Abstract
Multiobjective resource allocation of shared resources by group decision-making can combine analytic and qualitative modeling. Recently it has been pointed out that the goal programming model is superior to other models though it remained to be answered how to take into account hierarchy of decision makers (and objectives) [1]. In this article we present the fact that the quantitative model can be easily adapted to the qualitative STT/QFD model of objectives of top-level group of decision-makers. The subsequent phases of the qualitative and the analytic solution of a multiobjective cooperative resource allocation problem can be applied within the group decision-making framework of defence requirements capability-based planning.

Key words “Capability-based planning”; “Multiobjective group decision making”; “Resource allocation”; “Project selection”

Baseline Force Strength and Weakness
Estimating the “strength” or capability of a force is a prerequisite for comparing with potential foes, to determine “how much is enough” to spend for defence. What is a Capability? Military Capability has no worldwide accepted standard definition, though it likely is a multi-attribute function based on 3 fundamental components: conceptual, moral, physical.

In practice military capability is assessed by means of scoring, score-aggregation, and disaggregating. Resources are grouped into categories with scores (values or weights) assigned and force strength is calculated by multiplying the number of resources in a category by the weight of the respective category and by summing the products in the end. There are a variety of methods, for instance the “Lancaster-equations”, the WEI/WUV (1979) [2], the Quantified Judgement Model of Dupuy (1987) [3], the Correlations of Forces [4], the SAS (Situation Adjusted Scores) of Allen (1992) [5], Tascform (1993) [6]. How strength of force as a Military Capability ought to be assessed?

Equation:
\[
C = \sqrt{\sum_{r=1}^{R} s_r}
\]

where \( s_r \) is for strength of a service and \( r=1,\ldots, R \) and \( C \) is the military capability according to DYNPOT scoring method.

The underlying reason is that according to the comparative analysis of Anderson and Miercroft (1995) [7] the practical DYNPOT (Dynamic
Potential scoring method is superior over other scorings, measuring both our own military strength (lethality) and the weakness (vulnerability) of the opponent, calculated as the square root of the sum of the scores of all of the resources in the force.

However, with a number of problems (dependency from situation etc.) to be overcome, little theory lies behind scoring; the weights come from subjective judgement and even acknowledged authors have not provided a more systematic treatment of this problem [8].

**Objective-based capability planning**

MoDs in some new NATO-member states are about to develop a long-range defence planning (TVTR) process with an aim to improve defence procurement process. Defence procurement is influenced by a number of factors, and mainly the gap between our Baseline Force Strength and Goal Force Strength should be determined based on threats. However, in the present absence of regional threats, security goals can reflect mainly military capabilities demanded overseas by the NATO.

In the procurement context, capability should be specified in functional terms but without either technical or supplier-specific details. So specification at capability-level means functional-level specification without details. By means of stepwise refinement of functional requirements flowing from a top-level goal-hierarchy down to the functions (here: JET=Joint Essential Tasks), but without technical specification should be determined.

Military doctrine is a part of the conceptual component of Military Capability. In the framework of military doctrine the set of JETs is configured in a hierarchy of subsets which in turn have their inner hierarchical layers (groupings, subgroupings of tasks) as well:

– Grand Strategy Level Tasks (Defence Missions, Military Tasks) providing policy direction;
– Military Strategic Level Tasks, providing military strategic objectives;
– Operational Level Tasks, providing options for achievement of the strategic objectives;
– Tactical Level Tasks, providing options for achievement of the operational objectives;
– Capability Task Lists of Commands flow directly broadly from the Tactical Level Tasks.

STT is a technique for developing lower-level requirements from higher-level policy or goals by providing a bridge between each level, linking relevant elements within the level to those above and below.
STT (Strategy-to-Task)

STT was developed in the US [9] as a technique, which allows a traceable cascade from political grand-strategy level goals to lower level means (capabilities or requirements) contributing to accountability. It makes use of the textual model of doctrinal hierarchy as its main input, with an output of a prioritised list of low-level military tasks in ranked order. Highest level prioritisation can be set up by means of either some MCDA (Multiple Criteria Decision Analysis) techniques, or subjective expert judgement, or political bargain.

STT can produce and refine capability requirements prioritised and allows transparency with rapid assessment of options at a broad level by all stakeholders. However, at higher political level it is difficult to make the hierarchy of objectives into an explicit reality and normally not practiced since decision makers try to avoid establishing objectives or “requirements” that they cannot meet because of economic demands. Creating a clear explicit documented link from the political very top level down to the military task level ensures not only an audit trail of fiscal effectiveness, but rather military results accountability. The framing of military objectives depends on our security policy goals and the capabilities of our forces.

There can be a hierarchy of goal-levels, for instance:

– Permanent national goals/NSS (National Security Strategy) formulated at the executive branch, a sub-hierarchy within the frame of national security objectives (change in the geopolitical environment)/national economic, political, military objectives (how the NSS will be supported militarily), then another sub-hierarchy of objectives of national missions, peacekeeping military activities, and global, regional, functional operational objectives (defining various military strategies: how forces will be used), a sub-hierarchy of operational tasks (each task is defined by an operational concept composed of 5 key elements: surveillance, assessment, battle/dynamic control, mission preparation, and execution).

– STRM (Strategy-to-Task Resource Management) developed at RAND is used for linking resources to US NSS and identifying and prioritising of R+D or acquisition projects.

– STT is a straightforward concept that can be readily applied to a variety of scenarios, provided the enabler tool used for such application is sufficiently flexible and robust.
Flexibility

Enablers of STT could be various forms of MCA (Multicriteria Analysis). For instance AHP (Analytic Hierarchy Process) is a method converting subjective judgements into scorings to prioritise relative importance. Unfortunately, given M options and N criteria, the generation of N separate $M \times M$ matrices are required. This may prove unmanageable for large sets of tasks as used in practice. Relative importance is expressed by a 9-point intensity scale spread evenly over 1 to 9 which can be a shortcoming because in cases, where A is scored as 3 in relation to B, B is scored 4 in relation to C, the relationship between A and C is constrained to the scale and the intuitive value of 12 cannot be applied. With the QFD-based process (Quality Function Deployment as is referred later), the scores are viewed in independent, absolute terms.

MAVT (Multi-Attribute Value Theory) the sub-branch of DA (Decision Analysis) concerned with multiple objectives can make use of the subjective weighting-based EQUITY software for option prioritisation. Either EQUITY, or “Expert Choice” software of AHP, or SMART, SMARTER softwares could have utility in determining the top-level priorities. Other STT “drivers” applied for instance by the Space Force Command USAF, and in C4ISR R&D, are usually not accessible, except for QFD, a methodology had earlier already been in civilian use.

Compared to other business performance assessment methods like BSC (Balanced Scorecard) where it can be captured in a quantified systems dynamics model of business value-creation, QFD as a “driver” of STT (Strategy-to-Task) does not link performance measures to an ultimate financial objective, – QFD does it only to a “political” objective: satisfaction, gut feel.

Defence structure quality can be seen as its credibility and capability to deter threat. Threats are seen as “highly desirable” interests of the potential enemy directed at our assets. Without major direct military threat, forces are usually built in a proactive manner, with the goals of threat counter-balancing, or maximising defence value, military capability, and at a time strengthening national economy. The concept of maximum effectiveness seems to be substituted by the “high degree of satisfaction”.

QFD (Quality Function Deployment)

In order to maximise ultimate customer satisfaction, QFD was developed in Japan for functional design of industrial products. It proved to be an easy-to-use, and highly systematic qualitative soft-method and – being a defence plan a “social product” – it has been applied to defence planning as well. By means of QFD security needs can be integrated with
demands for counter-balancing the threats (here: capabilities of potential enemies) without serious conflicts of the interests of participants in the group decision-making. Although decisions depend on subjective judgement and weighting, the functionalities prioritizing is simple, it is easy-to-use as an audit trail for accountability and a contribution not only to defence, but corporate planning as well.

As a GDS (Group Decision Support), QFD systematically reveals what the group of ultimate customers “really require” in a prioritized manner. It captures requirements flow from general to specific and suits well to the STT approach. This is a top-down systematic transformation process producing an overarching cascade of matrices. As a broad method of applying STT, the model offers a very practical solution. Application of QFD to objective-based defence planning makes use mainly of the cascade of QFD matrices (quality houses) making sure that the needs of the ultimate customer are addressed by the product (here: the capability procured), without referring by us to the rest of the QFD methodology.

Each matrix (quality house) represents the relationships between two lists (subsequent levels of doctrine). These are structured in form of a matrix: rows represent demand, while columns identify the alternative ways to meet the demand. Demands are either explicitly enlisted or to be picked out from the body of the text of security/military doctrine. Each matrix represents relations between two subsequent levels within the set of hierarchically structured security-related tasks of doctrine.

By means of the matrix cascade explicitly prioritised requirements for capabilities with an associated audit trail are generated. Aligned to this the rationale behind each requirement can be easily identified. Any changes to requirements demand full recalculation of the cascade of matrices, though QFD software can easen that and to add or delete a layer in the cascade, vertical trails are established throughout the hierarchical structure of quality houses, because each $e_{ij}$ cell of an $E (M \times N)$ matrix represents an explicit link between “demand for security” (row $i$, where $i=1,\ldots, M$) and a potential “supply for security” (column $j$, where $j=1,\ldots, N$).

Results are very dependent on relationship configuration (and the method of identifying relationships) and on clear specification of original needs. Because of complexity and scenario-dependance of defence, one might tend to identify new vulnerabilities, dependeabilities and consequently specifying (filling) new cells of the matrix – additionally to the doctrine.
But that could make the method practically unmanageable. It is just the opposite, deletion of less important security-related tasks of doctrinal hierarchy what is likely required in practice.

One reason is, that the more a matrix tends to be heavily populated, the more the process becomes time-consuming when applied to large numbers of requirements and particularly if this is not part of a group process. As the matrix size increases, the corresponding subjectivity in assigning scorings in order to populate the matrix also increases. The result might be an over-complex model with limited usability.

For example, if the sizes of 4 matrices of a top-down cascade are (6x21), (21x21), (21x28), (28x10) and all relationships were to be considered, 126+441+588+280=1355 as a total of relationships ought to have been assessed. Provided this amount was unworkable in the limited time available, it could be tried to evaluate only approx. 10-25% of this total with the associated numbers of relationships identified in each matrices respectively, i.e. a total of 3-400 relationships might be evaluated in the model. But over-simplification affects credibility of the results and validation is made tenuous.

That is why an appropriate “well-balanced” relationship-scoring approach should be selected.

Other reason is, that the more a matrix tends to be heavily populated, the more insensitive the subsequent matrix cascade becomes. In order to avoid the “QFD quicksand” effect [10], when the STT model in the matrix cascade of QFD becomes insensitive if more than 20-40% (the “Vance limits”) of matrix elements are filled in, each matrix fill ratio ought to be limited. Otherwise the objective evaluation of the results can be made difficult. During an earlier analysis of the BMD (British Military Doctrine), the fill-in ratios of the matrix cascade were respectively as follows:

- 1st level QFD matrix (8x28) [11]: less than 23%;
- 2nd level QFD matrix (28x21) [12]: 32.6%;
- 3rd level QFD matrix (21x31): 36.7%;
- 4th level QFD matrix (31x26): less than 39%.

These fill-in levels were reached by “unfilling” (ignoring less important links) an existing series of cascaded QFD-houses. It is an open question, whether after such “Procrustes-bedding” of this model of the BMD, it has still remained the model of the BMD, – or of some other doctrine.

But at least it might be assumed that insensitivity of the QFD cascade is mainly not due to over fill-in, since fill-in ratios were pushed below the upper “Vance-limit” (40%).
Relative priority – GDS (Group decision support)

Although explicit links can be specified, the importance, or relative strengths are not indicated originally but the pure existence of the links. These perceived scores to each link at every level should be made explicit by means of group decisions.

Each $e_{ij}$ cell in the $E$ matrix represents a subjective judgement as to how strongly (if at all) the row relates to the column. Usual scores in QFD for an $e_{ij}$ can be either 0, or 1, or 3, or 9. Each options of supply of security is assessed against each relevant demand for security to provide a measure of the relative importance of the respective alternative.

Weightings are user-definable only at the top-level, with every weighting decision is made by a group of experts and based on agreed rules of thumb. The weight then influences the priority of the assigned linkages in the cascade. Weighting can be based on for instance $T_i$ the relative level of threat.

Amendments to scorings (or weightings) are easy to implement within specifically tailored team session worksheets.

From the weightings and scorings a relative priority calculated to be assigned to each option. The importance of each of the alternatives is indicated by a simple summation of respective scorings and corresponding weightings.

Equation:

$$D_i = \sum_{i=1}^{M} T_i \sum_{j=1}^{N} e_{ij}$$

where $T_i$ is the relative level of threat and $D_i$ is the relative level of defence against that sort of threat.

Conversion to a percentage in relation to other alternatives can yield a normalised priority index.

Priorities of the links form the subsequent weights for the next level of the matrix cascade.

Cross-Contribution “Roof” of the quality house

The ‘roof of the house’ permits comparison of the potential alternatives and is represented by a symmetric $F (N \times N)$ matrix. Any of them that are either incompatible or add to risk and those of mutually beneficial can be spotted.

Because of synergy in joint operations and interrelatedness of nearly every force elements can be mutually supportive. Although they are
dedicated to engage a specific threat, they may have the capability to counter other ones as well, playing multiple roles. Vulnerability of each force element to attack is relative to specific threats.

By calculating correlations (“roof of the quality house” – a triangle-matrix) at each level of the QFD cascade, it is expressed how some weakness of each element affects to some degree the capabilities and effectiveness of the rest of our defence.

Equation:

$$ G_j = \sum_i e_{ij} + \sum_j f_{ij} $$

(3)

where $G_j$ is for the extent of impact of one force element $e_{ij}$ on affecting the capability of the other $f_{ij}$.

Negative as well as positive numbers for scores can be used in the $E$ and $F$ matrices. Negative value means that our capability is enhancing threat effectiveness, so it is in fact a vulnerability of ours, while positive value means a capability to neutralize threat.

Equation:

$$ B = \sqrt{\left( \sum_j G_j + \sum_j e_{ij} \right)} $$

(4)

where $B$ stands for benefit, equal to overall capability of the force.

The actual degree of correlation [13] between force elements can be determined for instance by QFD software, which might be seen as of a new application of MCDA [14] with its coherent weighting of all elements of defence capability, expressing correlation between components.

**Output**

When decomposition is stopped, in the last house of quality a set of statements (associated with relative importance) had been derived from the doctrine manual as a set of broad requirements (characteristics), which the defence capability would be required to undertake. Promising complete solutions can be grouped together and competitor candidate weapon systems (or combinations of them) can be evaluated then against these requirements in terms of overall effectiveness. The score of raw importance reflects the indication of effectiveness of the $R+D$ defence project options.

The technique helps in identifying the extent to which functional requirements are met and if a combination of systems would be necessary
to meet these requirements. However, validity of the output is subject for debate. Subjective validation should be used to examine the credibility of the results.

A high level of military readiness and a range of military capabilities sustained, cost. Cost data of the R+D projects are also needed in order to conduct CEA (cost-effectiveness analysis). Facilitating the CEA analysis in a 2-dimensional diagram clusters of close cost/effect relationships can be identified.

A financial optimisation model (Goal Programming or Proportional Goal Attainment) can find optimum sets of projects within a number of budget restrictions. Proportional Goal Attainment can be applied in need of a more rapid decision paraphrasing the linear programming model as follows [15]. The notations are:

\[ m=1,\ldots, M \]

identifies each individual group member with his respective set of objective functions \( k \in K_m \), considering an \( i \in I_m \) set of projects, where \( 0 \leq x_i \leq 1 \) is the progress already reached by project \( i \).

Max \( zz \)
The Tshebyceff distance \( z_m \) to the ideal point of member:

\[ m \quad zz \quad z_m \quad \forall m \]

The objective levels achieved at the ideal point \( y^*_{mk} \) of member

\[ mz \quad \frac{y_k}{y^*_{mk}} \quad \forall m, \forall k. \]

Objective values are assumed to be linear combinations of all projects

\[ y_k = \sum_{i \in I} c_{ik} \cdot x_i \quad \forall m, \forall k \]

where \( c_{ij} \) is the contribution of each project \( i \) to reach objective \( k \).

Constraints of projects are local and global ones:

Local constraints:

\[ \sum_{i \in I_m} a_{ij} \cdot x_i \leq b_j \quad \forall m, \forall j \]

where \( a_{ij} \leq b_j \) is the required amount of category \( j \) local resource for project \( i \).

Global constraints:

\[ \sum d_{ip} \cdot x_i \leq R_p \quad \forall p \]

where \( d_{ip} \leq R_p \) is the required amount of category \( p \) global resource for project \( i \).
A series of trials of simulation is to be performed. Robustness of the balance of the budget forecasted should be taken into consideration. However, robustness of each single capability is assigned to a magnitude of cost as well.

**Robustness**

A robust force or capability performs well under a wide variety of scenarios. There is uncertainty at present about the nature of a future threat and key dimensions of a stable decomposition are blurred. The poorer the ability to predict future contingencies, the greater the desirability of robust capabilities. Forces possess a degree of robustness among alternative postures, but it is an aside, that unless analysts come up with a measure of it, robustness – like beauty – will remain in the eye of the beholder. In addition to the vast expense of multi-scenario development distributed interactive “growing uncertainties in strategy and tactics mean, that scenario-development has become more difficult than ever” [16].

**Capability assessment**

Provided it will be maintained a `portfolio` of capabilities, in situation independent quantification of military capabilities, rather than formulas applied, – and trying to use missing, or misleading, biased data, – a neural network can be trained extending effectiveness-scoring for future weapons as well. For instance an MPNN (Multilayer Perceptron Neural Network) can be trained [17] by WEI (Weapon Effectiveness Indices) [18] to determine the scores. So the objective of our force development could be stated in quantitative terms, comparable to our Base Force Strength in order to identify security gaps in kind.

In balancing a conventional force mix, for example the RSAS (RAND Strategy Assessment System) can be used to account for vulnerabilities in the force mix [19] based on situation dependent Strength Points. Force mix ratio can be calculated according to the minimum counter-capability to threat and to our goals.

**Conclusions**

It has been demonstrated that STT does not necessarily require expensive efforts in scenario-writing and in simulations, nevertheless it can reflect the threat assessment and military operational perspective. The method might be based on regularly published data on forces (potential threats), which provide one quantified basis for planning. As another input, the objective of our force is also to be stated in quantified terms: the requirement of balancing our force to counter specific threats. That is why our every force element is to be examined to counter specific threats. Force elements can be mutually supportive, which must be taken into
consideration when mixing the elements of the whole force to meet the required balance. Then our goal force strength is to be established for every force element and in order to account for sustainability, logistic and manpower requirements are to be met.

QFD provides easily assimilated cognitive-based “summaries” of situation instead of a quantitative analysis of the effective threat-levels concerning details of generic campaign scenarios, operations, exploratory multi-scenario analysis of capabilities and marginal analysis in the “scenario-space”. Instead of validation of the underlying model, the aim is to evaluate, how durable is the plan against changes in the input. Changes in the weighting, scoring, and changes in both (weighting and scoring) systems should be considered. Sensitivity analysis has been found that the final output (priority order of relative priorities of the procurement options) remained quite stable.

References


[12] Ibidem, p.27


[14] Ibidem, p.56


