SAS-108 RTG-048 on Methods to Support Decision Making for Joint Fires

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This paper provides a brief overview of the work that has been conducted by the NATO STO task group SAS-108, entitled "Methods to support decision making for joint fires".

The NATO definition of joint fires is "Fires applied during the employment of forces from two or more components, in a coordinated action toward a common objective". So the sort of decision making we are concerned with is being able to select the most appropriate weapon system, for a task or set of tasks, from a range or air, land or maritime platforms.

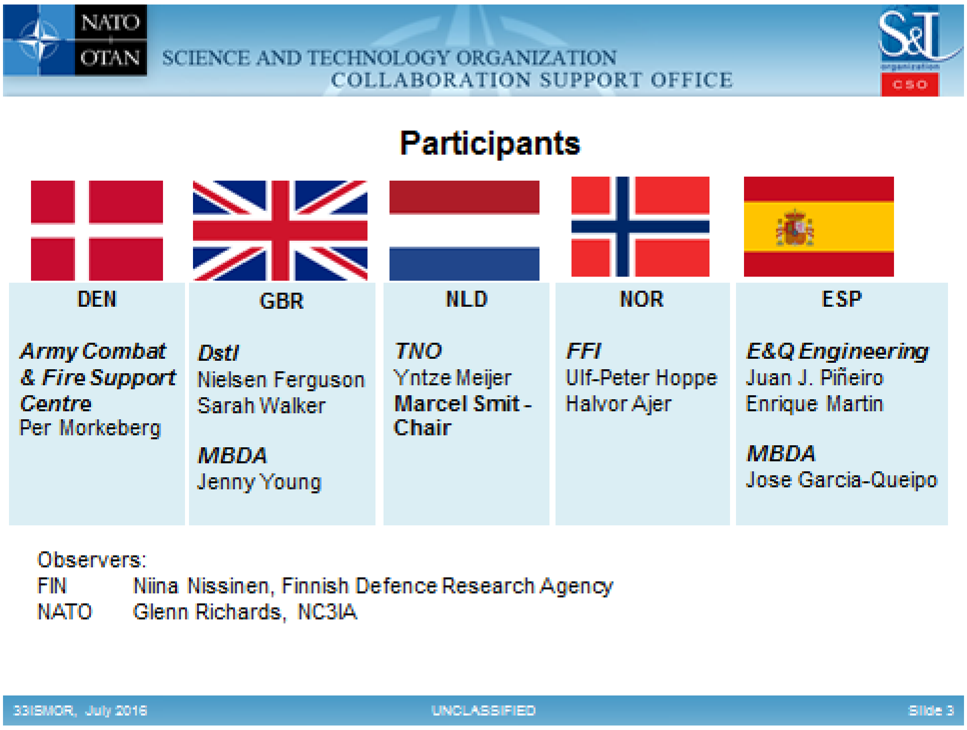
The objective has been to develop methods that can quantify the operational risks and at the same time optimize both the costs and the effects of Joint Fires. The focus has therefore been on effectiveness, cost and operational risk.

The study deliverable is in the form of a final report which is currently being reviewed and is expected to be available later in 2016.

This paper covers who was involved, the scope of work undertaken and then focuses on some of the conclusions that have emerged from 3 of the key activities:

- Reviewing existing models,
- Development of an analysis framework,
- and then testing of that framework through a number of case studies.

The paper concludes with a summary, the recommendations from the study, and the next steps that will be taken.



The activity has been in progress for just over 2 years, with the active participation of the 5 nations shown above. The activity has been led by TNO in the Netherlands with Marcel Smit as Chair.

Support has been provided from other NATO organisations:

- The NATO Army Armament Group (NAAG) subgroup 2, Integrated Capability Group Indirect Fire (NAAG/ICGIF/SG2) is represented in SAS-108. This subgroup has a program to develop software products focusing on effectiveness of weapon systems. All the products comprise the SG/2 sharable software suite, known as S4.
- Glen Richards from NC3IA has been an observer.

Canada also attended a couple of meetings and will be reviewing the final report.

Scope

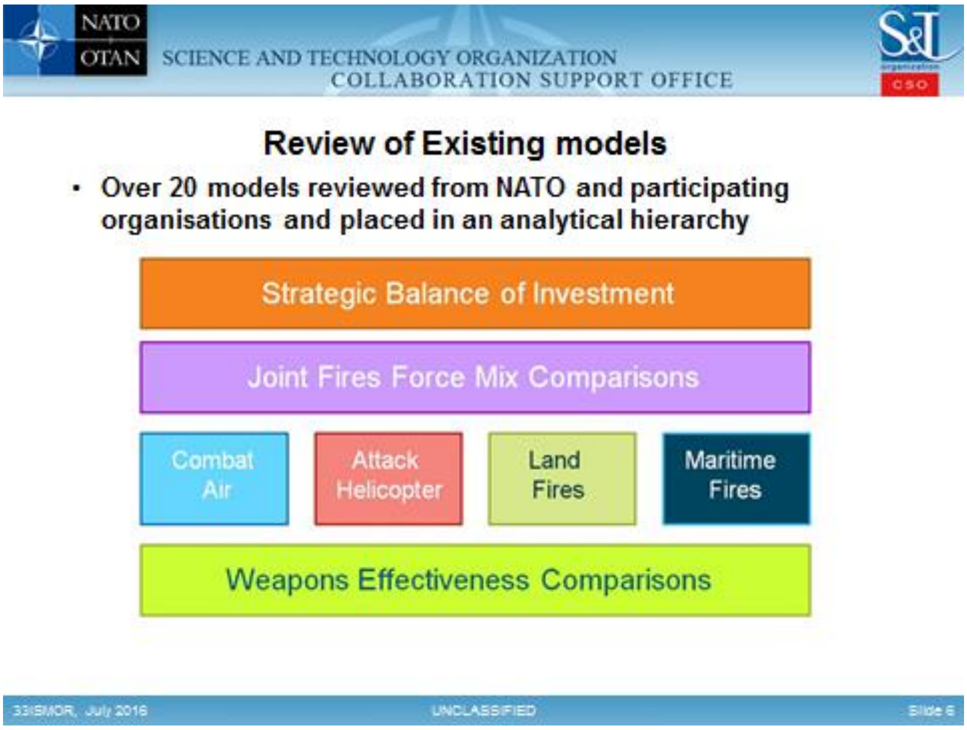
The programme of work started with establishing the scope of the study, including a number of definitions and boundaries. The next task was to investigate the existing methods and models that were in use for joint fires type applications. The group then began the development of an analytical framework, tested it with a number of case studies, and then began the final report. The work was progressed through 7 meetings with telephone conferences in between.

The participants of the group all had a range of different interests in joint fires, so we have been interested in a number of different types of decisions that might need to be made. These decisions related to procurement of joint fires equipment, pre-deployment planning and in theatre operations. However what everyone wanted to be able to do was to select the 'best' platform/weapon combinations for a given operational task or set of tasks.

When we say ‘best’ we want to take into account effectiveness, cost and risk – which adds a 3rd dimension to the cost-effectiveness trade-off that may be familiar. What constitutes ‘best’ will depend on the context of the decision being made, so work did not attempt to define that in any detail and formal optimisation methods were beyond the scope of the study –focus was on a framework that enables the 3 way trade covering cost, effectiveness and risk.

For risk, primary interest was in collateral damage risk, but other risks such as platform attrition and mission failure were also considered. Focus was on land targets only, with fire support from land, air and maritime platforms, and on lethal effects, but with an intention that the framework should also be valid for non-lethal effects.

Review of Existing Models



As one of the first activities, the group reviewed over 20 models that are in use with NATO and the participating organisations, and tested their applicability to the SAS-108 problem space.

The analytical hierarchy shown above was used as a way of categorising the scope of each model.

At the lowest level of the hierarchy sits the need to do weapon effectiveness comparisons. Here the focus is on the weapon and the effect it has on the target, and results from this level are used for weapon trade-offs or to inform higher level studies.

At the next level, systems of similar types can be compared, typically within a single service environment.

At the joint fires force mix level, systems of different types can be compared to identify a preferred force mix – This is the level of interest to SAS-108.

Then at the strategic balance of investment level, joint fires systems can be compared with other capabilities.

Several models fell into the Joint Fires Force Mix category:

- Alligator developed by Dstl,
- ADAM developed by MBDA,
- ITEM developed by BAE SYSTEMS CORDA

There are also 2 models in development : NLD Framework, and ARES-O developed by E&Q Engineering in Spain

Each of these models has its own strengths and weaknesses, which has been driven by the original application of the model and the study environment in which it has been used. However, overall, the study was unable to identify a single, existing, model that fully met the scope of the SAS-108 problem space.

The majority of the models considered were focussed on effectiveness calculations, with rather more limited consideration of operational risks and cost, and in general, older models lacked the flexibility to trade cost, risk and effectiveness. A number of models were restricted to weapon effectiveness, and not able to compare different types of joint fires capabilities.

The more modern tools tend to favour employing a suite of models that are integrated within an overarching analytical process. This provides a more flexible approach, and allows the process to be tailored to answer specific questions. The use of re-usable, specialist software modules such as the S4/NIFAK suite can be a valuable resource in this regard, forming a building block within a suite or federation of models.

Framework

The framework has 5 main steps:

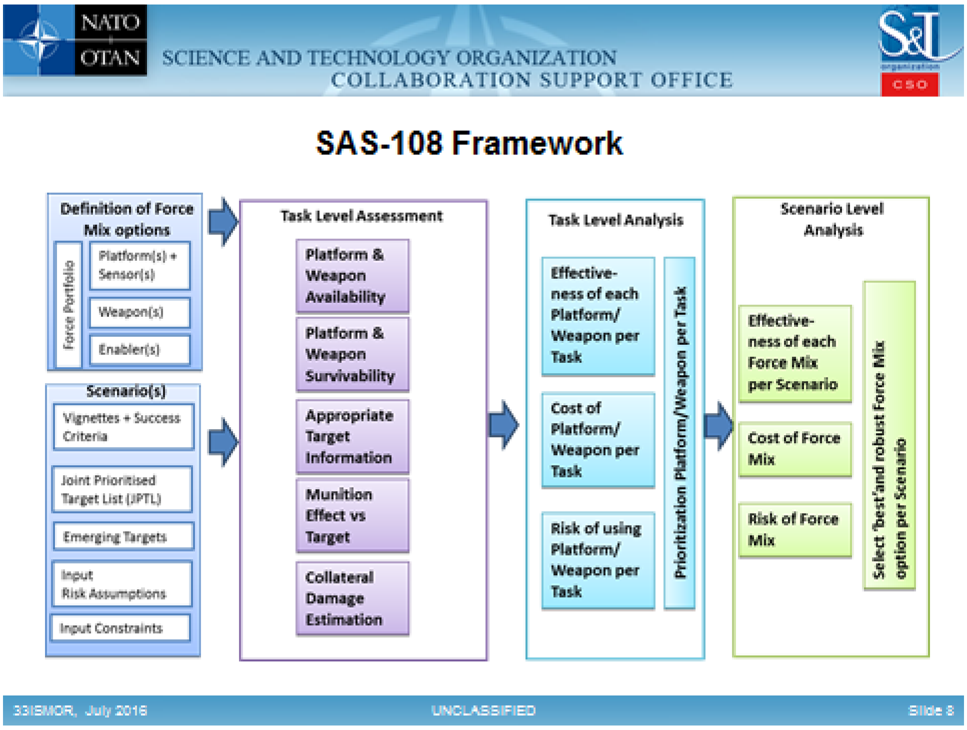
- Definition of the Force Mix options which are to be considered within the analysis.
- Definition of the Scenario(s) in which the Force Mix options are to be assessed.
- An assessment of how well each element, of each Force Mix option, is able to conduct each task in the scenario(s).
- An analysis of the data generated at task level. This may be an end in itself, or it may be a pre-cursor to scenario level analysis.
- Scenario level analysis, where the 'best' overall Force Mix options can be identified.

Within each of these 5 steps, the key processes have been identified and are shown as blocks in the diagram. Each of these processes has been defined in the report in terms of its possible inputs, possible outputs, exclusions and possible sub-components.

There are two distinct levels of analysis:

Task level: evaluation of individual tactical tasks in a military operation. The objective at this level of analysis is usually to generate a prioritised list of options for completing each task. The purpose and constraints of the task are specified in a vignette, and the task must be completed by one or more elements of the force mix under consideration. Evaluation is required of the effectiveness, risk (and possibly cost) of each option available to complete the task.

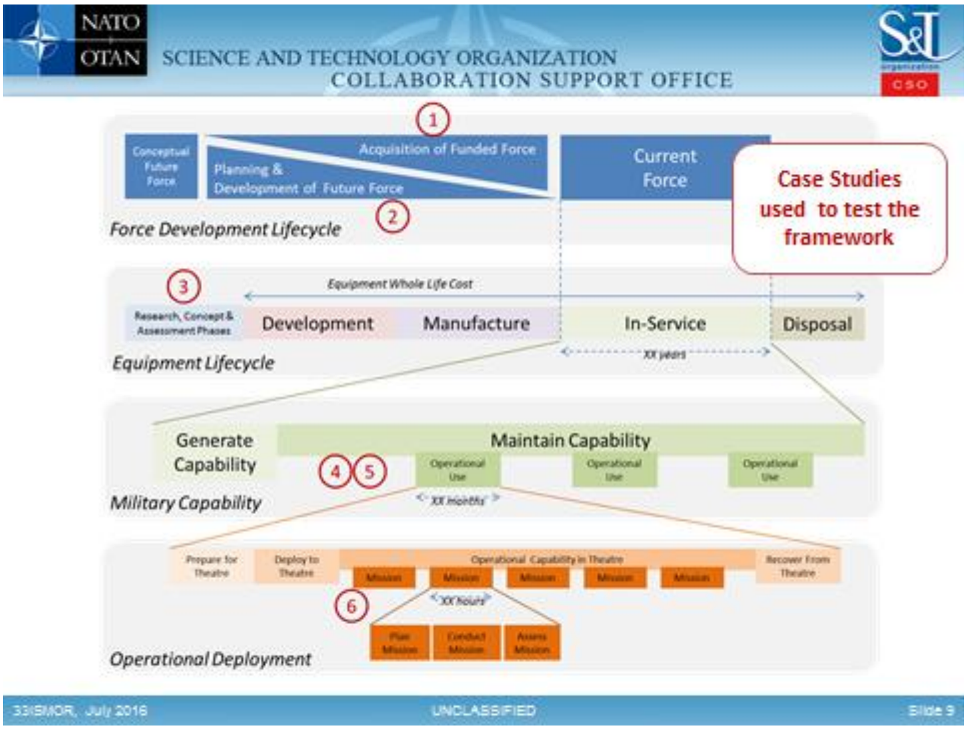
Scenario Level: Within SAS-108 we have defined a scenario to be multiple tasks or vignettes within a common timeframe, political situation and geographical area In scenario level analysis, the results from individual tasks are combined to identify the 'best' overall force mix option for that scenario. Depending on the analytical problem under study, it may be desirable to investigate multiple scenarios.



There is no single complete method that applies to all situations, but rather a suite of processes that can be used to define and build a methodology for specific situations. So, it is expected that users of the framework will need to tailor the approach to suit their specific study needs. In general the 5 steps must be conducted in sequence, from left to right as shown in the figure, but some variation in the order that processes are undertaken within each step can be expected. There is also likely to be iteration of steps or processes during a study as information and understanding matures.

The exact implementation of the method will therefore depend on the analytical problem under study and the design of the model(s) being used. As a consequence, the framework has been captured in a relatively abstract way to allow it to be applicable to a wide range of problem classes and models. It is not always essential to conduct all processes, and some can be omitted (or are not applicable) to some classes of problem.

Case Studies



In order to test the framework, the group have worked up a number of case studies, which will be available in an annex of the report. It should be noted that these examples are provided purely to illustrate and explore how the framework method could be applied to different types of problem. The examples should NOT be taken as representing existing NATO processes and activities.

Any military force must be developed over time and this is shown at the top of the figure above with a vision of a conceptual future force being created, and then planning and development of that force starting. As time progresses the focus switches to acquisition of the elements of the future force that have been funded. Two of the examples relate to the force development lifecycle:

- Example 1 – Artillery Acquisition. This example considers the acquisition of munitions for two already implemented land based Artillery systems, with the specific questions :

  "Which artillery system is the best solution considering effect, cost and risk in the given scenarios?"

  "What should the prioritization in the procurement of the munition portfolio be?"

- Example 2 – Force Planning. This example considers the quantity of platforms that will be required in a future force mix, with the specific question:

  "How many Joint Strike Fighters (JSF) should I buy as part of my UK Joint Fires force-mix?"

All major items of equipment that are acquired to form the 'current force' have their own lifecycle, starting with research and conceptual studies, and progressing through development and manufacture, to be accepted in-service and then disposed of at the end of life. One example relates to the equipment lifecycle:

• Example 3 – Weapon Design. This example takes an industrial perspective and illustrates how the SAS-108 methodology can be used to support weapon system design, with the specific questions:

"What improvement in capability does an upgraded air-surface weapon offer over the original ?"

"Is there any value in integrating the upgraded weapon onto a UAS platform?"

"What level of capability would a ground-launched variant provide, and how will it 'fit in' with a typical force mix ?"

The in–service phase for equipment might last 10, 20, 30 years, during which time the relevant capability must be generated, maintained and deployed for operational use as required. Three examples relate to the decision of which equipment to deploy to theatre:

•Examples 4 & 5 – National Pre-deployment Phase. These examples takes the perspective of a nation wishing to support a UN or NATO operation, with the specific question:

"Which mix of Fire Support systems should be sent to support a peace support mission in North Africa?"

Different approaches are taken, with Example 4 being a judgement based approach, and Example 5 using a mathematical model.

Each period of operational use might last a number of months, during which time the capability will need to be prepared for theatre, deployed to theatre, remain operational, and then be recovered from theatre. While operational in theatre, the joint fires capability will be assigned a number of missions, each of which will need to be planned, conducted and assessed. The final example relates to in-theatre planning:

• Example 6 – In Theatre Planning. This example illustrates the SAS-108 framework from the perspective of an in-theatre commander and studies:

"What is the 'force mix option' that is close to most effective for the purpose of the commander's intent, while having acceptable costs and involving acceptable risks?"

The full description of each case study can be found in the report.

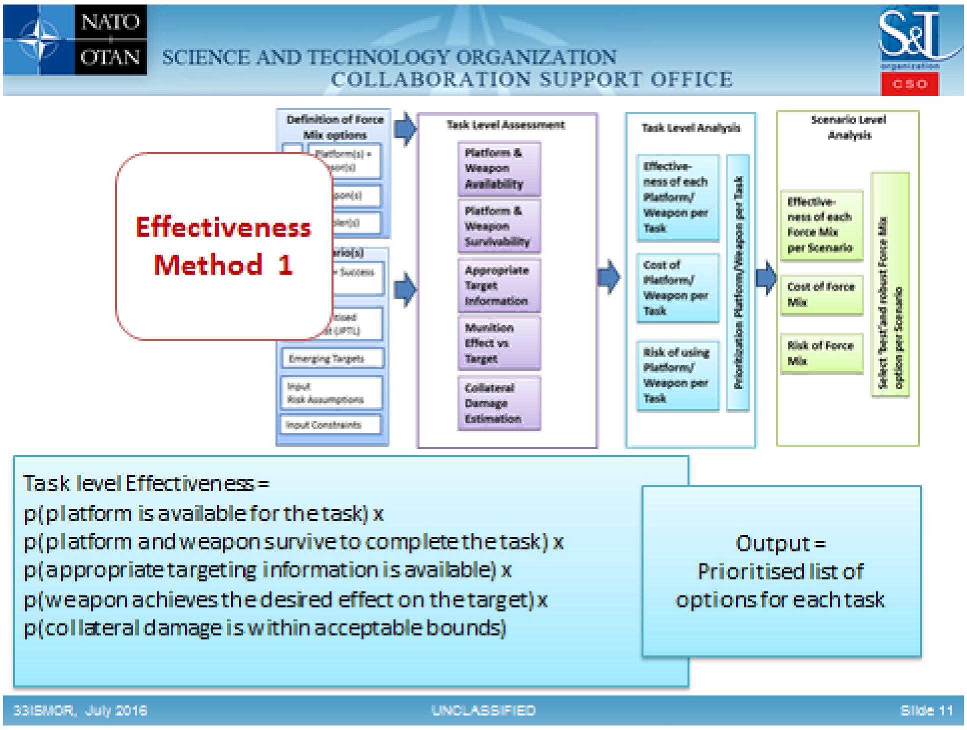
Conclusions

The main conclusions emerged from conducting the case studies.

Firstly, everyone in the group found the framework useful way to approach their case study. It provided a common language that was useful for discussions, and gave a structure to the problem.

Secondly, the framework can successfully be used with different types of analytical method. Each step of analysis or assessment could be undertaken using mathematical models, applying rules of thumb, interpreting previous study results, or simply from expert judgement. In fact a combination of methods could be used, and combined within the framework.

Effectiveness, cost and risk can be handled in several different ways within the framework, each will now be discussed in turn, starting with effectiveness.



Two main methods emerged for representing effectiveness.

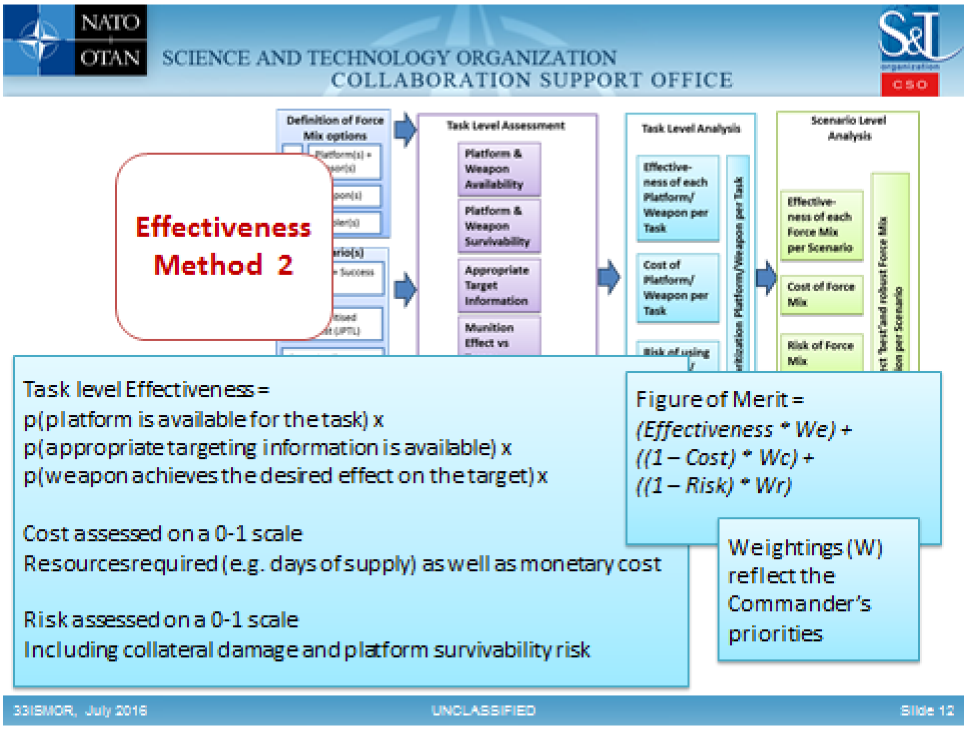
The first was to treat each aspect of task level assessment that is relevant to the problem (the purple boxes) as a probability, and combine them to give an overall measure of success at task level.

So to be effective the solution must be sufficiently available and survivable, with appropriate targeting information, achieving a desirable effect on the target and while producing an acceptable level of collateral damage.

A variation of this method would be to set pass/fail thresholds for each step of the assessment.

The output can then be expressed as list of options for each task, prioritised in terms of effectiveness. This can then be taken forward to scenario level analysis.

In this method we are including some aspects of risk (e.g. Collateral Damage risk, attrition risk) within the effectiveness calculation. This means depending on the method used, there is the potential for some double accounting of risk at Scenario level. This is an aspect that the team felt needs further investigation.



An alternative approach is to separate out the risks that are of particular interest, and estimate the effectiveness assuming that the risks have not occurred (or will not occur).

So here, the effectiveness is based on only 3 probabilities, the availability of the platform and appropriate targeting information, and the probability of achieving the desired effect.

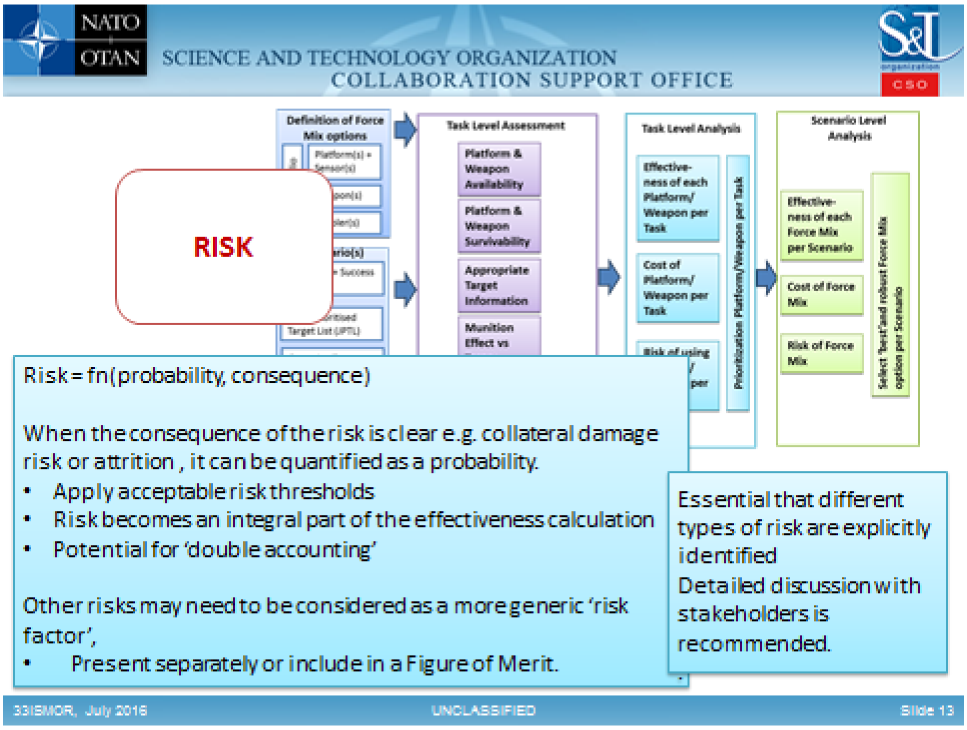
Cost and Risk are then assessed separately and normalised on a 0 to 1 scale, and Effectiveness, Cost and Risk can be combined to provide an overall figure of merit using a multi-criteria analysis type approach. Here weightings can be used to reflect the commander's priorities – for example he may be willing to accept a higher degree of risk in some situations.

This Figure of Merit might also be called a Commander's Utility Function: Linear or non-linear aggregation models can be used to define the utility function. In the example shown here, a simple linear aggregation, using an additive weighting technique is used to define the utility function.

Alternatively, different normalization criteria and techniques could be used for the weights and also for the utility function.

The main shortcomings of the function shown here are:

- There is only a judgemental method to assign weights, and a degree of subjectivity is introduced when weights are assigned to elements of different nature (effectiveness, risks and cost)
- Also, the correlation between elements is not considered.



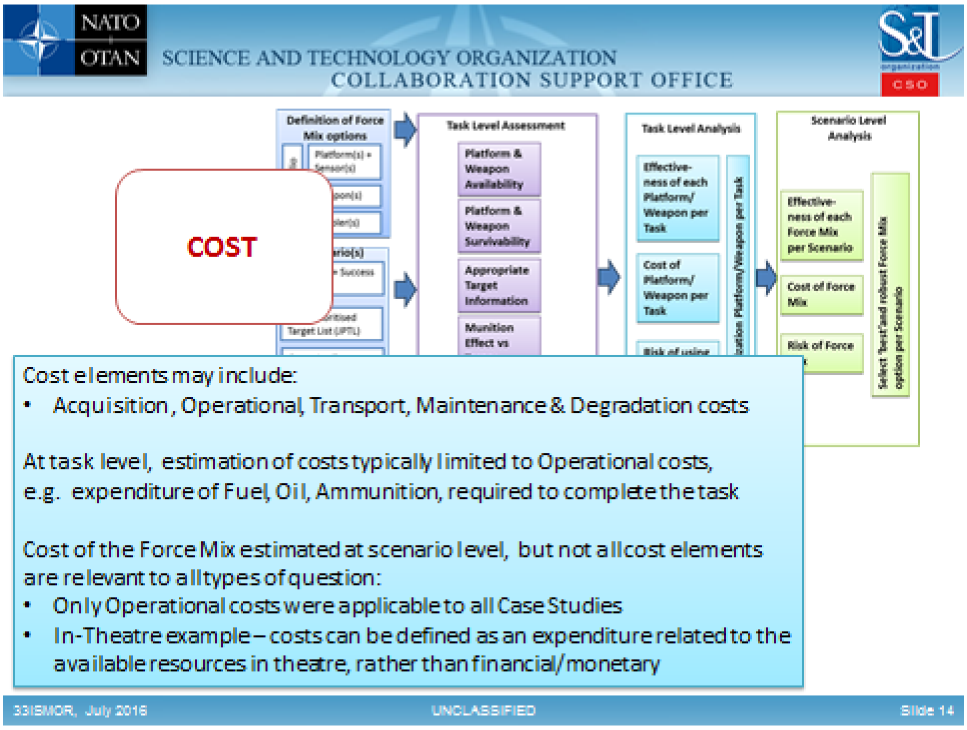
The group has used a standard project management type definition of risk, where risk is a function of both the probability of occurrence, and the consequence.

In some situations, if the consequence of the risk is clear, we may be able to quantify the probability of it occurring with mathematical models. We may also be able to set thresholds that define an acceptable level of risk, and use these in the models.

This could apply to collateral damage risk, or attrition, as we saw in Effectiveness Method 1.

In other situations, quantification of a risk may not be possible or practical, so judgemental approaches are needed, which will lead to a more generic risk factor, and these can be presented separately or included in an overall figure of merit.

Either way, it is essential that the different types of risk are explicitly identified, and the group recommends detailed discussion with stakeholders to do this.



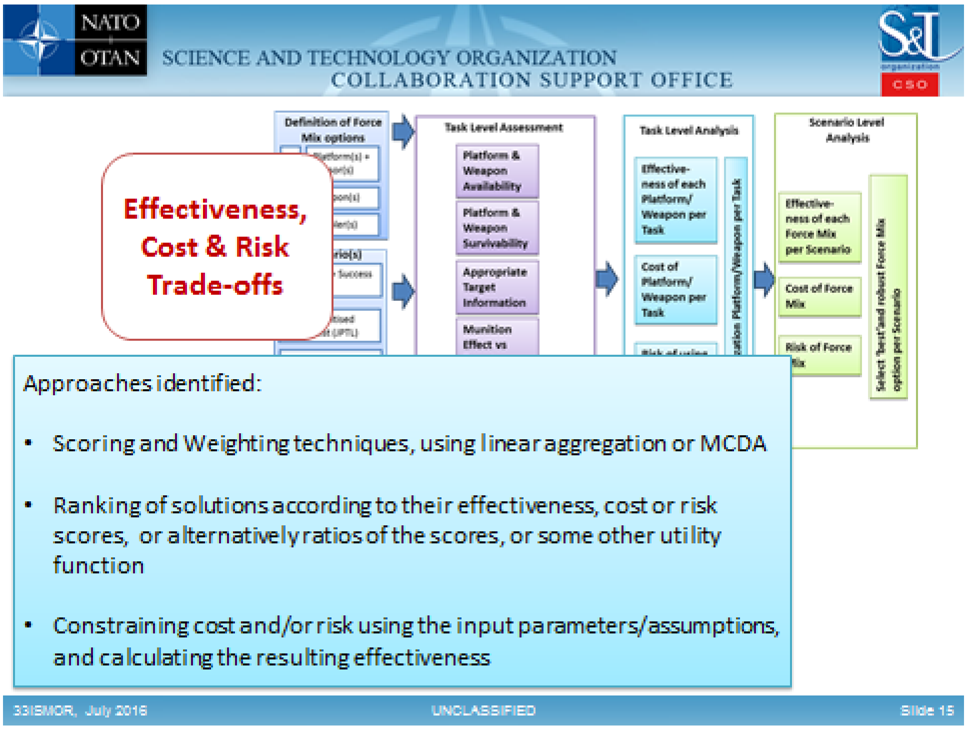
Cost elements may include Acquisition, Operational, Transport, Maintenance & Degradation costs.

Within the framework (like effectiveness and risk), cost can be estimated at both task and scenario levels.

At task level, the estimation of costs is typically limited to Operational costs, and comprises the expenditure of Fuel, Oil, Ammunition, that is required to complete the task.

The cost of the whole Force Mix is estimated at scenario level, and is likely to require other elements. However, not all cost elements are relevant to all types of question and only the Operational costs were applicable to all Case Studies investigated.

The In-Theatre example, presented an interesting case, and it may be more appropriate to define cost as an expenditure related to the available resources in theatre, rather than the conventional financial/monetary approach.



Some joint fires problems will require consideration of 3-way trade-offs between effectiveness, cost and risk. SAS-108 has identified 3 main approaches to such trade-offs:

The first is to use a scoring and weighting type technique, often known as linear aggregation or Multi-Criteria Decision Analysis.

The second is to provide a ranking of the solutions according to some criteria. This could be in order of their effectiveness, cost or risk score, ratios of their score, or some other utility function which is relevant to the problem.

The final approach is to constrain the options based on cost and/or risk, and calculate the resulting effectiveness.

Summary, Recommendations and Next Steps

SAS-108 has been investigating methods to support decision making for joint fires. By this we mean being able to select the best platform weapon combination for individual tasks and the best force mixes for multiple tasks, taking into account effectiveness, cost and operational risk.

There is a wide variation in the scope and complexity of joint fires analysis questions – each question is likely to require an individual approach, so a framework that is suitable for all applications was needed. Such a framework has been developed and tested, and it provides a way to describe the problem space, giving a common 'language' to discuss and structure issues. The framework is very flexible, and can be used with a wide variety of methods and models, as well as being suited to a wide range of study questions.

Nations, Joint Force Commands and Land, Air and Maritime Component Commands may wish to consider how the framework can be used to support decision making for joint fires.

There are no common definitions and metrics for operational risk within NATO. It is therefore recommended that NATO should consider developing common definitions and metrics for operational risks. Such definitions could improve communication and understanding between allies.

Methods for addressing risk need further exploration and testing, particularly using quantitative examples, and investigating how risk can be incorporated into joint fires simulation models.

Development of the framework has focussed on lethal effects. Further work is recommended to test if the framework can be applied to non-lethal effects, or if it needs modification.

The idea of a single analytical tool was originally proposed in the study scope, however this is no longer recommended. Different questions require different approaches and analytical tools, so a single analytical tool is not appropriate. However the framework could be of value in assessing the scope of existing models, and could be used as a guideline for the development of new models.

The SAS-108 report is currently undergoing its final review, and it is hoped that it can be presented at the SAS Panel meeting in October 2016. Meanwhile a number of national briefings have been planned, and papers will be presented at MORS-84 and hopefully also at the 10th NATO OA Conference.

The report will be available on the NATO Science and Technology Organisation website in due course.