Cost-Effectiveness of CC&D Measures and their Interaction

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ABSTRACT

Various protection measures are introduced in order to increase survivability of military objects. The measures can be in the form of camouflage, armour or tactical manoeuvres. The cost of procuring such measures is normally easily calculated. The effectiveness, however, will be more complicated to quantify. Determining the cost-effectiveness is especially important when a limited amount of money is to be applied for an optimal protection balance between several countermeasure candidates. Cost-effectiveness numbers will also be useful in studying interactions between various measures.

One way of quantifying the cost-effectiveness is illustrated by results from a model describing a duel between combat vehicles. For the chosen scenario the following CC&D measures were included: camouflage nets, decoys, and smoke. Other parameters like probabilities of hit and kill-given-hit are important factors included in the model. The last parameter is a function of armour, which can easily be altered. To a certain degree tactics is also included. For the modelled scenario the study showed strong interaction between some of the countermeasures and it resulted in very high cost-effectiveness numbers for the camouflage measures in both the visual and thermal spectral band.

1.0 INTRODUCTION

In the camouflage work at FFI several methods to establish the effectiveness of countermeasures have been used. The most obvious way is to apply the reduction in detection and identification ranges as obtained from simple field trials as a measure of effectiveness. More complicated will be to establish engagement ranges; still more complicated is finding the degree of damage to the object as a function of countermeasures applied. The ultimate solution is the final result from a real combat situation. Apart from the impossibility of such a gaol, it is also very difficult to simulate a combat situation in a realistic way.

Somewhere on the scale from the very simple to the impossible method has to be chosen.

A whole range of countermeasures from signature manipulation (camouflage) to hardening by armour is available – countermeasures that may be applied solely or in combinations. It is important to be aware of that for some combinations, the effectiveness of the countermeasures may interact – positively or negatively. Quantifying the cost-effectiveness is especially important when a limited amount of money is to be applied for an optimal protection balance between several countermeasure candidates.

Countermeasures are introduced in order to increase survivability by reducing the probabilities of detection, hit when detected, and killed when hit. Some of the countermeasures will have influence on more than one of these factors as shown schematically in Figure 1.

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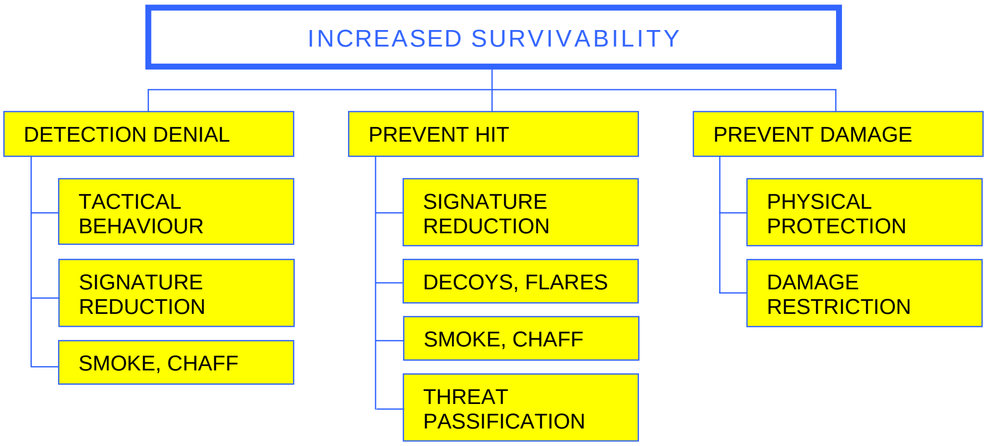

Figure 1: Schematic presentation of how countermeasures influence detection, hit and kill probabilities

The present paper describes a method for quantifying the effectiveness and the cost-effectiveness of countermeasures for MBTs engaged in a duel with other MBTs. Although emphasis is laid on camouflage and related countermeasures, the method can easily be applied for other measures – in fact, such measures are included in the example given in the next chapter.

2.0 EXAMPLE OF AN ANALYSIS

2.1 Scenario

As a scenario for investigating countermeasure effectiveness was chosen a duel between a platoon of 4 blue MBTs tasked to stop or delay a company of 13 orange advancing MBTs. Blue is divided in pairs as depicted in Figure 2. From their pre-recognized firing positions they engage orange, then withdraw under cover to new positions where from new engagements take place.

It is assumed that the orange vehicles cannot accept any large losses to get through. They will halt and withdraw when a given number of vehicles are lost. How large the number might be, depends of the importance of their task. For the present scenario they stop when half of their vehicles are lost.

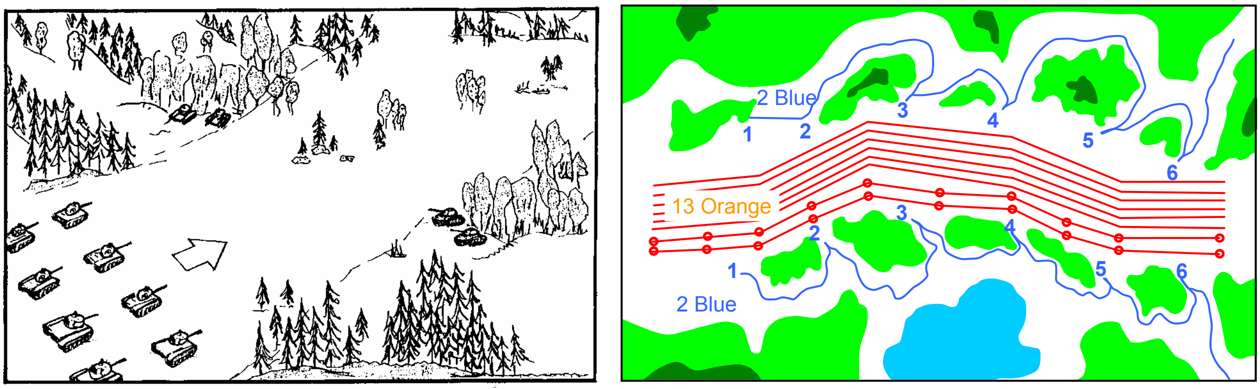

Figure 2: Artist impression and computer description of the scenario

In this scenario several physical countermeasures and tactical parameters are studied for both visual and thermal weapon sights. Camouflage, decoys, and smoke have been the main parameters of interest in this study. Two version of camouflage have been studied: visual and thermal. Four decoys were introduced. The confusion factor with the real targets was defined to 0.4. However, no opinion was made regarding how to move them around and about their construction. Both thermal and visual smokes were supposed to fully cover the targets when established. The establishing time for the smoke was, however, a variable parameter.

In addition to the degree of cover for the blue vehicles, the main variables of tactical behaviour were number of rounds fired before withdrawal and the time needed for withdrawal. The firing of a gun is strongly revealing even for a perfectly camouflaged object. The more glints the higher is the probability of being detected. The possibility of finding cover is dependent of the terrain. In this study this important parameter for blue was varied from uncovered, through half-covered, to fully covered i.e. just tower visible.

2.2 Results

2.2.1 Output from the model

In this section will be given some examples from the study. As the underlying information of the targets, the weapon systems, and the countermeasures investigated is not a part of this paper, the quantitative results presented must under no circumstances be regarded as universal.

The simulation model used for calculation of the duel will be described in the Section 2.3. An example of a part of the output from the model for one specific situation is presented in Table 1.

Table 1: Output example from part of one of the runs of the model

Time			Event			Dist
173.5	Blue	4	Detects	Orange	11	941
183.4	Blue	4	Shoots at	Orange	11	941
193.6	Blue	4	Shoots at	Orange	11	941
194.3	Blue	4	Kills	Orange	11	941
194.3	Blue	4	Leaves position			
194.6	Orange	10	Detects	Blue	4	938
197.1	Blue	3	Detects	Orange	6	1013
203.8	Blue	3	Shoots at	Orange	6	993
212.9	Blue	3	Shoots at	Orange	6	966
213.6	Blue	3	Leaves position			
213.6	Orange	3	Detects	Blue	3	967
214.4	Orange	6	Detects	Blue	3	969
214.6	Orange	5	Detects	Blue	3	969
214.9	Orange	4	Detects	Blue	3	972
224.0	Orange	5	Shoots at	Blue	3	1031
257.5	Blue	4	Arrives in new position			
276.8	Blue	3	Arrives in new position			

The simulation starts at time 0, and in the example is shown what happens between time 173.5 and 276.8 sec. The model stops running when one of the parties has lost all its vehicles or when the last blue has left its sixth position

The example starts with Blue vehicle #4 detects Orange #11 at a distance of 941 m, fires two shots and kills it. Then Blue leaves its position and arrives in a new position 63.2 sec later. While leaving its position Blue #4 is detected by Orange #10, but too late to be fired at. Blue #3 engages Orange #6 without managing to kill it. Blue #3 is detected by Orange #3, 6, 5, and 4, and engaged, but leaves its position safely and arrives in its new position ready for next engagement. By kill is here meant a hit that has stopped a vehicle from further action.

2.2.2. Effectiveness of the countermeasures

After several computer-runs for every situation with various countermeasures, the development of the duel can be studied. The results may be presented in many ways. In Figure 3 the results are presented as the force balance between blue and orange, starting at 4 blue/13 orange = 0.325. Increasing numbers means that blue is gaining relative power.

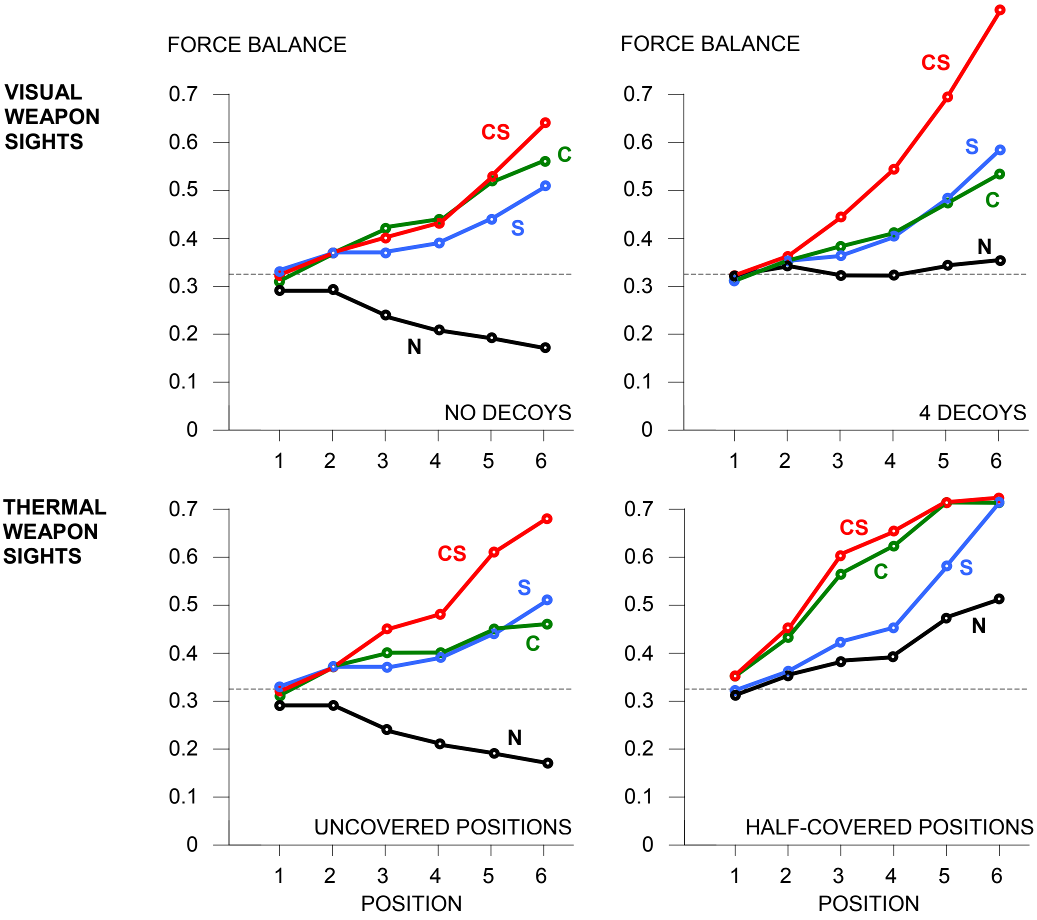

Figure 3: The force balance as a function of blue positions and countermeasures
Top: Visual weapon sights – with and without blue decoys
Bottom: Thermal weapon sights – uncovered vs half-covered blue positions
C = camouflage, S = smoke, CS = camouflage + smoke, N = no measures

Two factors should be noted from the results presented in Figure 3. The first is that blue will lose the duel if there are no countermeasures. The second is more interesting: the relative effect of the countermeasures is dependent on other measures introduced, here decoys and coverage. In the first case (visual weapon sights) adding smoke when the vehicle is camouflaged, have no effect till decoys are introduced. In the second case (thermal weapon sights) an additional smoke when camouflaged, loses its effect for vehicles operating from half-covered positions. This demonstrates clearly that there might be a strong interaction between some countermeasures in certain situations.

2.2.3. Cost-Effectiveness

As assumed, the orange vehicles stop and withdraw when 50% have been lost. In order to find how far they have reached and how many blue vehicles are left, the results are plotted as shown in Figure 4. From the figure can be seen that a 50% orange loss occurs at blue "position" 3.7 when no countermeasures are applied. At this position blue has 1.4 vehicles left. When blue applies smoke, the 50% orange loss occurs at "position" 3.2 where blue has 2.2 remaining vehicles.

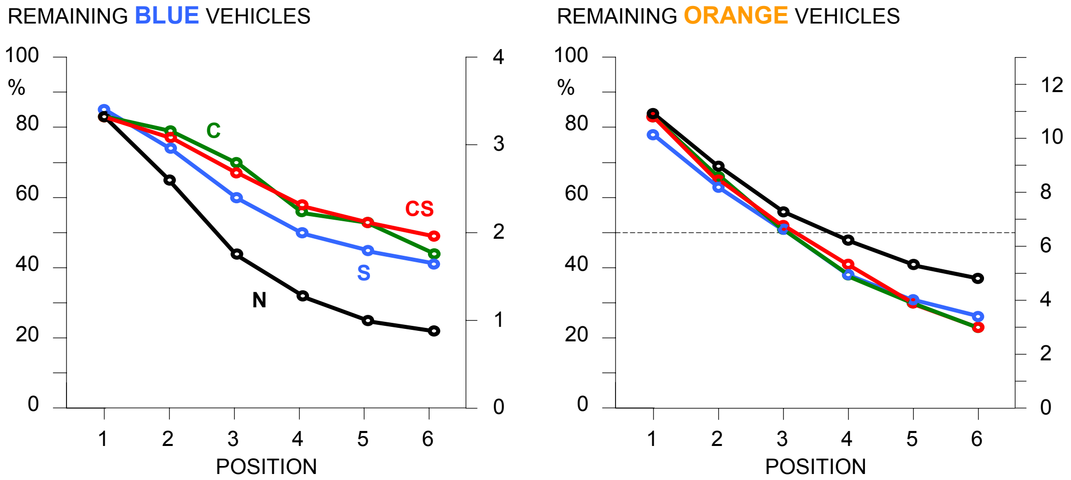

Figure 4: Remaining vehicles as a function of blue positions and countermeasures Visual weapon sights.
C = camouflage, S = smoke, CS = camouflage + smoke, N = no measures

Results from plots like those in Figure 4 are used for finding the remaining blue vehicles for all countermeasures studied – solely and in combinations. The results are now plotted vs. the cost of the countermeasures as shown in Figure 5. The cost numbers are old and should be updated according to more modern measures, but they are presented here to illustrate the method. It should be noted that the thermal countermeasures are in general more expensive than the visual, and that there is no cost related to coverage.

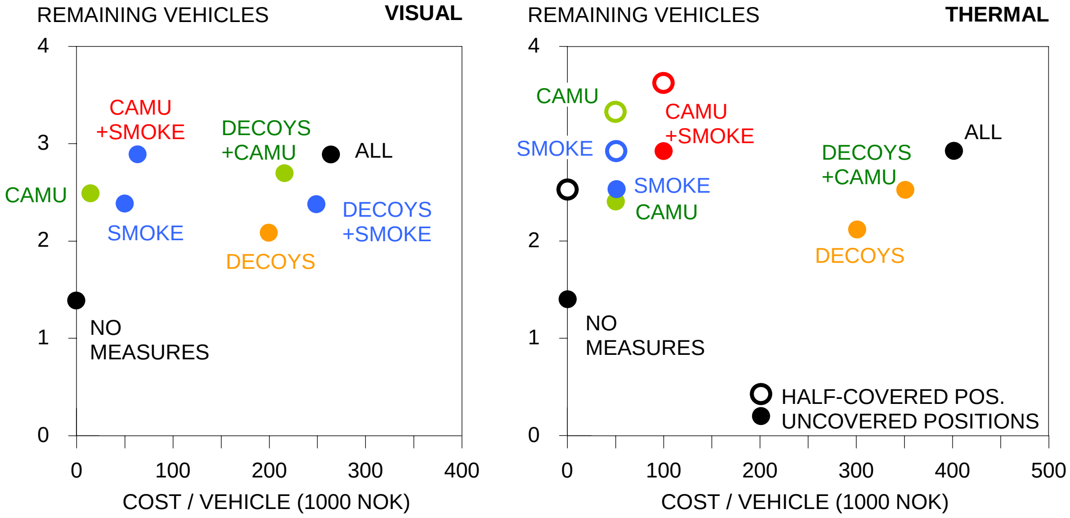

Figure 5: Remaining blue vehicles after an orange loss of 50% plotted against the cost of blue countermeasures

Effectiveness of one particular countermeasure is now defined as the reduced loss of vehicles due to that countermeasure. From the example given previously can be seen that by introducing smoke to the four blue uncamouflaged vehicles, results in saving 2.4–1.4 = 1.0 vehicles. The cost-effectiveness is calculated as the cost of saved vehicles vs. cost of countermeasures applied as read from Figure 5. Results from the calculations are presented in Table 2.

Table 2: Reduced blue losses and the cost-effectiveness of the countermeasures

Countermeasures	Visual		Thermal			
	Uncovered		Uncovered		Half covered	
	Reduced losses	Cost-effect.	Reduced losses	Cost-effect.	Reduced losses	Cost-effect.
No countermeasure	-	-	-	-	1.1	(∞)
Camouflage	1.2	400	1.1	110	1.9	190
Decoys	0.7	18	0.7	12	-	-
Smoke	1.0	100	1.0	100	1.5	150
Camu + Smoke	1.4	108	1.5	75	2.2	110
Camu + Decoys	1.7	40	1.5	21	-	-
Smoke + Decoys	1.4	28	1.4	20	-	-
All measures	1.8	34	1.8	23	-	-

The table illustrates clearly that the cost-effectiveness varies tremendously, the highest score is obtained by the cheapest measure – camouflage. For thermal weapon sights thermal smoke has the same cost-effectiveness as camouflage. The most expensive measure, decoys, is the absolutely least effective and consequently the least cost-effective. Combining all countermeasures is not cost-effective, although the result is that more vehicles are saved.

As there is no cost implied in utilising cover in a tactical way, the cost-effectiveness for vehicles without any special countermeasures goes towards infinity, which implies a certain “weakness” in the present definition of cost-effectiveness. However, the value of operating in a tactical way is convincingly illustrated.

2.3 The model

The MBT duel scenario is modelled in the object-oriented programme language Simula. The model will not be described in full in this paper – just a few important details will be discussed. At time 0 the orange vehicles start advancing, and as the time lapses as illustrated in Table 1, the various classes in the programme are activated and appropriate events take place.

In the model the terrain is assumed flat and each vehicle is given a fixed search sector – different for blue and orange vehicles. The search sectors are dependant of the terrain (trees). As orange vehicles advance, the vehicles will enter each other’s search sectors and detection may occur according to detection curves in the model (Figure 6).

The detection curves are based on results from field trials where search over a long period of time was included. Thus the curves represent the cumulative detection probability, P_{cum}, over this time. For moving vehicles the detection process is a dynamic process including search. The instantaneous detection probability, P_{inst}, is calculated from the formula $P_{inst} = 1 - (1 - P_{cum})^{1/15}$, which is based on assumed fixation times of 2 sec over a 30 sec period.

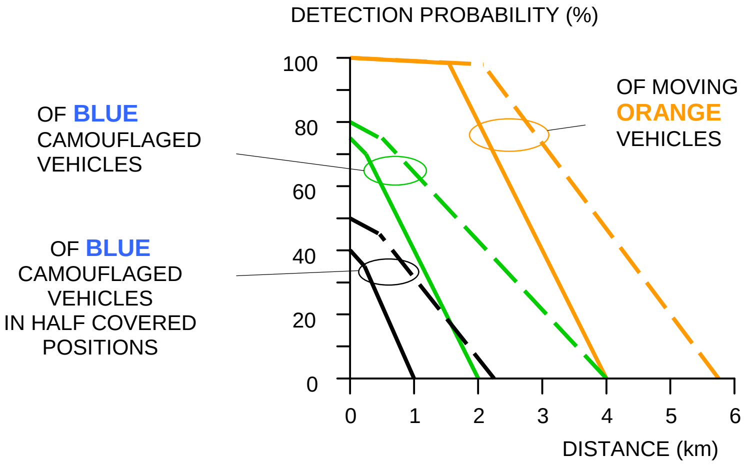

Figure 6: Examples of detection probability curves applied in the model
Broken lines are for vehicles firing

The model contains detection probability curves like those in Figure 6 for all situations: visual-thermal, orange-blue, moving-not moving, covered-half covered-not covered, and firing-not firing.

Two other parameters for the blue vehicles have to be mentioned: the time used for withdrawal and the establishing time for smoke. The longer this takes the more vulnerable to being detected and fired at.

When a vehicle of the opposite party is detected, the shoot, hit, and kill parts of the model are activated in that order. The hit probabilities (Figure 7) are dependent on the weapons systems including sights and ordnance, and on how large part of the target vehicle is observable. Movement of the firing vehicle or the target vehicle will be of importance for hit the probability. When firing, the hit probabilities will increase with the number of rounds fired, – and so will the probability of being detected.

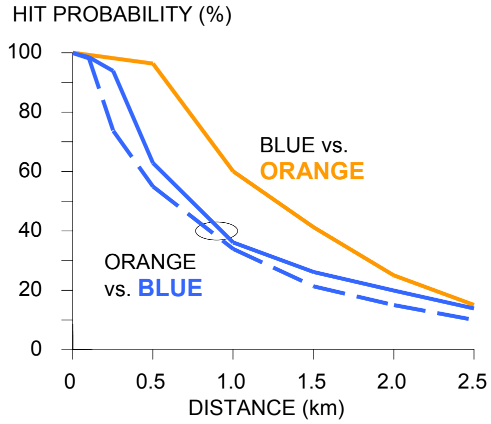

Figure 7: Examples of hit probabilities applied in the model.
Orange vehicles moving – Blue in their positions, not moving.
Broken curve is for Blue vehicles in half covered positions.

The kill probabilities are represented by fixed numbers from which a draw (killed – not killed) is made for each hit. The kill probability is dependent on ordnance and protection measures like armour. This parameter can easily be altered for studying the effect of this type of protection measures.

3.0 OTHER SCENARIOS

The examples from the analysis presented are for MBTs in one single scenario only. It is demonstrated that to perform such an analysis requires a reliable model and a large amount of input parameters. Many of the parameters can only be quantified by field trials. To obtain a complete picture of the cost-effectiveness of the various protection measures and their interaction for this particular vehicle, similar analyses should be undertaken for all scenarios in which the vehicle is planned to operate. It should not be expected to arrive at the same results for all scenarios – they may even appear to be contradictory. The results have therefore to be weighted according to how often that particular scenario may occur or how critical the task of the MBT is in that scenario.

For some of the scenarios there may be a variety of serious potential threats – from other MBTs, from anti-tank weapons on the ground, from the air, etc. In such cases a weighting process will again be necessary in order to arrive at a useful result.

For other types of objects quite different analyses have to be undertaken. It is not possible, however, to avoid defining the relevant scenarios and establishing a series of input parameters for a simulation model.

An important part of a cost-effective analysis is the definition of effectiveness. In the present case it was the number of blue vehicles saved for further action. It might have been the number of orange vehicles killed, or how far they managed to advance before they were stopped. Cost-effectiveness for MBT in other scenarios or for other objects may be defined quite differently.

4.0 CONCLUSIONS

When introducing protection measures, camouflage or armour, it is not satisfactory to investigate the effect of those particular measures independently of all other factors that contribute to survivability. The main reason for this is that some of the measures may interact as demonstrated in Chapter 2. It is imperative that the measures are studied in a realistic tactical situation. Such study is not straightforward and it requires a great effort for a trustworthy quantitative result.

It will appear as a waste of money to introduce costly armour when the same effect could be obtained by camouflage for a percentage of the price – as camouflage people would like to argue. A cost-effective study of candidate measures has to be performed in order convince both operating and procuring officers to balance the measures according to money available. It is necessary for a convincing result that the results from such a study have to be illustrated by numbers.

Independent of how to define cost-effectiveness, the protection measures in form of operating tactically smart, will always give a high score.