Modelling Of Operations Involving Non-Lethal Weapons

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Abstract. Modelling and simulation of Army operations that include the use of non-lethal weapons stretch current analytical capability. Nevertheless, this is not a challenge that can be ignored. The presence of civilians, insurgents or coalition forces in the operating space requires that, where appropriate, the Army commander has a range of both lethal and non-lethal assets at his/her disposal. For instance, where there is ambiguity in target classification or the risk of third party injury, non-lethal weapons may be a viable alternative. Such non-lethal weapons include kinetic, mechanical, chemical, acoustic, electric and electromagnetic devices that can be used to target both personnel and platforms. The challenges of modelling non-lethal weapons lie in three areas. First is acquisition of data on the effect of their use on a specific target. Second is the effect on third parties associated with the intended target, such as accomplices or bystanders. Third is the effect on the overall campaign where an antagonistic group may seek to exploit the tactics of the blue force. Thus we need to develop a new way of modelling and simulating actions where non-lethal effects may be employed. Of particular concern are determining both the “physics” and the “psychology” of one-on-one, one-on-few and few-on-many engagements. Equally important is modelling the rules of engagement and the effects on crowds, as these represent very different paradigms to conventional loss-exchange ratio wargames. This paper sets the scene for developing a novel modelling and simulation regime in this difficult area. We propose that the work area should comprise useful vignettes, concepts of employment, quantifiable models (for wargames and agent based approaches) and development of a rule set for critical parameters. Such investigation is essential if development of new techniques or acquisitions of new equipment are to have credibility.

1. INTRODUCTION

Modelling and simulation of Army operations that could include the use of non-lethal weapons (NLW) is a challenge to the analytical community. The motivation of this interest lies in the recent trends in conflict where Army actions are more likely to occur in urban environments, coalition forces are deployed and the nature of conflict has moved away from conventional warfare. NLW (Annati, 2008) potentially offer a viable alternative if for instance third party (civilian) injury is to be reduced or if there is ambiguity in target classification and thus the possibility of friendly-fire or other unintended casualties. Technology has also provided new means of exerting control over the battlespace, additional to the use of traditional kinetic, blast and fragment weapons. For these reasons, new tools and methods need to be developed to allow modelling and simulation of operations involving NLW.

In a military context, the use of NLW should be seen as one aspect of a managed lethality spectrum:

- Do nothing
- Verbal instruction
- Non-lethal force
- Lethal force

and the intent contained in this paper is to extend modelling capability to include operations where NLW could be used, not to just focus on NLW per se.

Many NLW concepts have been proposed and are in varying degrees of development. These are directed towards individuals (personnel), sensors, platforms (vehicles) and electronic systems. In this context, we differentiate electric devices which are physically linked, or in close proximity to the NLW from electromagnetic devices where the effect is propagated. Some generic examples are as follows:

- Kinetic devices
- Mechanical devices
- Chemical devices
- Acoustic devices
- Electric devices
- Electromagnetic devices

As will be seen, knowledge of the characteristics of NLW is sparse, sound analytical methodology is yet to be developed and we lack robust final products for analysis of operations using NLW. This paper sets the scene for developing a novel modelling and simulation regime in this difficult area.

2. POTENTIAL USES AND TYPES OF NLW

At a 2008 TTCP-initiated workshop attended by the authors, technology developers and Army end-users, it was clear that the prime motivation for development of NLW was to reduce unintentional casualties in conflict. Typical proposed uses of NLW are as follows:

- Deny access to a street, building or a facility
- Move crowds
- Protect convoy operations
- Conduct check point operations
Activities such as these allow plausible vignettes to be developed and modelled. In seminar wargame mode they allow identification of potential issues or problems such as through red teaming (Defense Science Board, 2003), and can help in development of concepts of operations and new tactics, techniques and procedures for NLW employment. Quantitative analysis of the vignettes also provides convincing material to senior decision makers involved in procurement and guides technical specifications for NLW.

Another approach to vignette based analysis is through the use of effects, for instance:

- Deny
- Disperse
- Disable
- Deter
- Deceive

An effects-like approach provides an alternative viewpoint as it gives a more generic and holistic appreciation of the NLW system. It might also be noted that this list is common to the use of conventional weapons. Given this, then it is pertinent to consider what NLW provide that is distinct and ensure these aspects are modelled. For instance, new types of action may be achieved that are not possible with the use of lethal force. We might also note that tactical actions may now be achieved with different strategic outcomes, such as civilians not being killed.

We also note that a combination (Curtis, et al, 2006) of two approaches also provides valuable insights, eg: “when you move crowds, what are the deny aspects?” followed by the same question with disperse.

By far the most work has been applied to the use of kinetic (blunt trauma) devices on individuals (Bigatti, 2008). However, the scope of NLW is much wider and modelling should be able to address a range of potential examples, including:

- Kinetic v personnel (eg bean bags)
- Kinetic v vehicles (eg high velocity blunt objects)
- Mechanical v personnel (eg obstacles, glues/foams)
- Mechanical v vehicles (eg obstacles, caltrops)
- Acoustic v personnel (eg loudspeakers)
- Chemical v personnel (eg malodoursants)
- Electric v personnel (eg tasers)
- Electric v vehicle (eg large taser-like device)
- Electromagnetic v vehicle systems (eg electromagnetic pulses)
- Electromagnetic v vehicles (eg directed energy)
- Electromagnetic v sensors (eg lasers)

Finally we note that the expected range where NLW would be used would typically be from a few metres to a few hundred metres, and thus they would be used in close combat role (Bowley, et al, 2001). However in contrast to conventional close combat, the range of the weapons is generally less than the detection distance.

3. GOALS OF MODELLING AND SIMULATION

Possibly the most important feature of analysis is to note that there is a hierarchy of modelling and simulation to be considered. At the lower end we have what may be termed “physics” or “item level” models. These look at efficacy of specific devices. These are valuable in technical design and in comparison of similar types of equipment (eg different calibre of essentially the same device). Slightly broader would be a comparison of different types of NLW as they are used to achieve a specific non-lethal effect (eg knock-down). Such modelling can be applied to parametric studies. Algorithms developed at this level are likely to feed into more complex models, as below.

The next level up refers to the effective use of NLW in operations. Put simply, while the NLW may work as planned, does it help achieve a successful outcome for the commander? Therefore the results from the lower level models need to be incorporated within larger simulations that lead to combat outcomes in specific vignettes. As we are essentially looking at small unit operations (from a few soldiers up to a company of about 100) then typical wargames such as IWARS (Natick Soldier Center) and CAEn (Hill, 2006) would be appropriate. Alternatively, agent based models, such as MANA (McIntosh & Lauren, 2008) could also be used. It is a matter of convenience if the actual algorithms or the results from studies are used in the higher modules (see later).

Typically we would define success criteria for a vignette in the form of an overriding mission achievement but often with significant qualifications. For instance, in a military action, it might be to displace an enemy from a hill, within a given time and within a certain number of blue casualties. For an operation involving NLW it might be to allow a truck to enter a crowded square, aid workers to unload food, and for blue forces to distribute the supplies. The qualifications might be that insurgent red forces are not allowed to instigate a riot through incitement of the civilian population. These are different in content as conventional warfare modelling is based on blue-red loss exchange ratio whereas operations that could involve NLW will almost certainly require invention of new paradigms.

From a modelling and simulation point of view, it should also be recognised that in an action the commander may choose to step up or down from the use of NLW. In a human-in-the-loop simulation these decisions would be made by the player. However this would not be practical in constructive simulations and thus a coding in of these possible actions needs to be considered.
Next we consider the actors (Hobbs & Egudo, 2006). In traditional conventional warfare, only blue (friendly) and red (enemy) were considered. This is no longer enough for conflict modelling. In NLW operations the effect on third parties needs to be considered, as well as the possibility of red posing as white, or white becoming hostile. Vignettes must contain a full list of actors (chromatic terms by convention):

- Blue forces
- Other blue forces (eg coalition)
- Regular red forces
- Insurgent red (possibly multiple) forces
- Civilians (whites)
- Aid agencies (greens)

though, again these are not specific features for NLW.

The unique aspects for modelling and simulation of NLW introduced in this section thus can be summarised:

- A need to develop models of the basic functions of NLW
- Incorporation of NLW-based modules within small unit wargames
- Ways to explore using agent based models
- Ways to encode rules of engagement into simulations
- Pertinent measures of success
- Ability to address campaigns

4. MODELLING PARAMETERS

Implicit to the above discussion is the concept of two fundamental parameters:

- The probability of a hit, $P_H$
- The probability of a kill, $P_K$

This is sometimes expressed in terms of the notion of a kill given a hit ($P_{KH}$ i.e $P_K = P_H \times P_{KH}$) but the concept remains the same. There are also preliminary phases that can also be included in any calculation:

- Probability of being in a vulnerable position
- Probability of detection
- Probability of recognition
- Probability of identification
- Probability of classification as a target

but in this context, $P_H$ will apply to the actual round being fired, as the other terms will be the same for conventional and NLW.

A working hypothesis is thus that there is no conceptual difference in treatment of both conventional and NLW. Put simply, NLW are used (as are conventional weapons) to engage individuals and platforms to achieve a desired effect. We can also assume that the target classification sequence above will be essentially the same for both sorts of weapons (even though there may well be different sighting systems). The initial modelling problem is thus the need for determination, and as will be seen, definition, of $P_H$ and $P_K$.

$P_K$ is a far more challenging concept and this is accentuated in NLW operations. A “kill” has many meanings and is not limited to death of an individual or the catastrophic destruction of a vehicle. The purpose of the use of weapons is, amongst other things, to allow the commander freedom of action on the battlespace.

A range of effects for conventional weapons is usually expressed as:

- Kill - complete loss of function
- Neutralise (or disable) - incapacity to exert significant influence on the battlefield
- Suppress - the use of threat to stop the enemy entering the battlefield, or producing aimed or unaimed fire
All of these may be considered as time based, for instance loss of function may take time and suppression is usually temporary. If we consider these three points on the spectrum for NLW operations then it is clear that all relate in some way to an effect achieved by the weapon – ie all can be considered as a form of “kill”. As an aside, the term “kill” is possibly too emotive to be used in studies using NLW as the intended effect is to avoid death. Nevertheless, “kill” has an established history in analysis and it is well recognised that it can be applied to defeat of functions. For instance, vehicles may be subject to:

- Mobility kill (vehicle stopped)
- Firepower kill (weapons disabled)
- Sensor kill (sensors disabled)
- Communications kill (communications disabled)

and it is apparent how these can be achieved by both conventional and NLW means. For instance, a tank can be stopped and cannot use its weapons (mobility and firepower kill), if for instance it was enveloped in a rapidly setting foam. This is a form of kill even though the tank can still operate as a sensor and communications platform. In a NLW environment this may be acceptable and preferable to any risks that may accompany any desire for a catastrophic kill that disables all functions and causes death or severe injury to the occupants.

We can similarly classify functional kills for personnel:

- Physical kill (eg physical knockdown with no ability to influence the battlespace)
- Mobility kill (eg knockdown but still able to use a mobile phone)
- Psychological kill (eg loss of desire to influence the battlespace – this may include retreat and could be pain induced)
- Equipment kill (eg night vision device disabled)

For instance, if the intent is to prevent an agitator from fomenting a riot in a crowd, then physical isolation (a tactic) and electromagnetic disruption of his mobile phone (use of NLW) may be sufficient. Of course, for an actual operation, and for modelling, identification of the individual is a challenge.

Thus it can be seen that there is considerable groundwork to be done in definitions and concepts of operation relating to the use of NLW. Extensive work will be needed to define a lexicon and taxonomy of battlespace effects. In particular, the concept of “neutralisation” and “kill” probably need to be merged and discrete objectives delineated.

A particularly difficult aspect of modelling and simulation for conventional weapons is the notion of third party effects. Thus while we might have information on the one-on-one (ie shooter-target) parameters, we also need to understand the effect on third parties. Thus hits/kills (or threat of hits/kills) on a target will cause a change in behaviour to other members of the group and may lead to a change in tactics, or to neutralisation or suppression. This will present an additional challenge for NLW, and while the concepts are similar to those for conventional weapons, they will merit separate study.

The unique aspects for modelling and simulation of NLW thus can be summarised:

- Derivation of a lexicon and taxonomy of effects relating to functional kills
- Determination of the effects of hits/kills on third parties

5. MODELLING AND SIMULATION NEEDS

In the preceding sections we have shown the notion of a hierarchy of models and the fundamental need for $P_H$ and $P_K$ values. In this context, we note three discrete data goals:

- Individual $P_H$ data requirements
- Individual $P_K$ data requirements
- Grouped or collective $P_K$ data requirements

These are treated in turn below. Much of the material presented came from the TTCP workshop, the authors’ interpretations and their background experience in modelling.

5.1 Individual $P_H$ data requirements

To a major extent we can consider that gaining $P_H$ data is mostly a calculation and data collection problem, particularly where laboratory and field testing can be applied. Two broad classes can be considered:

- Direct fire $P_H$
- Area effect $P_H$

Intrinsically, these terms are similar in effect – they give a level of threat on the battlespace, but they require different strategies to obtain.

The first term, as exemplified by projectile weapons rounds refers to the notion that firing a kinetic nature results in a distribution (dispersion) in both the y and x axes. Overlap of this dispersion with target size then gives the $P_H$. Much data already exists for instance for 12 gauge and 40mm bean bag rounds. Typically, this is expressed in the form of a combination of a mean point of impact error (accuracy) and distribution about the mean (precision). Nevertheless, data are still difficult to obtain in combat situations. For instance, we can fix a barrel in a laboratory setting to gain the inherent errors. It might be noted that there is always a distribution and these can arise from random effects within the weapon, the environment, aiming error, fixed biases etc. Of course, once the weapon is placed in the hands of a soldier in situ, the errors are compounded and distribution increases. The situation will be the same for kinetic NLW, tasers and other tightly directed devices though perhaps field data may be easier to obtain than for engagements where the firer is not under lethal threat. Such an approach is inherently discrete, as we are looking to see if the round hits or not (even though
we have used either deterministic or stochastic means of generating the probability).

Area effect $P_H$ data, such as for acoustic or chemical devices present a different challenge and may rely upon modelling based on theory. For instance, one form of output would be a contour map based on the cone of effect which, incidentally, would include time factors. We might propose that above a certain threshold value, then a hit is recorded (ie a deterministic approach such if the concentration of the agent $> c_i$ then $P_H = 1$).

Alternatively, we might adopt a stochastic approach and use the raw data (eg if concentration is $c_i$ to $c_j$ then there is a 50% chance of a hit – to be determined by “a role of the dice”). Without doubt the $P_K$ will depend on $P_H$ figure and it might be easier to combine the $P_H$ and $P_K$ terms. We might also consider bulk effects. For instance, at a certain chemical level, we might propose that 50% of the crowd is disabled, rather than simulating individuals.

The required level of detail is a moot point. While exact simulation of specific events may be superficially attractive it usually suffers from four problems:

- Extensive CPU time (real time wargaming not possible)
- Incomplete modelling anyway (eg exact angle of the truck and the hit point are not known)
- The use of proxies in wargames studies (eg a generic APC)
- We often use stochastic and aggregated techniques (“if a certain truck is hit, no matter at what range or angle, the $P_K$ is $x$”)

All of these lead to a need for “reasonable” data that is fit for purpose. For instance, analysts often employ a “cookie cutter” approach. Thus a table like this might suffice (eg for an individual personnel target with a bean bag round – example values only):

<table>
<thead>
<tr>
<th>Range (m)</th>
<th>$P_H$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-20</td>
<td>0.5</td>
</tr>
<tr>
<td>20-50</td>
<td>0.2</td>
</tr>
<tr>
<td>50-100</td>
<td>0.1</td>
</tr>
<tr>
<td>100-200</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The compounding factors here would include visibility, intervening obstacles, human population variability, shooter variability etc. Some of these can be coded into simulations and some can’t. Thus the level of detail in the table may well be sufficient. What we do need to know, however, is that the top value is around 0.5 and not near 0.1. Alternatively a simple algorithm based on range may also do the job. Parametric studies would identify how critical the actual value is (and this would lead back to design considerations).

Our interpretation of current knowledge is that the principal issues are:

- Extensive $P_H$ data are still required for anti personnel effects, though kinetic data are reasonably well documented
- Libraries of $P_H$ data need to be built up for platforms and sensors, particularly under operational conditions
- $P_H$ data for area effect devices (chemical and acoustic) need to take account of a threshold value
- $P_H$ data for electromagnetic devices will require detail of propagation effects

5.2 Individual $P_K$ data requirements

As discussed before, much work needs to undertaken first to define the term “kill” and then to populate databases. As an example we will consider bean bag rounds used against personnel. Such rounds will have a measurable effect in terms of the energy delivered to the target, and these can used to predict physiological damage. Such data for this can be obtained from the use of animal tissue and body surrogates.

We might adopt a similar approach to gaining $P_K$ values for platforms, sensors and electronic systems. In these cases, a combination of theory and actual field testing can be carried out. However, the vast array of vehicle types, vulnerable electronic equipment, the presented aspects (side on, front on etc) mean that a library of weapon and target pairs need to be developed. This is likely to result in generic terms eg $P_H$ and $P_K$ against jingle trucks, under “typical” conditions.

There are also “off-axis”, or unintended occurrences to be determined. For instance a large kinetic weapon may well disable a truck, but what would be the effect of the uncontrolled moving vehicle? Similarly, use of electromagnetic devices may also disrupt traffic-lights or heart pace-makers.

The most difficult challenge is for the psychological terms. Insights on psychological and cumulative effects can be obtained though the use of volunteers (this is similar in context to paintball skirmishes) to see what it would take to cause them to stop. However, the link between the motivations driving the volunteers and other groups may be difficult to make. It should also be noted that a hit with a NLW may be a triggering event and the target may change behaviour, possibly becoming more committed.

Another opportunity for data collection is through video analysis of past events. The use of such information may contravene ethical standards, for instance if there was a deliberate intention to subject (for instance) a crowd to a NLW with the intent of studying what happened, rather than using it to achieve the desired effect. This is quite different to video capture and action after review using conventional weapons in warfare. Nevertheless, third party material (eg news agencies) is a potential source.

The principal issues are thus:

- Pain or discomfort needs to be translated to target behaviour
- A library of NLW effects on specific and generic platforms and sensors needs to be established
• The consequences of using a NLW device on moving vehicles need to be evaluated
• Unintended consequences need to be examined
• Ethical means of video data recording need to be developed

5.3 Collective Pk data requirements
In a modelling environment, the consequences to third parties of an actual or threatened kill need to be evaluated. This is the most intellectually challenging and emphasises some of the issues from the previous discussion. It might also be the simulation area where very significant input comes from non-military sources. Examples are useful to show the potential consequences here. Suppose a crowd of 1000 people is faced by a small blue force who instructs the crowd to maintain a distance from an aid truck. Two individuals, Persons A and B, are present and can be described as young, fit and “civilian bystanders” (ie “white”). They are both walking towards the blue element. The perceived behaviour of the crowd leads the commander to fire a limited volley of NLW. Person A is hit (whether intentionally targetted or not) and falls to the ground. Person B, who is standing next to him, might do one of five things:

• Comply with instructions (eg move away)
• Help Person A (and will stop moving)
• Nothing (eg carries on walking)
• Act unpredictably (eg panics)
• Oppose the instruction (eg advances and throws stones)

Now consider if the Person A is elderly and Person B is incensed that they have been struck. Or, Person B is an insurgent sympathiser (ie white who might turn red). There are many such credible vignettes that can be drawn up here.

From an analyst’s point of view, we might question if the use of NLW (and which ones and how many) was sound, irrespective of the one-on-one effect. If it is sound, where should the crowd be targetted and what would be good tactics?

All of these comments lead us to the conclusion that the effect on third parties needs to be investigated in some detail. This will include crowd dynamics amongst other things. While it can be noted that similar set of five possibilities (as above) can be expected through the use of lethal force, we have little data on how the situation would play out if NLW were used, or could be used.

These issues can be summarised as:
• The effect on third parties of seeing NLW being used on a nearby target needs to be determined
• Crowd characteristics and behaviours need to be investigated

6. PROPOSED WAYS FORWARD
A number of issues and challenges have been raised in this paper, and can be consolidated:

1. A lexicon and taxonomy of terms should be created, particularly to define the nature of desired effects and measurements of success. This should be compatible with a set of typical use cases, and will include concepts of operation.
2. Data need to be collected for PH and PK both for “physics” and “psychological” outcomes for the full range of NLW types. This should include both direct (one-on-one, shooter-target) and indirect (perceptions of third parties) features. It should include consequences of actions. Both effects on personnel and platforms need to be considered.
3. Item level models that include credible values of PH and PK should be developed to measure the efficacy of one-on-one (shooter-target) engagements.
4. Vignette based models need to be developed that allow exploration of the effectiveness of the use of NLW. This will include both the one-on-one and third party aspects. These may be based on small unit wargames or agent based models. Rules of engagement need to be coded into these simulations.
5. Campaign level wargames need to be developed to explore the longer-term consequences of the use of NLW.

7. CONCLUSIONS
Modelling and simulation of the use of NLW has been shown to be complex but is a developing area. Work needs to be done to complete data collection, particularly for non-kinetic devices. Rationalisation of the desired effects of the use of NLW and the pertinent measures will be required. Incorporation into vignette and campaign level wargames will require detailed knowledge of the psychological aspects of NLW usage, both for target-shooter pairs and for third parties bystanders.

The intent of this paper has been to expose the problems of modelling operations using NLW to a wide audience, and if possible seed new lines of research in the area. It might also be noted that many aspects of the problem are not limited to Army operations with, for instance, direct application to police or security operations. There are also links to other human modelling such as crowd control.

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