly at a pin-point of light it will not see the outline of the tank from which the light is coming.

2. **Do Not Stare Fixedly** - The eyes tire rapidly at night so an object will disappear if it is looked at for a long time.

3. **Avoid Looking at Any Bright Lights** - Shield the eyes from parachute flares, spotlight or headlights. Dim flashlights and turret lights and blink when firing weapons.

4. **Look Briefly at Illuminated Objects** - The time spent glancing at lighted objects such as maps or illuminated dials must be kept to a minimum.

5. **Do Not Scan Quickly** - Move the eyes in a series of separate movements to give the eye a chance to pick up a target which will appear much slower than daylight.

6. **Limit Time Spent Scanning** - Continuous scanning will cause the eye to partially black out. The eyes should be rested for 10 seconds every 2 minutes.

7. **If Necessary Use Eyes Individually** - If a lit area has to be observed, then protect the night vision of one eye by keeping it shut. One eye should be shut as an automatic reaction if a bright light suddenly appears.

Previous generations of night-vision training have focused on techniques that are intended to help individuals maximize their remaining visual resources. As we shall see, however, the rising number of accidents has convinced several military organizations to revise this approach. Instead, the focus has moved to training in team-based decision making. In this approach, members of a group are encouraged to compare and contrast their observations so that all available information is considered before making critical decisions. Increasingly this information is being derived from night vision equipment as well as from direct visual observations.

## Image Intensification Systems

Personnel can compensate for the limitations imposed by low light conditions either by training to make the most of their night vision or through the provision of night vision equipment. Image intensification systems support direct observations by amplifying low levels of ambient light. They do not 'turn night into day' (US Department of Justice, 1996, US Army Center for Lessons Learned, 2003a). Nor do they compensate for many of the problems that affect vision in low light environments. Most image intensification systems perform poorly in total darkness. Amplification can range up to 35,000 times the available light. Higher amplification is associated with more expensive devices and can imply increased levels of distortion. The intensified image is, typically, viewed on a phosphor screen that creates a monochrome, video-like image, on the user's eyepieces. Unfortunately, a number of disadvantages affect the application of this technology.

Most image intensification systems are attached to the users' helmet. Early models included relatively heavy battery packs that restricted the users' head movements. This problem was exacerbated by the need to move the head because many of these devices offer a highly restricted field of vision This may only be 40-60 degrees. The importance of these factors should not be underestimated. A post action review of the Canadian Army's deployment in Kosovo found that "the current issue helmet and night vision goggles are not compatible and are painful to wear". (Canadian Army Center for Lessons Learned, 2001). This led to situations in which soldiers had to remove the devices to reduce the fatigue and frustration that built up during prolonged use. There are further problems. Image intensification equipment can also create problems in depth perception. Colour cues and binocular information are lost with many commercial systems. All of these limitations are being addressed by technological innovation. In particular, it is now possible to buy light weight and extended field of vision systems. However, these tend to be expensive (Salazar and Nakagawara, 1999). They can also be difficult to maintain under field conditions.

Visual acuity from night vision devices provides a vast improvement over human night vision. However, it is far from perfect. As with direct sight, higher levels of accuity are associated with closer, slower targets. The visual accuity offered by image intensification rapidly diminshes for objects over 400 feet away. This distance is further reduced, the faster the target is moving. A number of environmental factors can also reduce the accuity of image intensification systems. Rain, clouds, mist, dust, smoke, fog all affect performance. In particular, landing in a dusty area will cause ‘brown out’. This phenomenon has contributed to a number of accidents and incidents where helicopter crews have relied on images from night vision equipment that are suddenly degraded by the dust that is brought up in the wash created by their rotors (Department of the Army, 2000).

The impact of environmental and meteorological factors can be illustrated by a recent incident involving a Canadian military helicopter in Bosnia (Canadian Air Force, 2002). The reporting officer described how reports of adverse weather conditions initially convinced them to remain in Banja Luka. However, if they left immediately they calculatted that they could return to their base in Velika Kladusa within their eight hour flying limit. “We strapped on our night vision goggles after refueling and decided to go for it”. They were seven miles from their destination when they noticed that the lights on the hills were no longer where they expected them to be. They also began to lose sight of the lights ahead of them using their night vision equipment. The cloud lowered until it engulfed the hills that surrounded them. They realized that they could not go back to Banja Luka and so were forced to follow the only open valley in sight. The presence of mines from previous conflicts meant that they could not simply set down in any available field. The officer goes on to state “My arms and legs were rubbery, and the night vision goggles were literally washed out by the downpour as we made our descent… it took three passes before we landed safely in the helicopter-landing site and we could start breathing normally again” (Canadian Air Force, 2002). The subsequent analysis of this incident identified the danger that crews will become unduly complacent about the support provided by night vision equipment under adverse meteorological conditions.

The performance of image intensification systems can be impaired by a number of external light sources. Looking at the moon has the same effects as looking directly at the sun under daylight lighting conditions. This creates problems when soldiers move toward a bright moon that is low on the horizon. The brightness of the ‘ambient’ light source degrades the intensified image. It will also cast deep shadows that can hide hazards, including excavated fighting positions. This creates considerable problems for drivers trying to locate these emplacements using night vision equipment (US Army Centre for Lessons Learned, 2001). External light sources can also support the use of image intensification equipment. For instance, city lights often provide useful illuminations especially if cloud cover reflects the available light back onto a scene. However, there is a risk that personnel will fixate on these external light sources. This will further degrade their night vision.

Similarly, flares can provide the indirect light that is often necessary for image intensification systems. However, such a strong source will adversely affect device resolution if users look directly at them.

Many of the problems associated with image intensification systems stem from their operational environment. Vehicle instrument lights and cockpit displays can create “washout” or halo effects. In many road-based vehicles it is possible to turn-off instrument illumination. However, it is a complex and expensive task to alter cockpit lighting systems without compromising the daytime use of the aircraft. These problems are compounded because red lights are frequently used in speedometers and engine instruments. Night vision systems are often particularly sensitive to these sources. Personnel must also be trained not to use red-lens flashlights in situations where image intensification equipment is being used. In ground operations, oncoming headlights pose a major hazard because drivers must often use their goggles at times when other road users rely on their vehicle lights. These light sources can dazzle the wearer of a night vision device to the point where they will not see barriers and obstacles, including equipment or people. These are not the only source of light polution that affect the users of image intensification systems. Many aviation systems are sensitive to the anti-collision lights required by FAA regulations. These will be intensified to a point at which they can distract or even dazzle the wearer of an intensification system. All of these factors imply that experience and recurrent training must be provided if personnel are to operate image intensification systems. Risk assessments should also consider the problems that can arise, for example if external lights are likely to create the deep shadows that hide hazards such as excavated fighting positions or if the users of image intensiufication systems are momentarily dazzled by the headlights of other road users.

### Infrared and Thermal Imaging Systems

Image intensification systems typically enhance light that is visible to the human eye. In contrast, thermal imaging systems detect infrared radiation that is emitted by heat sources. Although the human eye cannot directly observe these signals, they can be focused in the same way as conventional light. Transducers detect the thermal emissions. Their output is then processed to represent the difference in temperature amongst the objects in a scene. Thermal contrast is then translated into a visual contrast that is, typically, represented in shades of gray on a monochrome display.

In contrast to image intensification devices, infrared systems can be used in total darkness because they do not rely on the light reflected by an object. A further benefit is that thermal imaging systems avoid the “blooming” that occurs when strong light sources swamp intensification systems. Infrared devices also avoid some climatic problems. For instance, they can see through some types of fog. However, problems can arise under different environmental conditions. A wet runway may be cooled to such an extent that it appears to be further away than it actually is. High-humidity reduces thermal contrast and so will adversely affect image quality. There are further limitations. For instance, infrared systems cannot be used to identify precise details on remote objects that are not distinguishable by different heat profiles. Unlike image intensification systems, infrared devices cannot register facial features.

The sensitivity of thermal imaging systems is measured in terms of degrees celcius per optical *f*-number. In other words, it provides an indication of the temperature change that would be required to provoke a change in the image. These differences are typically in the region of 0.05-0.2 degrees Celsius. The resolution or sharpness is measured in terms of the instantaneous field of view (IFOV) in milliradians (mrad). 17.5 milliradians is equal to an angle of 1 degree in the instantaneous field of view. The lower the IFOV value, the sharper the image and the longer the range. Military systems have IFOVs of less than 1.0 mrad. However, as the magnification of the thermal sensor increases, the field of view decreases. In consequence, operators must use scanning techniques that are similar to those associated with direct observations. Training is required both in the deployment of the devices and also in the interpretation of the images that they present under low-light conditions.

Thermal imaging systems can be used in conjunction with infrared landing and searchlights. These tend to be most effective at low levels of illumination. If there are external lights then pilots tend to limit their scan to within the area directly covered by the searchlight. They have to be trained to expand their search on either side of the beam. Brownout can also occur when there are reflections from an infrared searchlight caused by the dust that is raised in a rotor wash. The heat emitted by infrared searchlights can also help enemy personnel who may themselves be using night vision equipment. As with image intensification systems, individuals can quickly become fatigued through prolonged use of these devices. A recent Lessons Learned review was conducted into the initial deployment of light armored vehicles. One of four main findings was that “Long periods of using thermal optics can lead to crew fatigue…this can be overcome by having the dismounts trained on the functions of the turret” (New Zealand Army, 2003).

## Statistical Studies of Night Vision Equipment in Military Mishaps

Table 2 presents the results of a study by the US Army Safety Centre into the accident rate for various forms of night operation involving rotary winged aircraft. As can be seen, there is a lower accident rate for flights involving direct ‘unaided’ visual observations than there is for flights with this equipment. Such a counter-intuitive finding can be explained in a number of ways. It might be that the use of night vision equipment impairs situation awareness, distracts from the use of other information systems and hence increases the likelihood of an adverse event. Equally, it might be argued that these devices tend to be used under adverse meteorological and environmental conditions when accidents are more likely to occur anyway. Similar results have been obtained by studies that focus on particular systems. For instance, the US Army’s Black Hawk helicopter fleet has suffered more than 20 fatal accidents in its 27 year service history. Approximately half of these occurred while pilots were wearing night vision devices (Hess, 2002). However, the fact that an accident occurred while the crew were using this equipment does not imply that the incident was caused by these devices. It can be very difficult to assess the role that particular technologies play in an adverse event. This is especially problematic when crewmembers may have suffered psychological or physiological trauma. They may be unable or unwilling to discuss the details of their actions in the aftermath of an accident or near-miss incident. Without reliable first-hand accounts it is difficult to assess the role of night vision equipment in a mishap. Flight data recorders and even cockpit cameras yield few insights into the perceptual problems that face the operators of many night vision systems. Further problems arise because these statistical studies do not consider those accidents under direct visual conditions that could have been avoided if the crew had been provided with night vision equipment.

| | FY95 | FY96 |
|---|---|---|
| Day | 7.59 | 7.69 |
| Night | 9.72 | 13.87 |
| Night unaided | 6.37 | 9.31 |
| Night aided | 11.28 | 15.80 |
| Night systems | 17.15 | 22.54 |
| Night goggles | 11.97 | 14.37 |
| Total | 8.09 | 9.14 |

**Table 2.** Class A-C Rotary-wing Accidents per 100,000 flying hours

| Percentage | Driver Error Category, Description of Accidents |
|---|---|
| 43 | Driver did not detect the obstacle prior to the impact, or detected the obstacle immediately prior to impact. |
| 19 | Driver was aware of the presence of the obstacle, but misjudged the size, depth, or location of the obstacle. |
| 6 | Driver was aware of the obstacle and correctly judged the obstacle characteristics, but made an improper decision on how to proceed. |
| 15 | Driver made a proper decision regarding the obstacle, but improperly executed the action. |
| 1 | Driver properly executed the action, but had no opportunity to avoid the impact due to sudden events |
| 16 | Insufficient information was contained in the narrative to determine the type of driver error. |

**Table 3.** Ground vehicle accidents in driver error categories (n=160) (Ruffner et al, 1997).

Some attempts have been made to conduct a more detailed analysis of the accident statistics. For instance, Ruffner, Piccione and Woodward (1997) analyzed US Army data to identify 160 accidents that were related to the use of night vision devices in ground vehicles between 1986-1996. Over two-thirds were attributable to three categories of terrain and roadway hazards: drop-offs greater than three feet (34%), ditches of three feet or less (23%) and rear collisions with another vehicle (11%). 34% involved the High Mobility Multipurpose Wheeled Vehicle (HMMWV), 18% involved the M1 Abrams Tank and 14% involved the M2/M3 Bradley Fighting Vehicle. The most commonly occurring environmental conditions that included dust (24%), blooming from light source (9%), and smoke (8%). Table 3 illustrates a further stage of analysis that the authors conducted to identify 'error categories' associated with these accidents. The inability to detect a hazard or obstacle resulted in most accidents.

Braithwaite, Douglass, Durnford and Lucas (1998) conducted a similar study of aviation accidents that focused on spatial disorientation caused by the use of night vision devices in helicopter operations. They argued that the various limitations of night vision devices, including the issues of depth perception and orientation mentioned in previous pages, predispose aircrew to 'spatial disorientation'. In order to support this hypothesis, they analyzed all US Army class A-C mishap reports involving night-aided flight from 1987-1995. The Braithwaite et al analysis was based around the work of three independent assessors who read through each of the incident reports in the A to C categories in order to identify those that involved some form of spatial disorientation. These were then subject to a further analysis that was intended to identify 'associated factors' and 'possible countermeasures'. They found that approximately 43% of all spatial disorientation mishaps occurred during flights that used night vision equipment. Only 13% of accidents that did not involve spatial disorientation involved these devices. An examination of the spatial disorientation accident rates per 100,000 flying hours revealed a significant difference between the rate for day flying and the rate for flight using night vision devices. The mean rate for daytime flight was 1.66, while the mean rate for flight with night vision devices was 9.00. In contrast to the problems for ground operations listed in Table 3, the most important factors associated with helicopter accidents were related to equipment limitations, distraction from the task, and training or procedural inadequacies. They concluded that the use of night vision devices increased the risk of a spatial disorientation accident by almost five times.

## Using Mishaps to Identify the Costs and Benefits of Night Vision

It is often argued that previous accidents would not have occurred if personnel had been provide with access to night vision equipment (Johnson, 2003). Such counterfactual arguments can be dangerous if there is a rush to introduce image intensification or thermal imaging systems in the aftermath of an adverse event without an adequate risk assessment. It can also be difficult to gather the evidence that is necessary to prove that this equipment would have helped team members to avoid an accident or incident.

### Lack of Night Vision Equipment Fails to Prevent Mishaps

Counterfactual arguments about the benefits of night vision equipment can be illustrated by the claims and counter claims that were made in the aftermath of an accident leading to the loss of a US Marine KC-130. The aircraft crashed into a Pakistan hillside near Shamsi airfield. There were no approach lights or navigational aids. The KC-130 was not equipped with any night vision equipment. Helicopter operations and noise restrictions prevented the crew from using their preferred approach. However, other KC-130s had landed at the same airfield without problems. The crew was experienced and rested. They had all flown into the airfield before. The official report concluded that the crew had "stopped navigating with instruments" and relied on direct visual observations during their approach (Durrett, 2002). Several analysts, therefore, argued that night vision equipment would have helped to avoid the accident because direct visual observations had failed to identify the hazard (Vogel, 2002). After the crash, the Marines began to retrofit KC-130s with night-vision equipment as well as a GPS linked map-based navigation system. The official report rejected this argument and insisted that while the provision of night vision equipment would have helped the crew, it would not necessarily have prevented the accident (Durrett, 2002). It can also be argued that the provision of these devices might actually increase the risk of controlled flight into terrain if crews resort to the images provided by these devices rather than the information provided by more conventional flight information systems. As Braithwaite et al (1998) have shown for the US Army helicopter fleet the provision of night vision equipment can increase rather than reduce the problems of spatial disorientation.

The problems of using accident information to analyze the strengths and weaknesses of night vision technology can also be illustrated by litigation following a land-based training accident (Maryland Court of Appeals, 1999). A US Army Major was run over by a truck. Two Maryland Army National Guardsmen were driving the vehicle as part of a training exercise. The intention was for their unit to simulate an attack on their colleagues in the Florida Army National Guard. The Major belonged to an active duty unit that was evaluating the exercise. The accident occurred just after midnight, when the two guards drove their truck along a dirt road to pick up a patrol. The Major had remained seated in the roadway after he had finished evaluating another exercise. He made no apparent effort to move as the truck approached. The vehicle was driving under “blackout conditions” without headlights. Although one of the soldiers in the truck had a set of night vision goggles, he was not using them at the time of the accident. Neither soldier had received any training in their use. Neither saw the Major prior to the accident. He suffered serious injuries that were exacerbated by a series of delays in his evacuation. Two ambulances arrived on the scene of the accident with inadequate equipment. He was then transported to the wrong hospital and was eventually declared dead on arrival at the intended destination.

The U.S. Army and Maryland National Guard had different views about the incident. The National Guard determined that the Major’s death was caused by his lack of situation awareness during night vehicle maneuvers. They argued that if the Major had been alert, he would have heard the truck in sufficient time to remove himself from the road. The accident was also blamed on resource limitations that prevented the National Guard from providing and training troops to use night vision equipment. The Florida units had provided some goggles during this exercise but the Maryland soldiers had not received the training that was necessary to use them. In contrast, the Army rejected lack of funding and training as reasons for the drivers not using night vision goggles. The accident was caused more by the driver's excess speed rather than the Major's inattention. As a result of these investigations, the Major's widow sued for negligence claiming that the drivers of the truck were speeding, sleep-deprived, and failed to use night vision goggles. She also sued the State and the Maryland National Guard for maintaining insufficient supplies of night vision goggles to provide them to all members during blackout conditions and for failing to provide training to the drivers in the use of night vision goggles.

The outcome of this litigation illustrates some of the problems that arise when the proponents of night vision equipment use accident investigations to support the wider introduction of these devices. Maryland's Court of Appeals unanimously upheld a Montgomery County Circuit Court decision to reject the $6 million lawsuit. This was justified not in terms of the technical argument for or against the provision of image intensification and infrared devices. Instead, the court focused on whether the court had jurisdiction over National Guard operational decisions, including the provision of particular items of equipment. To establish negligence it was argued that a jury would have to decide how many night vision goggles should have been acquired. This would involve questions about procurement priorities for a range of different equipment. The judge and jury might also have to consider how such vision equipment should have been allocated, what kind of training should have been provided and when it should have been offered etc. The Appeal Court concluded "one can only imagine the problems that would arise if a Maryland jury were to decide these issues one way, an Ohio jury another way, and an Alabama jury a third way… any attempt (by the judiciary) to determine these issues would constitute a substantial interference with the authority and discretion vested in the other two branches of government (Executive and Legislative)" (Maryland Court of Appeals, 1999).

## Provision of Night Vision Devices Contributes to Accidents

Previous paragraphs have shown how difficult it can be to argue for or against the introduction of night vision equipment in the aftermath of mishaps in which these devices were not available to military personnel. It is often easier to analyze those adverse events in which the provision of image intensification and infrared systems contributed to an accident or incident. This can be illustrated by a fatality that was recently investigated by the US Army Centre for Lessons Learned (2003). Existing night vision currency requirements in the US Army's Aircrew Training Manual state that aviators must fly at least one hour using night vision equipment every 45 days. This incident demonstrated that the minimum requirement is insufficient for many missions. A UH-60L instructor pilot had over 8,000 hours of rotary-wing experience. All the crewmembers had flown together many times in the past. Both pilots were qualified and current for the night vision goggle training mission.

However, they both averaged less than 3 hours of night vision flight per month over the preceding 7 months. The Army Safety Centre (2003) report argued, “If any one of the conditions — low recent experience, dust, winds, or low illumination — had not been present, perhaps the accident would not have occurred. If the aircrew had more recent experience, they would have been better able to deal with the harsh environment. If the illumination had been better, their low recent experience might not have been a factor. If the conditions had not been as dusty, perhaps the crew would not have become disoriented…”

This incident not only illustrates the importance of recurrent training with Night Vision Equipment. It also illustrates how a number of adverse factors can combine to create the conditions in which an incident occurs. In other words, the use of night vision equipment plays a necessary but insufficient role in the accident. Sufficient conditions often exist when personnel rely on these devices in extremely hazardous environmental or meteorological conditions. The complex nature of many night vision incidents can also be illustrated by an adverse event involving an officer with a motorized rifle platoon (US Army Centre for Lessons Learned, 2001). His unit was to occupy a battle position during a training exercise using an M551A1 Sheridan light tank. The officer’s platoon was to move from their hiding positions to occupy prepared fighting positions. His orders included information about the safety requirements associated with zero illumination operations. The officer also had access to a compass, a map and a GPS receiver to assist with nighttime navigation. Although the officer was relatively unfamiliar with the area, the gunner had several years of experience on this range. Even so, they spent a number of hours driving around looking for their battle position.

Standard operating procedures and the orders for this exercise stated that the gunner should have been ordered to dismount and guide the driver when traveling cross-country in zero illumination. Instead, the officer used night vision goggles while his driver used a night sight. When they failed to find their fighting position, the officer was told to wait until first light before continuing the search. However, he carried on looking until the vehicle eventually overturned in the excavation. The officer was standing in the nametag defilade position and received fatal crush injuries.

The Army Safety Centre argued that the crew relied too much on their night vision equipment as they searched for their battle positions. Their training should have encouraged them to use minimal additional lighting to support their image intensification equipment. Standard operating procedures should also have encouraged the use of ground guidance techniques. Above all, they should have considered the potential hazards of continuing to search for their positions after they were told to wait until first light. Soldiers must gain “an understanding and appreciation of the risk-management process and know that if the risks outweigh the benefits, then the mission should be a no-go” (US Army Centre for Lessons Learned, 2001).

### Risk management

Risk management is the process of identifying and controlling hazards. This is a non-trivial task. In particular, the introduction of night vision technology can reduce the likelihood of some accidents whilst at the same time increasing the risks associated with other types of adverse event. In particular, personnel are likely to conduct operations that would not have been attempted without the technology and which in retrospect ought not to have been attempted even with this additional support. The accident involving the Sheridan light tank provides an example of such an incident; the crew decided to continue looking for their fighting position using the vision systems even after being told to wait until it became light. Other risks stem from the limitations of the technology; these include visual illusions and the problems associated with environmental hazards such as the distractions created by conventional headlights.

It is difficult to survey the risk 'landscape' in which night vision increases the likelihood of some hazards and diminishes the likelihood of others. It can also be difficult to trade-off this changing risk landscape against the operational benefits that this technology provides. Further problems are created not so much by the risks of misusing the technology but by hazards that relate to the operational procedures that support the use of night vision technology. For instance, it is critical that personnel use all available intelligence to alert themselves and their colleagues about potential hazards when conducting low-level operations with night vision equipment. However, local maps often lack necessary detail. Hazards such as power lines are often not marked. Army aviators may have to conduct day reconnaissance missions to that they can draw up the hazard maps. Unfortunately, such operations create further hazards if they are detected.

In peacekeeping operations, senior staff are often faced with more complex decisions in which the use of night vision equipment forms part of a much wider set of concerns (Johnson, 2002). This is best illustrated by an incident involving the Canadian force in Somalia (Canadian Department of National Defence, 1997). Such adverse events are of particular concern given the increasing importance of peacekeeping tasks for many armed forces. This incident resulted in the death of one Somali and the wounding of another. It was a turning point in the Canadian involvement in this country because it demonstrated that some soldiers believed their rules of engagement allowed them to shoot fleeing civilians if they were believed to be thieves or saboteurs. The incident occurred when a Reconnaissance Platoon observed two Somalis walking around the wire of the Canadian Engineer's compound. The detachments had overlapping arcs of observation and fire. Infrared chemical lights were used to mark their positions. These glow sticks were visible through their night vision equipment but were invisible to the naked eye. The night vision equipment and markers were intended to avoid any risk of the patrols shooting at each other. The precise sequence of events was contested during subsequent investigations. However, it appears that the two men fled from the patrol after being challenged. They were then were shot at from behind. One was wounded and the other continued to run.. The fleeing man was subsequently shot dead by another part of the patrol.

As mentioned, night vision equipment only played a small part in this incident. The soldiers' interpretation of their rules of engagement and the leadership of the Reconnaissance Platoon were identified as primary factors in this incident. However, the subsequent inquiry did identify the importance of the decision to use night vision equipment in this situation. It was argued that if the compound had been better illuminated with conventional lighting then local civilians, especially petty thieves, would have been less inclined to approach the installation. Shortly after the incident, the Engineers constructed a light tower. This was perceived to have had an immediate effect on the previous problem of petty theft. However, the shootings may also have had a deterrent effect. The key issue here is that additional lighting was not initially installed because it would have interfered with the use of night vision goggles by reconnaissance patrols. The risk of night-time friendly fire incidents was perceived to outweigh the potential benefits in terms of crime reduction. The shooting incident showed that this was a simplistic assessment by underestimating the consequences of what many perceived to be the unjustified shooting of Somali civilians. The government inquiry found that "we are nonetheless satisfied that installing a light tower and a surveillance tower, along with increased foot patrols and firing off paraflares, would have provided more acceptable and lasting deterrence to infiltrators in the long run" (Canadian Department of National Defence, 1997).

## Night-Vision Accidents and Training

A range of training material is intended to reduce the frequency of these mishaps. US Army driver training requirements cover the use of night vision equipment in AR 600-55*, The Army Driver and Operator Standardization Program (Selection, Training, Testing, and Licensing*). This is supported by training circulars such as TC 21-305-2 *Training Program For Night Vision Goggle Driving Operations* and FM 21-*305 Manual for the Wheeled Vehicle Driver*. Support is provided through a range of courses designed for specific vehicles as well as more general training, including *TC 1-204 Night Flight Technique and Procedures*. Local units in the US Army can download a training support package for the use of night vision goggles that includes a computer-based training package.

Much of this material has been informed by the lessons of previous adverse events. For example, a series of previous accidents similar to thise described in this paper led to a reminder being issued across the US Army that bright lights from vehicle headlights and other sources will drive the goggles' gain down to the point that everything else in the field-of-view all but disappears. In addition, if the bright light exposure continues for 70 seconds (+30 seconds), the PVS-7s will turn off. The practical advice includes encouragement to keep bright lights out of the goggles field-of-view and to cycle the switch on and off if the goggles shut down after exposure to bright light. Similarly, officers were reminded that the natural illumination provided by the moon is often critical for image intensification systems and so missions should be planned to take into account the 15 degrees per hour change in the height of the moon as it waxes and wanes (US Army Safety Center, 2003a). The emphasis on risk assessment is also apparent in advice that officers should restrict the use of vehicle headlights in areas where night vision devices are being used. Formal risk assessment is critical because such restrictions remove a key source of illumination for those drivers who are not suitably equipped or trained in the use of this equipment.

The US Army also operates systems for learning lessons about the use of night vision equipment within particular operational contexts. In particular the insights gained from Operations Desert Shield and Desert Storm together with rotations in Kuwait helped to develop training materials that were put to use in more recent conflicts (US Army Safety Center, 2003b). Desert operations in Iraq again illustrated the importance of integrating information obtained from night vision equipment with accurate data from GPS applications. This, in turn, had to be linked to accurate intelligence information. For instance in army aviation it was and is critical to maintain accurate records about the location of wires, towers, terrain features etc. In other words, the operation of night vision equipment should only be seen as one component in the more complex information sources that supported each operation. Any failure in one of those sources is likely to create an over-reliance on the remaining systems and this can lead to accidents or incidents. In the desert environment, rapid troop movements created a constant challenge to update intelligence reports on the location of key infrastructure and topography. Hence, increased emphasis was placed on the use of night vision equipment. This resulted in incidents similar to those that have been described in previous sections. Many of the lessons that were learned about the use of night vision equipment in desert environments were more prosaic. In particular, operational experience reinforced the need for personnel to be trained to keep the lenses clean and the goggles stored safely when not in use. Sand and dust accounted for a higher than expected attrition rate for most units with access to these devices.

Earlier generations of pilots were more accustomed to the dry lakebeds and scrub of their National Training Centre but were relatively prepared for the impact of features, such as shifting sand dunes, and extreme temperatures on the operation of night vision equipment. For instance, crews found that their training manuals authorized airspeeds that were too fast to safely operate at night over sand dunes with night vision equipment; “the authorized airspeed for nap of the earth flight is 40 knots, but an aircraft flying in zero illumination at 25 feet in sand dunes should fly just ahead of effective transitional lift…Just keep in mind that at airspeeds below ETL, you may encounter rotor induced blowing sand” (US Army Safety Center, 2003b).

While it is possible to train personnel in recommended speeds during particular flight conditions, it can be far more difficult to train operators to resist the problems created by visual illusions. For instance, night vision devices can provide an impression of a false horizon when light-colored areas of sand surround dark areas, especially when other environmental factors, including dust and haze, may also obscure the horizon. Desert conditions often also lack the visual markers and reference points that support accurate height perception. Under such circumstances, ground lights can often be mistaken for the lights of other aircraft or even stars. Lack of features and relatively slow speeds can also persuade pilots that they have stopped moving even though the aircraft is actually moving forward. Other aspects of desert operations served to compound some of the more general limitations of night vision devices mentioned in the opening sections of this paper. For instance, we have already described how infrared searchlights can create a number of illusions for the users of infrared vision systems. In flat terrain, such as that found in dry lakebeds, these devices also provide the illusion that the terrain slopes upwards at the edges. Particular problems are created when using the searchlight to view other helicopters that may appear to be landing into a crater when they are landing on level ground.

Recent years have seen a move away from training individual crewmembers to recognize the optical illusions that affect night vision equipment. These illusions can be so persuasive that individuals will still fall prey to them even though they have been trained to recognize that they can occur. In contrast, greater attention has recently been paid to team and crew coordination as a potential barrier to incidents and accidents. For instance, the Army Safety Center's Southwest Asia Leaders' Safety Guide emphasizes the need to synchronize crew observations and communications in order to combat some of the problems created by these illusions. Guidance is provided on scanning responsibilities for pilots and non-rated crewmembers in different types of flight. These responsibilities must be planned and rehearsed prior to any mission so that team members can detect and compensate for the current limitations of night vision technology. From this it follows that team selection is particularly important.

The provision of training does not always match up to the standards that are claimed in many official publications. For instance, one of the lessons learned during the Canadian deployment in Bosnia was that more ground forces need to be trained in a wider range of this equipment. One of the participants in this deployment observed that "personnel were unable to train on the variety of Night Vision Devices that were eventually made available to us in theatre… not having this equipment available prior to deployment meant that we had to utilize valuable time to train personnel on equipment that they should have been familiar with before they arrived". Some of the equipment that they were expected to use only arrived six weeks after their deployment. However, the units were able to overcome these limitations. The Post Action review found that this equipment helped dismounted patrols in the towns and villages. The technology provided local inhabitants with a "dramatic" example of their fighting capability. This was claimed to have deterred crime and established credibility (Canadian Army Centre for Lessons Learned, 2001).

This paper has focused on accidents and incidents involving night vision equipment. We have not considered the problem of fratricide. Many friendly-fire incidents directly stem from the use of this technology. Brevity prevents a more sustained analysis of these adverse events. However, some of the problems in training to use night vision devices can be illustrated by the following account of an incident that occurred during the Serbian peacekeeping operations (Marshall, 1996). A section commander was in an armored vehicle. Although he had significant experience in an anti-armor platoon, he had undergone two weeks of training in his current vehicle priot to deployment. In particular, he only had a basic training in his Tube launched, Optically tracked and Wire guided (TOW) weapons system. He received orders that a command post was underfire and that Serb vehicles were being moved up. His gunner prepared to open fire. The gunner had just finished the TOW course using two different forms of simulator. Unfortunately he had only fired one live missile during the course. This had been during the day and on a stationary target.

The commander received the order to open fire and ordered his gunner to search for targets. There was insufficient time to align the Crew Commander's Target Acquisition System. The gunner used his thermal imaging system to find a hot spot in his field of view. The Commander had no time to check precisely what the target was and had insufficient training in the available recognition systems to check the gunner's decision. Two missiles were launched against two different friendly targets. A subsequent Board of Inquiry investigated the deaths of five soldiers. The causes were identified as "poor navigation, the lack of rehearsals by day and night, the lack of arcs of fire for the gunner, the lack of effective thermal fighting vehicle recognition training, and the absence of any Standard Operating Procedures to deal with fratricide incidents".

## Conclusions and Further Work

This paper has described the strengths and weaknesses of night vision equipment in a range of military applications. The intention has been to look beyond the advertising and hype that surrounds many of these devices. Statistics studies have shown that image intensification systems and infrared imaging devices have been used during an increasing number of incidents and accidents. Further work is urgently required to determine whether or not the use of this equipment is actually *causing* an increase in the nighttime mishaps that are being reported across many armed forces. We have also used more qualitative accounts to look behind the statistics. The intention has been to provide the reader with a more direct impression of the types of incidents that occur when personnel use night vision devices. This analysis has shown the complex role that image intensification and thermal imaging plays in military accidents and incidents. Some investigators have argued that these devices were a primary cause of military mishaps. Conversely, it has also been argued that the availability of night vision equipment would have prevented other accidents from occurring. A key conclusion is that the successful introduction of these systems depends upon a range of supporting factors. These include complementary technology ranging from GPS systems to maps. The supporting infrastructure also depends upon appropriate training. This should focus on individual users familiarizing themselves with individual devices but must also consider the ways in which teams of soldiers interact to overcome the limitations of existing technology. In particular, we have argued that greater support should be given to the personnel who are involved in the risk assessment that must take place before these devices are deployed in support of military operations.

Studies of ground and aviation accidents have argued that this existing training needs to be improved in order to reduce the frequency of mishaps involving night vision equipment. For instance, Ruffner, Piccione and Woodward (1997) have shown that the existing curriculum helps drivers to identify ditches and other road conditions. It does not, however, help them to identify those depressions and other hazards that they have shown to be the cause of most night vision accidents. Their analysis of the mishap reports indicates that while drivers were vigilant, they lacked knowledge of the cues that could help them spot and properly judge the depth of depressions in the 'roadway'. Most of the training was also conducted during daylight or with the assistance of headlights when soldiers often received an unreliable impression about the capabilities of image enhancement technology. Both ground-based and aviation personnel often complain that they receive inadequate training in how to focus night vision goggles. This remains a focus of human factors research within the Night Vision Operations groups of the US Airforce's Crew Systems Interface Division at Wright Patterson (Pinkus and Task, 2000). The accidents and incidents identified in this paper have supported many of the criticisms put forward by Ruffner et al. More recent events have shown that the provision of night vision equipment continues to be piecemeal. Several of the coalition partners in the Gulf were forced to use accelerated procurement to ensure that sufficient devices were made available to troops prior to the conflict. For example, the UK Ministry of Defense (2003) issued an Urgent Operations Requirement action. Further work is required to determine whether the successful acquisition of these devices shortly before the conflict led to accelerated training procedures and whether this, in turn, led to the accidents and incidents predicted by Ruffner and his colleagues.

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