A Tree-view of Strategy

1. APPLICABLE RESEARCH QUESTION

In this chapter we address the research question:

> How can the extent of the many-to-many relationships that exist between a military strategy, its ends, ways and means be quantified?

In order to answer this question we shall follow the scheme detailed directly below:

First, we shall develop a ranked tree to model a military strategy's ends, way and means by vertices at six defined levels of abstraction as follows:

Level 0: The root of the tree representing a military strategy.

Level 1: The military strategy's ends.

Level 2: Military Missions. The higher order military strategic ways.

Level 3: Military Tasks. The lower order military strategic ways.

Level 4: Operating Systems. The higher order military strategic means.

Level 5: Force Design Elements: The lower order military strategic means.

Second, we shall develop measures for

- the degree to which entities represented by the vertices in the tree enable entities represented at their predecessor vertices;

- the degree to which entities represented by the vertices in the tree enable the entities represented at the root or military strategy; and

- the degree to which sets of vertices at a particular level of abstraction enable the entities represented at the root or military strategy.

Third, we shall show that it is possible to quantify these relationships by the use of analytical models, heuristics and the utilisation of military judgement.

Fourth, we shall show how a ranked tree, can represent a military strategy by deriving a military strategy for South Africa from the South African Department of Defence's Strategic Plan and cast it into such a tree structure.

Finally, we shall demonstrate how this model or framework could be used to augment decision-making by supplying quantified measures.

2.   A SUITABLE STRUCTURE FOR THE RELATIONSHIPS BETWEEN A MILITARY STRATEGY'S ENDS, WAYS AND MEANS

In Chapter 1, the many-to-many relationships of a military strategy's ends, ways and means are depicted in a relationship diagram in Figure 1.3. Figure 2.1 below is a simplified version of Figure 1.3. The many-to-many relationships of a military strategy's ends, ways and means may be represented by a tree structure. We illustrate this by showing that the relationship diagram in Figure 2.1 can be re-written in the tree structure depicted in Figure 2.2.
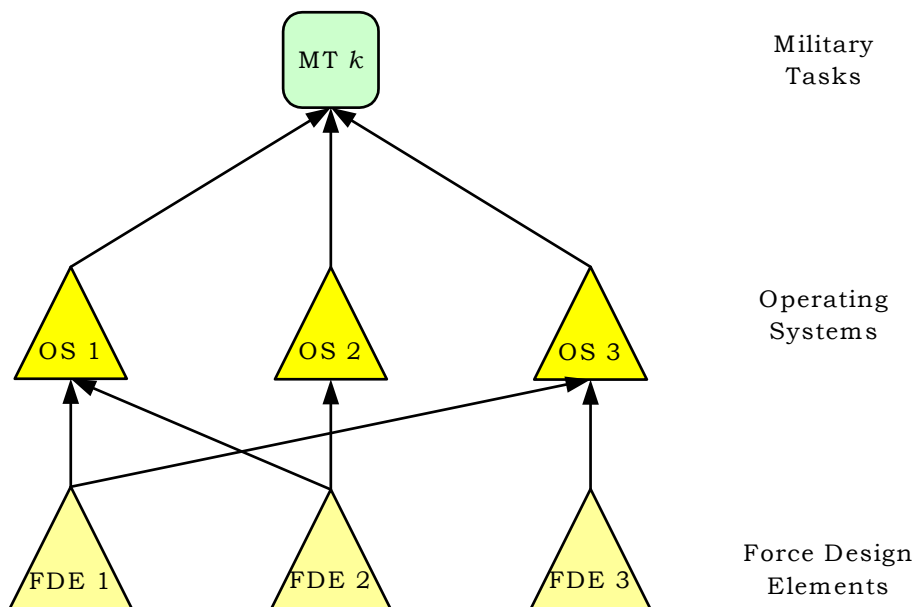

Figure 2.1: Generic relationships between a military task, its associated operating systems and force design elements.
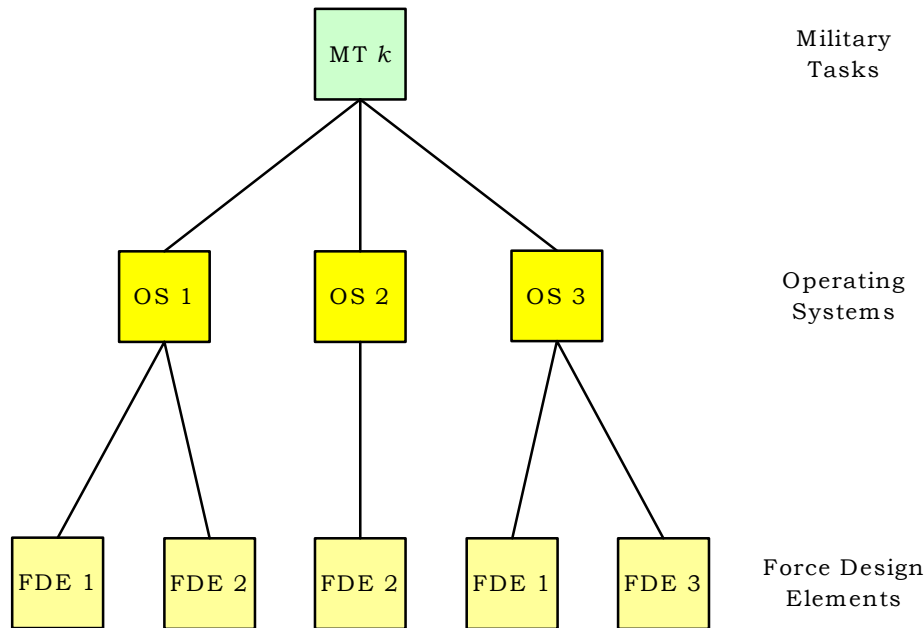
Figure 2.2: Generic tree structure delineating the kth military task and its descendants.

From the two Figures, it is clear that the relationship diagram delineated in Figure 1.3 may be re-written in a ranked tree.

Let M be a ranked tree with a finite collection of vertices or nodes connected by lines or arcs so as to form a connected figure that includes no simple closed curves and let M delineate a military strategy. We fix a unique vertex in the tree, called the root, and denote it by $\langle R \rangle$. Then there is an implicit direction in the tree, either away from, or towards, $\langle R \rangle$. Without loss of generality, assume the direction is away from $\langle R \rangle$.

Further, let V(M) be the complete set of all vertices within M and L(M) be the complete set of all arcs within M. Given any two vertices $\langle A \rangle$ and $\langle B \rangle$ within M, then it follows that there is a unique sequence of arcs and vertices joining $\langle A \rangle$ to $\langle B \rangle$. A vertex $\langle C \rangle$ follows the vertex $\langle B \rangle$ if the sequence of arcs joining $\langle R \rangle$ to $\langle C \rangle$ passes through $\langle B \rangle$ whilst the vertex $\langle C \rangle$ follows the vertex $\langle B \rangle$ directly if $\langle C \rangle$ follows $\langle B \rangle$ and there is an arc joining $\langle B \rangle$ to $\langle C \rangle$. A vertex $\langle X \rangle$ is said to be terminal if no vertex follows $\langle X \rangle$. We shall refer to a vertex $\langle B \rangle$ that follows a vertex $\langle A \rangle$ directly as the successor vertex of $\langle A \rangle$, whereas we shall refer to the vertex $\langle A \rangle$ as the predecessor vertex of $\langle B \rangle$.

In future we shall identify a vertex with an element of a military strategy. For example, if $\langle \varphi \rangle$ denotes the *command and control operating system*, we shall use $\langle \varphi \rangle$ and the *command and control operating system* interchangeably. Also, we shall store all relevant information appertaining to the element of a military strategy on $\langle \varphi \rangle$.

We define the rank, $\mu(v)$, of a vertex $\langle v \rangle$ as the distance measured by the number of arcs from $\langle R \rangle$ to $\langle v \rangle$. Then the collection of vertices with the same rank may be associated with a level of abstraction of a military strategy.

Let

$$M_{\xi} = \left\{ v \in V\left(M\right) \middle| \mu\left(v\right) = \xi \right\} \tag{2.1}$$

where ξ = 0, 1, 2, 3, 4, 5 denote the six sub-sets of vertices within M with rank $\mu(v)$. Then the following relationships between the ranks of the vertices in M and the levels of abstraction in a military strategy exist:

- For a vertex with $\mu(v)$ = 0, the corresponding level of abstraction is a military strategy. Note that M_0 is associated with $\langle R \rangle$.

- For a vertex with $\mu(v)$ = 1, the corresponding level of abstraction is the ends of a military strategy.

- For a vertex with $\mu(v)$ = 2, the corresponding level of abstraction is the military missions relating to the various ends of a military strategy.

- For a vertex with $\mu(v)$ = 3, the corresponding level of abstraction is the military tasks associated with military missions.

- For a vertex with $\mu(v)$ = 4, the corresponding level of abstraction is the operating systems that are integrated as Task Forces to conduct military tasks.

- For a vertex with $\mu(v)$ = 5, the corresponding level of abstraction is the elements of the force design that can, in turn, be grouped into operating systems.

2.1. VERTICES IN A MILITARY STRATEGY TREE

Consider Figure 2.2. If a vertex in the relationship diagram of Figure 2.1 relates to n entities at the next higher level of abstraction, then that vertex will appear n times at the same level in the ranked tree as vertices that follow directly the n vertices that it relates to.

Furthermore, if we consider any vertex $\langle v \rangle$ in the tree with $\mu(v)$ = 0, 1, 2, 3, 4 and its successor vertices, we define a specific order for the successor vertices. In a canonical ordering of M, we order the successor vertices in a fixed sequence from left to right whilst in a left to right representation of M, we order the successor vertices in a fixed sequence

from top to bottom. Also, we label the vertices in M in accordance with their position in relation to their predecessor vertices and the other successor vertices which have a common predecessor vertex.

Consider Figure 2.3. Suppose there are p successor vertices to $\langle R \rangle$ and M has been represented in a top-down manner, then we label the left-hand successor vertex $\langle 1 \rangle$, the second most left-hand successor vertex $\langle 2 \rangle$, the ith most left-hand successor vertex $\langle i \rangle$ and the right-hand successor vertex $\langle p \rangle$.

Suppose there are q successor vertices to $\langle i \rangle$, then we label the successor vertices to $\langle i \rangle$ in a similar manner, that is, we label the left-hand successor vertex $\langle i1 \rangle$, the second most left-hand successor vertex $\langle i2 \rangle$, the jth most left-hand successor vertex $\langle ij \rangle$ and the right-hand successor vertex $\langle iq \rangle$.
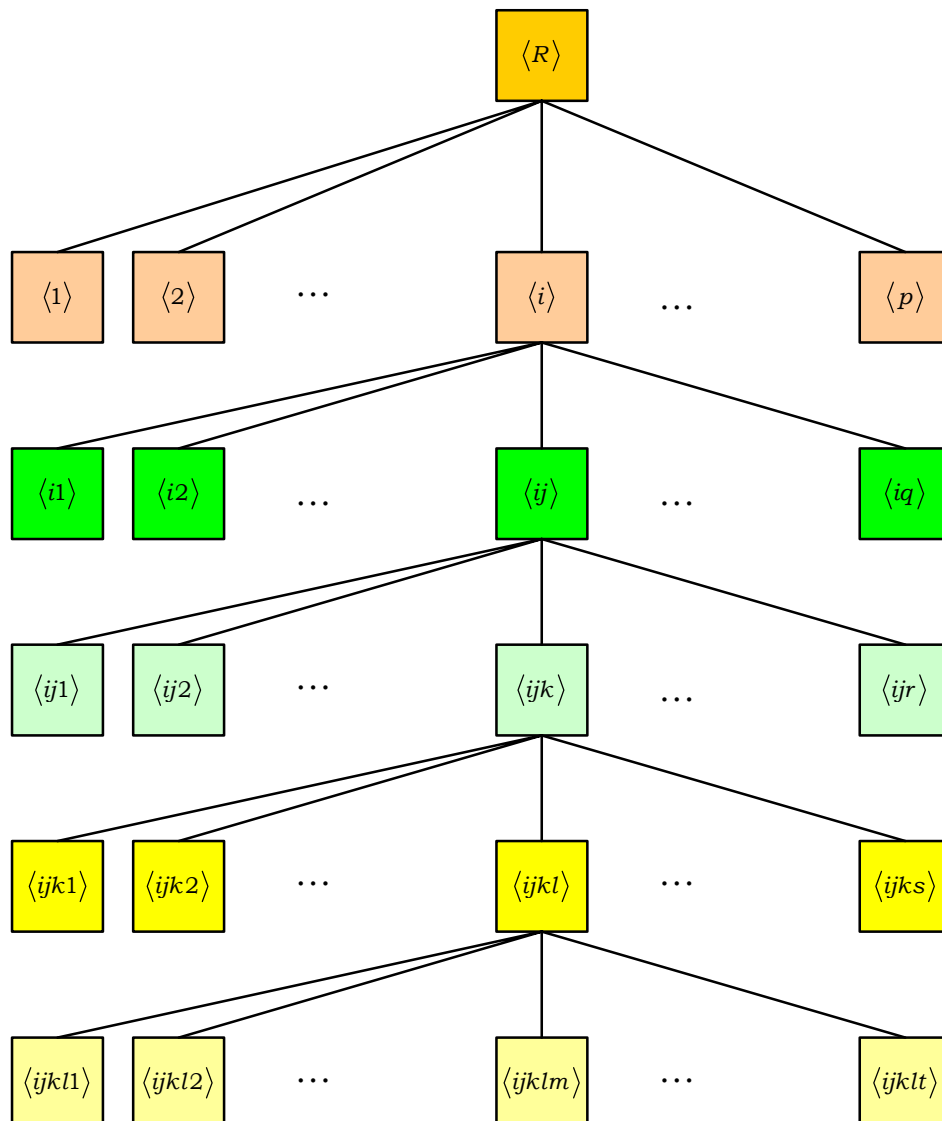

Figure 2.3: Notation for Vertices in the Tree Representing the Military Strategy.

We carry on labelling successor vertices by expanding the label in a similar manner for successive successor vertices. Thus, the kth successor vertex to $\langle ij \rangle$ is labelled $\langle ijk \rangle$, the lth successor vertex to $\langle ijk \rangle$ is labelled $\langle ijkl \rangle$ and the mth successor vertex to $\langle ijkl \rangle$ is labelled $\langle ijklm \rangle$.

Note that the placing of the vertices in M is an arbitrary process whereas the labelling of the vertices fixes them so that they can be referred to in a unique manner. Also, it is of interest to note that the number of entries in the label of a vertex corresponds to the value of $\mu(v)$ for that vertex.

2.2.   RELATIONSHIPS WITHIN A MILITARY STRATEGY

The many-to-may relationships in Figure 2.1 can be expressed as the relationships between the vertices of the tree representing a military strategy or, more precisely, as the arcs between the various vertices or vertices. The relationships between the vertices within the tree are characterised by the extent that successor vertices contribute towards enabling their predecessor vertex.

2.2.1.   Assumptions Necessary to Develop an Initial Ranked Tree

Suppose a vertex $\langle \varphi \rangle$ has n successor vertices, $\langle \varphi 1 \rangle$, ...,$\langle \varphi n \rangle$. Let the extent that the ith successor vertex, $\langle \varphi i \rangle$, contributes towards enabling its predecessor vertex $\langle \varphi \rangle$ be $v_{\langle \varphi i \rangle}$. The unit of measure appertaining to $v_{\langle \varphi i \rangle}$ is dimensionless and in this context constitutes a proportion.

In order to develop an initial ranked tree for the relationships within a military strategy, we make the following three assumptions:

Assumption 2.1: The model is requisite, that is, the successor vertices contain the requirements for enabling their predecessor vertices fully[1]. For example, if the force design does not include a particular force design element such as an air early warning aircraft, but such an aircraft (vertex) is necessary in order to fully enable the related operating system (predecessor vertex) then the particular aircraft type will be included in the ranked tree despite the fact that it is not part of the force design.

Assumption 2.2: The extent that the ith successor vertex, $\langle \varphi i \rangle$, contributes towards enabling its predecessor vertex, $\langle \varphi \rangle$, is relative to the extent that the other successor vertices also contribute towards enabling $\langle \varphi i \rangle$.

If Assumption 2.1 is read with Assumption 2.2, then it follows that the total contribution of a vertex's successor vertices is

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[1] Phillips, L.D., Requisite Decision Modelling, *Journal of the Operations Research Society*, Vol 33, 1982, p. 37.

$$\sum_{i=1}^{n} v_{\varphi i} = 1. \tag{2.2}$$

Assumption 2.3: The terminal vertices or force design elements are fully combat ready or effective. Thus, the force design elements are able to successfully meet an overall operational demand within a given time under specified conditions[2].

2.2.2.   Contribution of Vertices to their Predecessor Vertices

From the above, we have noted that the terminal or force design element vertex $\langle ijklm \rangle$ contributes $v_{\langle ijklm \rangle}$ to its operating system or predecessor vertex $\langle ijkl \rangle$. We denote this relation to be

$$\langle ijklm \rangle \xrightarrow{\; v_{\langle ijklm \rangle} \;} \langle ijkl \rangle. \tag{2.3}$$

Likewise we have that

$$\langle ijkl \rangle \xrightarrow{\; v_{\langle ijkl \rangle} \;} \langle ijk \rangle,$$
$$\langle ijk \rangle \xrightarrow{\; v_{\langle ijk \rangle} \;} \langle ij \rangle, \tag{2.4}$$
$$\langle ij \rangle \xrightarrow{\; v_{\langle ij \rangle} \;} \langle i \rangle$$

and

$$\langle i \rangle \xrightarrow{\; v_{\langle i \rangle} \;} \langle R \rangle. $$

2.2.3.   Contribution of Vertices to other Vertices than their Predecessor Vertices

As long as two vertices are on the same path in the ranked tree, M, we may determine the degree to which any vertex contributes to the other vertex in M. For example, if we want to know to what extent the vertex $\langle ijkl \rangle$ contributes to the vertex $\langle ij \rangle$, then we have that

$$\langle ijkl \rangle \xrightarrow{\; \tilde{v}_{\langle ijkl \rangle}^{\langle ij \rangle} \;} \langle ij \rangle, \tag{2.5}$$

where

$$\tilde{v}_{\langle ijkl \rangle}^{\langle ij \rangle} = v_{\langle ijkl \rangle} \cdot v_{\langle ijk \rangle}. \tag{2.6}$$

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[2] Blanchard, B.S. and Fabrycky, W.J., *Systems Engineering and Analysis.* 2 ed., New Jersey: Prentice Hall, 1990, p. 360.

2.2.4. Contribution of the Vertices to the Root

Moreover, we can express the contribution of any vertex to the root $\langle R \rangle$ as

$$
\begin{aligned}
\langle ijklm \rangle & \xrightarrow{\tilde{v}_{\langle ijklm \rangle}} \langle R \rangle, \\
\langle ijkl \rangle & \xrightarrow{\tilde{v}_{\langle ijkl \rangle}} \langle R \rangle, \\
\langle ijk \rangle & \xrightarrow{\tilde{v}_{\langle ijk \rangle}} \langle R \rangle, \\
\langle ij \rangle & \xrightarrow{\tilde{v}_{\langle ij \rangle}} \langle R \rangle
\end{aligned}
\tag{2.7}
$$

and

$$
\langle i \rangle \xrightarrow{\tilde{v}_{\langle i \rangle}} \langle R \rangle
$$

where

$$
\begin{aligned}
\tilde{v}_{\langle ijklm \rangle} &= v_{\langle ijklm \rangle} \cdot v_{\langle ijkl \rangle} \cdot v_{\langle ijk \rangle} \cdot v_{\langle ij \rangle} \cdot v_{\langle i \rangle} \cdot v_{\langle R \rangle}, \\
\tilde{v}_{\langle ijkl \rangle} &= v_{\langle ijkl \rangle} \cdot v_{\langle ijk \rangle} \cdot v_{\langle ij \rangle} \cdot v_{\langle i \rangle} \cdot v_{\langle R \rangle}, \\
\tilde{v}_{\langle ijk \rangle} &= v_{\langle ijk \rangle} \cdot v_{\langle ij \rangle} \cdot v_{\langle i \rangle} \cdot v_{\langle R \rangle}, \\
\tilde{v}_{\langle ij \rangle} &= v_{\langle ij \rangle} \cdot v_{\langle i \rangle} \cdot v_{\langle R \rangle}
\end{aligned}
\tag{2.8}
$$

and

$$
\tilde{v}_{\langle i \rangle} = v_{\langle i \rangle} \cdot v_{\langle R \rangle}.
$$

Note that in (2.8), the last term on the right hand side of the various equations is $v_{\langle R \rangle} = 1$. This term allows for a model of a national strategy where a military strategy is but one of its instruments.

2.2.5. Contribution of Sets of Vertices to the Root

The sum of the contributions of all successor vertices to a particular predecessor vertex is always one. Let $M_5(f)$ be all vertices in the set M_5 corresponding to the force design element f. Then the degree to which a particular force design element, f, contributes to a military strategy relative to the other force design elements

$$
w_f = \sum_{\delta \in M_5(f)} \tilde{v}_{\langle \delta \rangle}.
\tag{2.9}
$$

We have previously shown that if a vertex in the relationship diagram of Figure 2.1 relates to n entities at the next higher level of abstraction, then that vertex will appear n times at the same level in the ranked tree as successor vertices of the n predecessor vertices that it relates to. Thus it might not be feasible to examine one terminal vertex only to find the

degree to which a particular force design element contributes to the strategy or any other level within M.

Likewise, then we may find contributions such that

$$w_\beta = \sum_{\delta \in M_\xi(\beta)} \tilde{v}_{\langle\delta\rangle} \tag{2.10}$$

where $\beta \in \{s, t, m, e\}$ and where

- s is the operating system under consideration and M_4 is the set of all operating systems at the level of abstraction where $\mu(v) = 4$;

- t is the military task under consideration and M_3 is the set of all military tasks at the level of abstraction where $\mu(v) = 3$;

- m is the military mission under consideration and M_2 is the set of all military missions at the level of abstraction where $\mu(v) = 2$; and

- e is the military strategic end under consideration and M_1 is the set of all military strategic ends at the level of abstraction where $\mu(v) = 1$.

In practical terms, t, m and e might not be of much use as the strategic ends, military missions and their related tasks might not appear more than once in M.

2.2.6.   Actual Versus Relative Contributions

Given the assumptions that we have made previously, the model thus far can be considered to be an idealised representation of the relationships between the military strategic ends, ways and means. In the remainder of this chapter, we shall consider the impact on the model when assumptions 2.1 and 2.2 do not apply. The impact when assumption 2.3 does not apply will be considered in the next chapter. We shall illustrate the impact on the model when assumptions 2.1 and 2.2 do not apply by an example from vertices where $\mu(v) = 5$.

2.2.6.1.   *Assumption 2.1 does not apply*

Firstly, let us consider assumption 2.1. When assumption 2.1 applies, we note that where d is any element of the force design and M_5 is the set of elements that makes up the total force design inclusive of force design elements included under the assumption, we have that

$$\sum_{d \in M_5} \tilde{\upsilon}_{\langle d \rangle} = 1 \,. \tag{2.11}$$

Now, if assumption 2.1 does not apply, then the successor vertices do not describe the requirements for enabling their predecessor vertices fully. We consider the case where $\mu(v) = 5$ and when the model is not requisite. Under these conditions certain force design elements that must enable certain operating systems are not present in the force design. As a result, the applicable operating system is not fully enabled. Thus we have that (2.2) for t force design elements as they relate to $\langle ijkl \rangle$ is now modified to read

$$\sum_{m=1}^{t} \upsilon_{\langle ijklm \rangle} < 1 \,. \tag{2.12}$$

Furthermore, when assumption 2.1 does not apply, (2.11) will now also be amended to read

$$\sum_{d \in M_5} \tilde{\upsilon}_{\langle d \rangle} < 1 \,. \tag{2.13}$$

Under assumption 2.1, we have used the example that if the force design does not include an air early warning aircraft, but such an aircraft is necessary in order to fully enable the related operating system, then the particular aircraft type will be included in the ranked tree despite the fact that it is not part of the force design. This enables assumption 2.1. Now, when assumption 2.1 is not in force, then we see that (2.11) is of the form (2.13). This would inhibit the holistic analysis of a military strategy as it would skew the relative contributions of successor vertices to enable predecessor vertices and the potential worth in terms of its contribution to a military strategy of such elements will not be apparent to decision makers.

Thus, we insist that, as a matter of practice, the model to be requisite. All vertices, wherever it may be in M, that may potentially impact on the enabling of a military strategy should be part of the model. The result is that assumption 2.1 is considered a prerequisite for quantifying a military strategy.

2.2.6.2.   *Assumption 2.2 does not apply*

Secondly, let us consider M when assumption 2.2 does not apply. Thus, we have that the individual contributions by vertices to enable their predecessor vertices are not expressed relative to one another. Now, let us consider the level of abstraction where $\mu(v) = 5$. Thus, we are considering the force design element level.

At this level in M, given assumption 2.1, the actual contribution of the force design elements to enable an operating system, $\rho_{\langle ijklm \rangle}$, as opposed to their relative contributions, $\upsilon_{\langle ijklm \rangle}$, may be

$$\sum_{m=1}^{t} \rho_{\langle ijklm \rangle} \geq 1 .$$
(2.14)

If, in (2.14), the equality holds, then we may assume that

$$\upsilon_{\langle ijklm \rangle} = \rho_{\langle ijklm \rangle}$$
(2.15)

and the equality holds for all vertices, then the idealistic model as discussed with assumption 2.2 in place will be appropriate. However, due to redundancy, designed or otherwise, it is unlikely that the equality of (2.14) will apply to all vertices where $\mu(v) = 5$.

To illustrate, we consider the case where the Situational Awareness (Reconnaissance, Surveillance and Intelligence) operating system against an enemy in the maritime battle space could be enabled by, *inter alia*,

- Long Range Maritime Patrol Aircraft,

- Frigate Small Guided Missile,

- Fast Attack Craft Missile,

- Submarine Conventional,

- Maritime Attack Helicopter,

- Maritime Unmanned Aerial Vehicle, and a

- Satellite Reconnaissance Force Design Element.

The degree to which these force design elements may contribute to the enablement of the operating system and the relative values associated with the actual contributions are shown in Table 2.1. Note that in this case $\rho_{\langle ijklm \rangle}$ was arbitrarily chosen in order to illustrate the concept.

The relative contributions by the t force design elements can be calculated by normalising such that

$$\upsilon_{\langle ijklm \rangle} = \frac{\rho_{\langle ijklm \rangle}}{\displaystyle\sum_{m=1}^{t} \rho_{\langle ijklm \rangle}} .$$
(2.16)

Serial	Force Design Element		ρ_{ijklm}	υ_{ijklm}
(*m*)	a		b	c
1	LRMP Aircraft		0.700	0.233
2	Frigate Small Guided Missile		0.300	0.100
3	Fast Attack Craft Missile		0.100	0.033
4	Submarine Conventional		0.200	0.067
5	Maritime Attack Helicopter		0.400	0.133
6	Maritime Unmanned Aerial Vehicle		0.300	0.100
7	Satellite Reconnaissance Force Design Element		1.000	0.333
Totals for $\sum_{m=1}^{7} \rho_{\langle ijklm \rangle}$ and $\sum_{m=1}^{7} \upsilon_{\langle ijklm \rangle}$ respectively			3.000	1.000

Table 2.1: Situational Awareness (Reconnaissance, Surveillance and Intelligence) Operating System

If the equality does not hold in (2.14), then we see that there is spare capacity for enabling the relevant operating system. For example, if one submarine is required to fire a torpedo at a merchant vessel, then the fact that there are three submarines in the inventory allows for two submarines as spare capacity only. It will not allow for the single torpedo to be fired more effectively and as a result, will not contribute more to the operating system's contribution to the military task of firing the torpedo. Under assumption 2.3 and for the reason expounded above, the spare capacity cannot be transferred to the higher levels of abstraction within M.

However, in order not to lose the information gained by determining $\rho_{\langle ijklm \rangle}$, (2.14) should be stored with the relevant operating system vertex. This will enable the recovery of $\rho_{\langle ijklm \rangle}$ when it is required for analysis.

In determining the actual contribution of the force design elements to enable an operating system, $\rho_{\langle ijklm \rangle}$, many factors may influence the final value allocated to $\rho_{\langle ijklm \rangle}$. Thus we have that $\rho_{\langle ijklm \rangle} = f\left(x_1, \ldots, x_n\right)$ where the x_i represents the variables necessary to consider in order to find the force design element's actual contribution to the operating system. We shall illustrate this idea by means of a number of examples.

Example 1. Consider a manoeuvre and direct fire operating system. A significant contributor to the operating system is the Infantry Corps. Suppose we have a military task to execute within a larger mission scenario where the infantry only is required to enable the manoeuvre and direct fire operating system. Furthermore, we consider the contribution that the infantry makes as an exponential utility function of the number of infantrymen that is deployed such that

$$U(x) = 1 - e^{-x/R}, \qquad\qquad (2.17)$$

where x is the number of infantry men deployed and R is the risk tolerance of the decision maker. Clemen[3] fully describes the use of exponential utility function and a betting methodology to find R. A graph of this exponential utility function where $R = 300$ is at Figure 2.4.
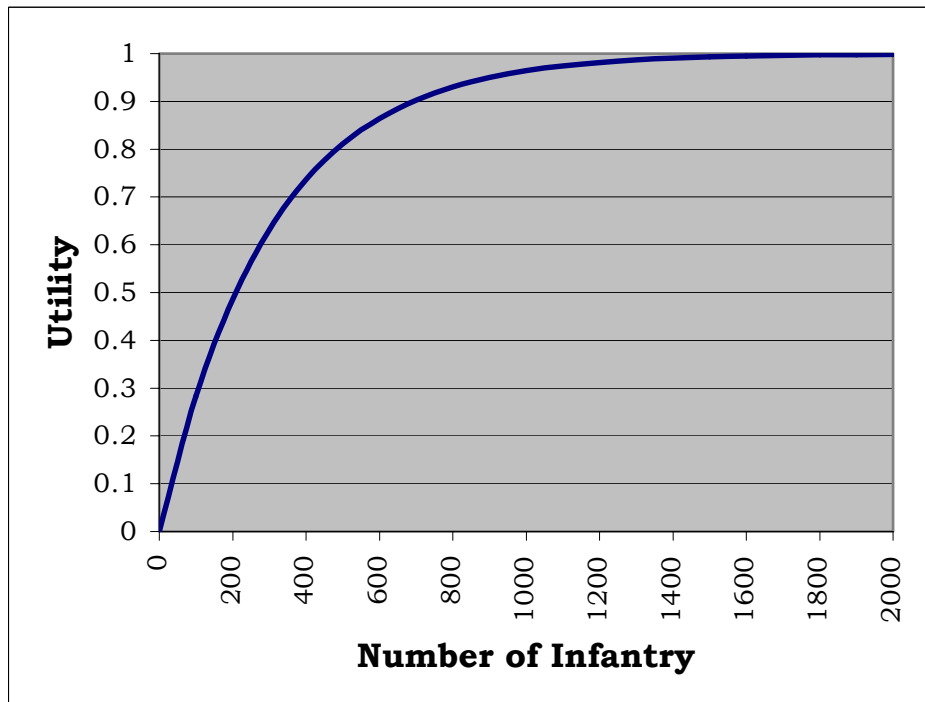

Figure 2.4:   Utility of the Contribution of the Motorised Infantry to a
Manoeuvre and Direct Fire Operating System

Suppose that for this scenario we have 2000 infantrymen available for the task at hand. Now, if we consider the exponential utility function, we note that the first one third of the possible 2000 infantrymen will have a utility of 89%. The second one third of the possible 2000 infantrymen will add about 10% to the utility of the first third whereas the last third will add less than 1% to the utility of the first two thirds of the available infantrymen.

Furthermore, we accept utility as a measure of the degree to which the infantrymen will contribute to the enablement of the manoeuvre and direct fire operating system. We may do so because utility is a measure of usefulness and we may regard the degree to which the infantrymen will contribute to the enablement of the manoeuvre and direct fire operating system also as a measure of usefulness. Thus, in this example we see that we might be able to express $\rho_{\langle ijklm \rangle}$ for any given number of infantrymen as an exponential utility function. Note that the exponential

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[3] Clemen, R.T., *Making Hard Decisions - An Introduction to Decision Analysis*, Boston, Ma: PWS-Kent, c1991, pp. 379 - 382.

utility function is a continuous function whereas the number of infantry is discrete. Thus we use the function to find the values for particular numbers of infantrymen and as such it allows for discrete values in $\rho_{\langle ijklm \rangle}$.

Example 2. Consider an indirect fire operating system that is enabled by fighter aircraft only. Furthermore, let the military task require the simultaneous engagement of ten ground targets, the destruction of which is of equal value to own forces.
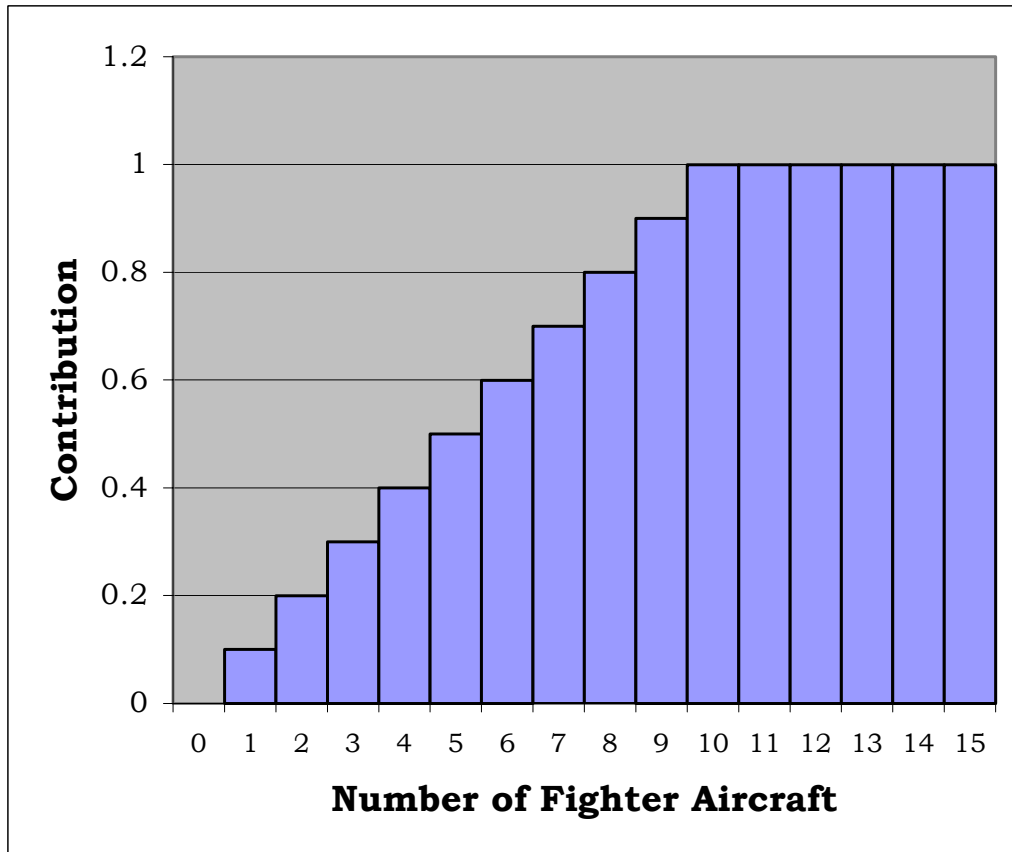
Figure 2.5: Contribution of Fifteen Fighter Aircraft to an Indirect Fire Operating System

Figure 2.5 depicts the contribution of the fifteen fighter aircraft to the enablement of the indirect fire operating system. Because of the relatively small number of entities involved, the discrete nature of the function is more pronounced. In fact, the graph depicts a step function that increases by 10% for every aircraft up to ten aircraft. The remaining five aircraft have no influence on the degree to which the indirect fire operating system is enabled by the force structure elements. This demonstrates again that where more than the required number of force design elements are present, the excess force design elements may be considered superfluous regarding their contribution towards enabling the associated operating system, military task, military mission and military strategic end. By associated operating system, etc. we mean the operating

system, military task, military mission and military strategic end that are connected by a single set of arcs.

Now, we may write the actual degree to which the fighter aircraft will enable the indirect fire operating system to be

$$\rho_{\langle ijlkm \rangle} = \begin{cases} 0.1x & \text{for} & 0 \leq x \leq 10 \\ 1 & \text{for} & x > 10 \end{cases} \tag{2.18}$$

where x is the number of fighter aircraft available.

<u>Example 3</u>. Finding values for $\rho_{\langle ijklm \rangle}$ might often be more complex than the case we have expounded upon in Example 2. Consider the application of Fast Attack Craft armed with Surface-to-Surface Missiles (FAC(M)). These ships displace about 400 tons and are essentially surface combatants with point defence weapons in the air defence environment only. Because of their light displacement, the FAC(M)s main mast is only about 12,7 m above the sea. This height is not conducive to long radar ranges and the FAC(M) is reliant on electronic intelligence equipment to find the opposing force timely. As only bearing information can be obtained from electronic intelligence equipment, it is necessary for FAC(M)s to be deployed in pairs so as to enable the tracking of the opposing force in bearing and in range. Thus if one FAC(M) is deployed, its contribution is much less than if it is deployed in a pair. This situation where up to six FAC(M) are available to be deployed against a modest single surface force is depicted in Figure 2.6.
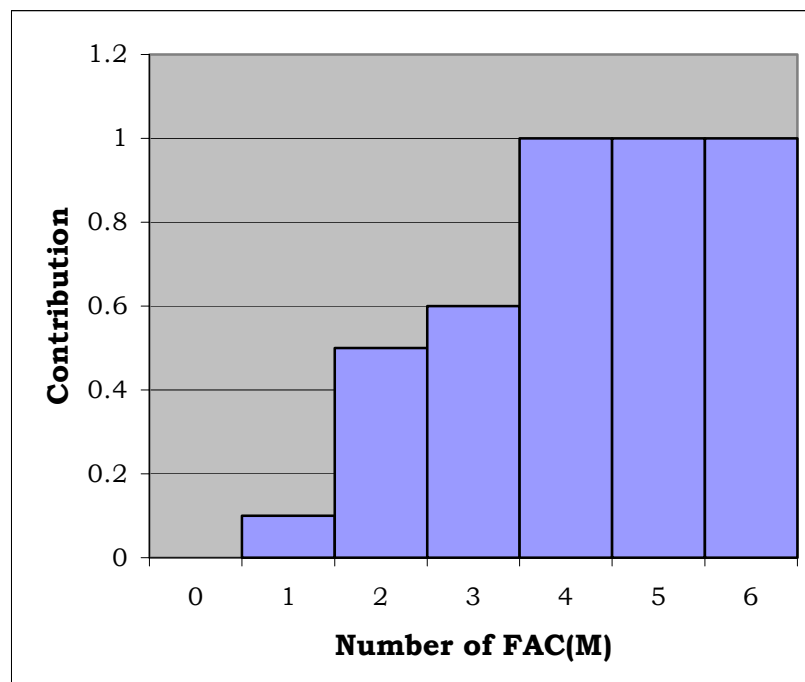
Figure 2.6: Contribution of Six FAC(M) to a Manoeuvre and Direct Fire Operating System

We note that whereas a single FAC(M) may contribute 10% to the enablement of the associated manoeuvre and direct fire operating system, its contribution could be as much as 25% when deployed in a pair. Again, two pairs are considered to be sufficient for such an attack. The extra pair that is available is superfluous. In this case, this is because of the difficulty in manoeuvring pairs over large sea areas in order to get all of them to engage the opposing force simultaneously form widely divergent directions precludes the use of more than two pairs.

$$\rho_{\langle ijklm \rangle} = 0 \qquad \text{for no FAC(M)},$$

$$\rho_{\langle ijklm \rangle} = 0.1 \quad \text{for } 1 \times \text{FAC(M)},$$

$$\rho_{\langle ijklm \rangle} = 0.5 \quad \text{for } 2 \times \text{FAC(M)},$$

$$\rho_{\langle ijklm \rangle} = 0.6 \quad \text{for } 3 \times \text{FAC(M)}$$

and

$$\rho_{\langle ijklm \rangle} = 1 \text{ for 4 or more FAC(M)}.$$

Example 4. Thus far, we have considered single types of force design elements only. When a mix of force design elements are combined to enable some operating system, finding values for ρ_{ijklm} may become even more complex. Consider a more than modest opposing surface force dispersed in two task units at sea. Also, this time we decide not to consider FAC(M) in any other configuration but pairs and we shall also consider the use of Corvettes or Small Guide Missile Frigates (FSG) simultaneously. Suppose we have six FAC(M) and three FSGs available. We depict values for $\rho_{\langle ijklm \rangle}$ when these forces are used in different configurations in Figure 2.7.

The higher complexity for the determination of $\rho_{\langle ijklm \rangle}$ is demonstrated in Figure 2.7. The interaction of FAC(M) and FSG exacerbates the problem of determining values for $\rho_{\langle ijklm \rangle}$ and it follows that as we add more force design elements such as long range maritime patrol aircraft, conventional submarines, maritime attack helicopters and maritime strike aircraft to the mix, the problem of determining values for $\rho_{\langle ijklm \rangle}$ may become extremely complex. In this case,

$$\rho_{\langle ijklm \rangle} = 0 \text{ for no ships},$$

$$\rho_{\langle ijklm \rangle} = 0.25 \text{ for 2 FAC(M)},$$

$$\rho_{\langle ijklm \rangle} = 0.5 \quad \text{for 4 FAC(M)},$$

$$\rho_{\langle ijklm \rangle} = 0.7 \quad \text{for 6 FAC(M)},$$

$\rho_{\langle ijklm \rangle} = 0.35$ for 1 FSG,

$\rho_{\langle ijklm \rangle} = 0.45$ for 1 FSG and 2 FAC(M),

$\rho_{\langle ijklm \rangle} = 0.8$ for 1 FSG and 4 FAC(M),

$\rho_{\langle ijklm \rangle} = 0.9$ for 1 FSG and 6 FAC(M),

$\rho_{\langle ijklm \rangle} = 0.7$ for 2 FSG and no FAC(M),

$\rho_{\langle ijklm \rangle} = 0.95$ for 2 FSG and 2 FAC(M), and

$\rho_{\langle ijklm \rangle} = 1$ for 2 or more FSG and 4 or more FAC(M).
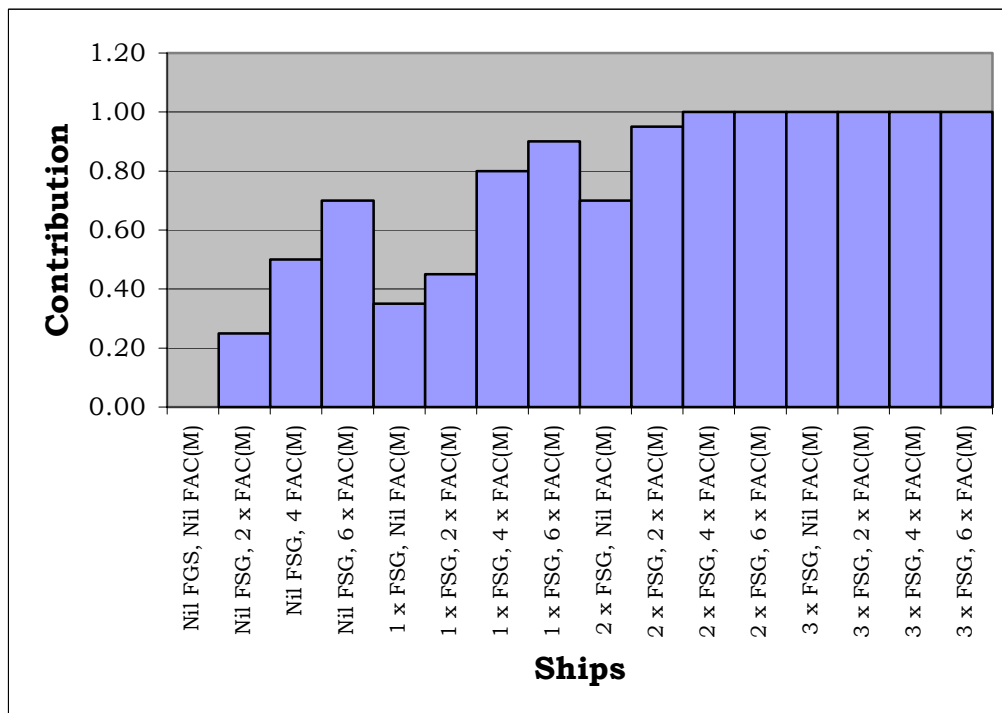
Figure 2.7: Contribution of Six FAC(M) in pairs and three FSGs to a Manoeuvre and Direct Fire Operating System

Note that in Example 4, we studied the simultaneous effects of two force design elements on an operating system. Under these circumstances the problem posed is further exacerbated by the need to discriminate between the FAC(M) and FSG in order to find their respective $\rho_{\langle ijklm \rangle}$.

These examples, together with the more detailed list in Table 2.1 further emphasise that the complexity of determining values for $\rho_{\langle ijklm \rangle}$ will increase as n becomes larger. However, as we shall see in Section 3, by taking recourse to various scientific methodologies, it is possible to determine approximate values for $\rho_{\langle ijklm \rangle}$ despite its complexity.

3. QUANTIFYING THE RELATIONSHIPS BETWEEN A MILITARY STRATEGY'S ENDS, WAYS AND MEANS

The following categories of methods can be applied to quantify the complex relationships between a military strategy's ends, ways and means:

- Analytical Methods.

- Heuristic Methods.

- Judgements.

Hoebner[4] uses the air combat problem to demonstrate that model complexity increases as the number of entities under consideration increases. This section is aimed at showing how values for the various relationships between a military strategy's ends, ways and means, such as $v_{\langle \varphi \rangle}$ and $\rho_{\langle \varphi \rangle}$, should be found under these highly complex conditions by analytical, heuristic and judgement methods.

In general, scientific analysis by professional officers as well as civilians, is an accepted feature of creative problem solving in the military[5]. The category of analytical methods are considered to be the most effective way to determine the relative contributions of, for example, force design elements to their associated operating systems. This statement is motivated by the fact that analytical methods, when they are applicable, generally lead to results that can be proved to be optimised.

On the other hand, heuristic methods are dependent on the analyst to ask the right "what if" questions in order to improve the quality of the answers that the analyst obtains from the model under construction.

When the problem is too complex to be dealt with adequately by analytical or heuristic methods, or time constraints prevent the building of such models, the judgement of professional officers or other experts may be used to determine the extent of the relationships between a military strategy's ends, ways and means.

3.1. ANALYTICAL METHODS

Operations Research and other sciences have developed a wide spectrum of analytical methods that may solve the problem of determining the relationships between a military strategy's ends, ways and means. The following non-exhaustive list depict some of the more pertinent methods:

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[4] Hoeber, F.P., *Military Applications of Modeling – Selected Case Studies*, New York: Gordon and Breach, 1981, pp. 22–24.
[5] *Naval Operations Analysis*, 2 ed., Annapolis, Maryland: Naval Institute Press, c1977, p. 5.

- Comparative Statistics.

- Linear Programming.

- Non-linear Programming.

- Game Theoretic Models.

- Markov Chains.

- Deterministic Dynamic Programming.

- Detection Models.

We shall illustrate the use of some of these methods by means of the following examples:

- Comparative Statistics.

- A Detection Model.

- A Linear Program.

- A Game Theoretic Model.

3.1.1. Comparative Statistics

Kimball and Morse[6] describe how comparative effectiveness statistics were used by the British Forces in World War II in order to decide on the contribution of Axis surface ships, aircraft, mine-laying forces and submarines in the casualties suffered by Allied Cruisers. In Table 2.2 ships, aircraft, mine-laying forces and submarines are equated with shells, bombs, mines and torpedoes respectively.

According to Kimball and Morse, it is important to be able to assess the relative importance of ship damage to ship sinking. In such cases a profitable measure of comparison is the amount of time a dockyard will take to make up a loss. A damaged ship requires a given allocation of dockyard time for repair whereas building a ship to replace a sunken one requires a different allocation of dockyard time. These dockyard times to repair or replace ships may be expressed as Cruiser-time lost to the Allied Forces. If we consider the percentage of Cruiser months lost to the Allies for the four types of Axis force structure elements, value for $v_{\langle ijklm \rangle}$ can be derived. A visual presentation is at Figure 2.8.

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[6] Kimball, G.E., and Morse, P.M., *Methods of Operations Research*, 10th Printing, Los Altos, Ca: Peninsula Publishing, 1970, pp. 48–49.

Effect		Cause				Total/
		Shell	Bomb	Mine	Torpedo	Average
	Ships Sunk	3	9	1	11	24
	Ships damaged	18	56	9	19	102
	Casualties	21	65	10	30	126
Cruiser-months lost	by sinking	110	320	40	400	870
	by damage	30	90	60	180	360
	Totals	140	410	100	580	1230
	Percentage	11.38	33.33	8.13	47.15	100.00
	Cruiser-months per casualty	6.67	6.31	10.00	19.33	10.58

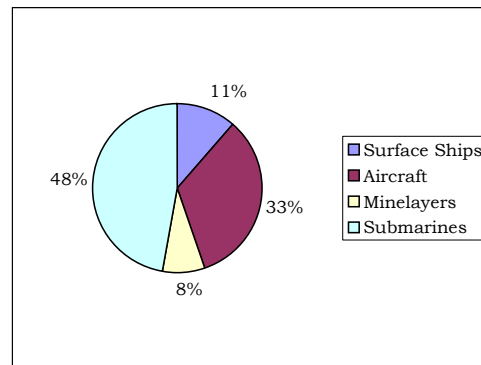Table 2.2: Casualties to Allied Cruisers by Axis action

Figure 2.8: Values for $v_{\langle ijklm \rangle}$ regarding the Axis force design element's contribution in enabling a typical Manoeuvre and Direct Fire Operating System

3.1.2. Detection of Randomly Distributed Vessels at Sea[7]

Consider the case of a search for a damaged ship as part of a combat search and rescue mission. We assume that the vessel is randomly positioned in an area through which the combat search and rescue force design element is sweeping. This is often a valid assumption since, in wartime, the location of the damaged ship is not usually known and the movement of the damaged ship is at best an estimate. Consider that the damaged vessel has some chance of being detected, that is, its lateral range is some value between $-R_m$ and R_m where R_m is the search force design element's maximum possible detection range. The damaged ship is just as likely to follow a relative track line through the detection area at one lateral range than any other lateral range. The lateral range, X, is therefore a random variable and has a uniform probability distribution over the range of values from $-R_m$ to R_m. From basic probability theory, it follows that X has a probability density function

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[7] *Naval Operations Analysis, op. cit.*, pp.115–119.

$$f(x) = \begin{cases} \dfrac{1}{2R_m}, & -R_m < x < R_m \\[2mm] 0, & \text{elsewhere.} \end{cases} \tag{2.19}$$

Given certain parameters for the force design element's search equipment such as, *inter alia*, height above the water, transmitting power for radar or enlargement detail for visual devices, let $\bar{P}(x)$ be the probability of detecting a damaged ship which transits at some specific lateral range, denoted x. The probability of detecting any ship whose lateral range is not known, that is, its range is a random value, is the expected value of $\bar{P}(x)$ or

$$E\left(\bar{P}(x)\right) = \int\limits_{\text{All } x} \bar{P}(x) \cdot f(x)\, ax. \tag{2.20}$$

Since x is uniformly distributed, and as a result, $1/2R_m$ is a constant, (2.20) can be written as

$$E\left(\bar{P}(x)\right) = \frac{1}{2R_m} \int\limits_{-R_m}^{R_m} \bar{P}(x)\, dx. \tag{2.21}$$

We have that (2.21) gives the probability of detecting the damaged ship if it transits the detection area. Now, we may compare the probability of detection for the various force design elements against an operational requirement for combat search and rescue, R, by setting

$$\rho_{\langle ijklm \rangle} = \frac{R_m}{R} E\left(\bar{P}(x)\right) \tag{2.22}$$

for $R \geq R_m$ and

$$\rho_{\langle ijklm \rangle} = \frac{1}{2R_m} \int\limits_{-R}^{R} \bar{P}(x)\, dx \tag{2.23}$$

for $R < R_m$. Recall that we find $v_{\langle ijklm \rangle}$ by (2.16). Finally, we have chosen the expected probability of detection against an operational requirement for combat search and rescue. Note that we may have chosen other related concepts such as sweep width and speed over the ground or the probability of detection with a given or random search pattern.

3.1.3. A Weapon Mix Problem[8]

Consider a Task Unit Commander who must assign n force design elements to a particular vulnerable area that is under air threat. It is assumed that no more than one force design element will be used against any particular aircraft from the opposing force. Typical South African force design elements would be air-landed Ground Based Air Defence Systems (GBADS), motorised GBADS and mechanised GBADS.

The problem is to determine a mix of force design elements to maximise the average number of kills of the opposing force's aircraft approaching the vulnerable area in a single attack. We define the following variables:

- k_d : Probability of kill of an opposing force's aircraft by a force design element of type d where d = 1, 2, ...,D.

- c_d : Cost of deploying force design element d.

- C : Total budget for deploying force design elements in the vulnerable area.

- m_d : Number of soldiers required for operating a force design element of type d.

- M : Total number of soldiers available assuming that each soldier can function within any of the force design elements.

- N_d : Total number of force design elements of type d available.

Let x_d be the number of force design elements of the dth type deployed in the vulnerable area. Then the average number of the opposing force's aircraft killed by the dth type of force design element is $k_d x_d$. The total number of aircraft killed is given by the objective function

$$z = \sum_{d=1}^{D} k_d x_d$$

which must be maximised. Therefore, we can express the problem as a Linear Program such that

Maximise $\quad z = \sum_{d=1}^{D} k_d x_d$

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[8] Jaiswal, N.K., *Military Operations Research*, Boston, Ma.: Kluwer, c1997, pp. 132–134.

Subject to $\displaystyle\sum_{d=1}^{D} c_d x_d \leq C$ (Budget Constraint)

$$\sum_{d=1}^{D} m_d x_d \leq M \qquad \text{(Manpower Constraint)}$$

$$x_d \leq N_d \qquad \text{(Force Design Element Constraint)}$$

$$x_d \geq 0 \qquad \text{(Non-negativity Constraint)}.$$

Suppose we have the following three types of force design elements:

- d = 1: Air-landed GBADS.

- d = 2: Motorised GBADS.

- d = 3: Mechanised GBADS.

This problem can be solved by an enumerative simplex method called the branch and bound[9] method. Moreover, suppose we model the problem and obtain the result,

$$x_1 = 1,$$
$$x_2 = 4$$

and

$$x_3 = 2.$$

Then we have that

$$\sum_{d=1}^{3} x_d = 7.$$

The relationship between the three force design elements has been optimised for this scenario and the relative contributions are depicted in Figure 2.9.

Now suppose the solution included x_d = 0, then the dth type of force design element is, under the constraints, of no value and could well be discarded from the force design. On the other extremity, if x_d = N_d, then it would indicate that there is cause to consider the position of the dth type of force design element in the force design. Indications are that more of that type might be beneficial to the degree to which the Protection of Own Forces Operating System is enabled. Thus, the resources allocated to the Task Unit Commander should be re-evaluated.

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[9] Salkin, H.M. and Mathur, K., *Foundations of Integer Programming.* Amsterdam: North-Holland, c1989, pp. 644–663.
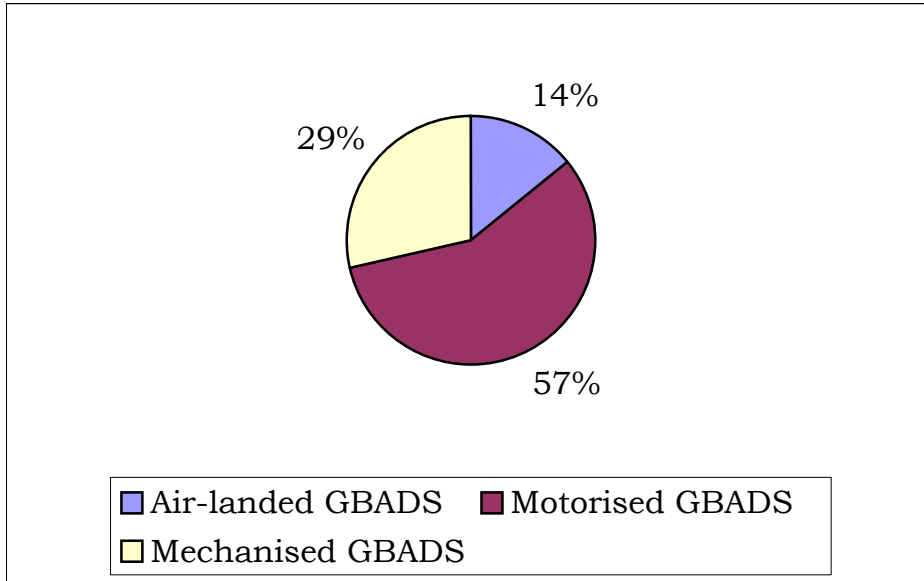
Figure 2.9: Values for $v_{\langle ijklm \rangle}$ for GBADS Force Design Elements as components of a Protection of Own Forces Operating System

3.1.4.   The Inspection Game

Suppose intelligence indicates that an opposing force might carry out a raid with Special Forces on installations in a particular sensitive area. Because of the clandestine nature of such operations, the opposing force will endeavour to evade own forces and would call off the raid if they were to be detected by own forces. On the other hand, we need to patrol the area using force design elements to detect and neutralise the opposing forces.

Owen[10] states that this problem is a game of exhaustion with the payoff matrix

$$\Gamma = \begin{bmatrix} 1 & -1 \\ -1 & -\dfrac{N-2}{N} \end{bmatrix} \tag{2.24}$$

where N is the number of time periods in which own forces can inspect the area with a particular force design element. An optimal strategy for own forces, x^N, would be

$$x^N = \begin{bmatrix} \dfrac{1}{N+1} & \dfrac{N}{N+1} \end{bmatrix} \tag{2.25}$$

whereas an optimal strategy for the opposing force, y^N would be

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[10] Owen, G., *Game Theory*, 3 ed., San Diego: Academic Press, c1995, pp. 93–94.

$$y^N = \left[\frac{1}{N+1} \quad \frac{N}{N+1} \right]. \tag{2.26}$$

We interpret (2.24) as follows:

- If own forces patrol the area and the opposing force carries out the raid, the opposing force would be compromised and the payoff for the own force is 1.

- If the own forces are not patrolling and the opposing force carries out the raid, then the payoff for the own force is -1.

- If own forces patrol and the opposing force does not carry out the raid, then the opposing forces are free to carry out the raid in the remaining time periods and own force's payoff is -1.

- If own forces do not patrol and the opposing forces do not raid, then both forces are free to act later and the game is played again. The eventual payoff to own forces for these strategies is $-(N-2)/N$.

We interpret (2.25) and (2.26) as follows:

- Own force's optimal strategy is, for every time period, to decide with probability $1/(N+1)$ to patrol the area.

- The opposing force's optimal strategy is, for every time period, to decide with probability $1/(N+1)$ decide to raid in the area.

The object of own force's strategy is to minimise the value of the game for the opposing force. This is achieved by (2.25). Now, Owen[11] gives the value of a 2×2 game as

$$v_\gamma = xAy^{\mathrm{T}} \tag{2.27}$$

where x is (2.25), A is (2.24) and y is (2.26). The values for the inspection game for $N = 1, 2, \ldots, 21$ are given in Figure 2.10.

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[11] Owen, *op. cit.*, p. 20.
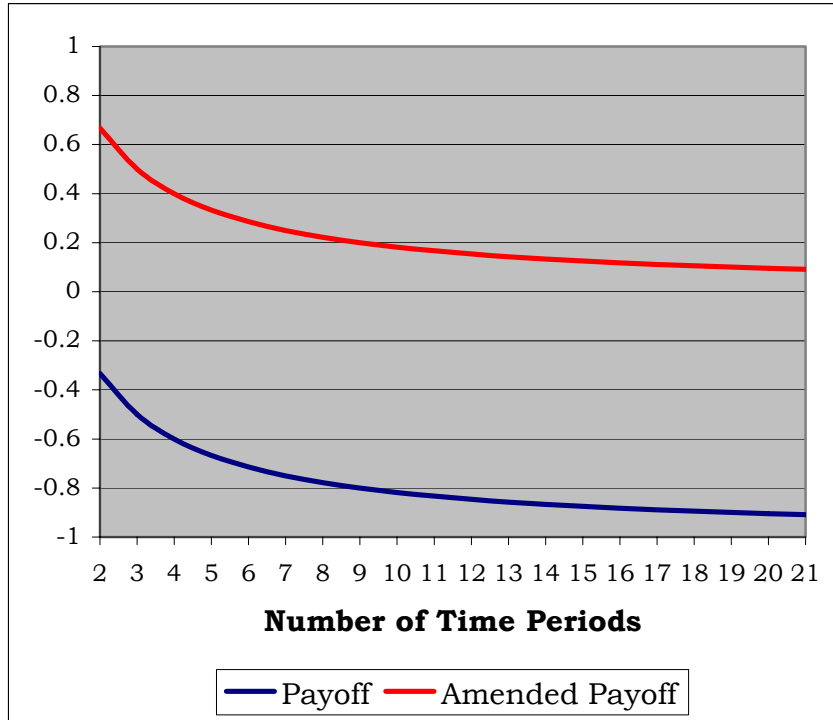
Figure 2.10: Payoffs and Amended Payoffs (v_γ) for the Inspection Game with $N = 1, 2, ..., 21$

Suppose we have t force design elements and the mth force design element has the ability to inspect the area of operations once in every N_m time periods. As we are working with negative numbers, we may set an amended payoff value

$$\rho_{\langle ijklm \rangle} = \omega + v_\gamma \text{ for } N_m \qquad (2.28)$$

where $\omega > 1$ in order to obtain a positive scale. Again we find $v_{\langle ijklm \rangle}$ by using (2.16).

We prefer the measure v_γ to the other obvious measure, $1/N$, as the first measure takes cognisance of the force design elements optimal strategy whereas the latter measure only considers the frequency with which patrol can be done in determining the degree to which the force design element is contributing to the enablement of its operating system.

3.1.5.   Conclusion

In the preceding examples, we have endeavoured to show how analytical methods can be used to find values for $\rho_{\langle ijklm \rangle}$ and $v_{\langle ijklm \rangle}$. To demonstrate the methods, we have illustrated thse by

- an example of using comparative statistics;

- a detection model for search and rescue at sea;

- a weapon mix problem; and

- an inspection game.

In all of these illustrations, the analytic nature of the technique leads to quantifiable and justifiable distinction between the various values for $\rho_{\langle ijklm \rangle}$ and $\upsilon_{\langle ijklm \rangle}$.

The more complex the problem becomes, the more difficult it becomes to model it analytically. A boundary for complexity exists where it becomes infeasible to model such problems analytically. Moreover, a high degree of complexity may also result in high costs to research the problem to the degree to which it may become possible to construct an analytical model thereof. In these cases, it might be advantageous to model the problem as a heuristic.

3.2.   HEURISTIC METHODS

Winston[12] defines a *heuristic method* as a method to solve a problem by trial and error when an algorithmic approach is impractical.

He uses the travelling salesman's problem to point out that to use the branch and bound method to solve this problem for a large amount of cities may require such large amounts of computer time that the normal travelling salesman will not be able to make use of this analytic method. However, he may use a method such as the nearest neighbour heuristic to solve his problem with, hopefully, near optimal results.

In order to gain some confidence in heuristic methods, Winston[13] proposes that there are three methods for evaluating heuristics. They can be summarised in the following list:

- Performance guarantees.

- Probabilistic analysis.

- Empirical analysis.

A performance guarantee for a heuristic gives a worst bound on how far away the heuristic is from optimality. Travelling salesman problems have been constructed where, for *r* cities, the nearest neighbour heuristic yields a tour that is *rz* long and where *z* is the optimal tour length. Thus, we may consider the heuristic to perform poorly. However, for a

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[12] Winston, W.L., *Operations Research - Applications and Algorithms*, 3 ed., Belmont, Ca: Duxberry, c1994, p. 526.
[13] *Ibid.*, p. 528.

symmetric travelling salesman problem satisfying the triangle inequality, $c_{ij} = c_{ji}$ where c_{ij} is the distance between the ith and the jth city and $c_{ik} \leq c_{ij} + c_{jk}$ for all i, j and k, it has been shown that the tour length given by the nearest neighbour heuristic cannot exceed $2z$.

Probabilistic analysis is an evaluation of the heuristic output and in this case it assumes that the location of the cities follows some known probability distribution. The for every solution by the heuristic we may compute

$$R = \frac{E(z)}{d_T}$$

where R is the ratio between the expected value of the optimal solution and the distance travelled by following the heuristic. The closer R becomes to one the better is the solution.

Empirical analysis allows for the comparison of d_T directly with known z. Golden[14] *et al* reports that for 100 city travelling salesman problems, the nearest neighbour heuristic produced tours where, on average, $d_T \approx 1.15z$. Thus, from empirical analysis, it is suggested that the nearest neighbour heuristic produces better results for the travelling salesman problem than a performance guarantee would suggest.

In the remainder of section 3.2 we shall discuss two major heuristic methods that may be employed to find values for $\upsilon_{\langle ijklm \rangle}$ and $\rho_{\langle ijklm \rangle}$. First, we shall discuss the use of war games and secondly, we shall illustrate the use of simulation by using two examples as a tool to find these values.

These two methods are the two most widely used methods in military research of this nature. They allow for the accurate modelling of complex situations. The two heuristics suffice as examples as they adequately demonstrate the use of heuristics to find values for $\upsilon_{\langle ijklm \rangle}$ and $\rho_{\langle ijklm \rangle}$.

3.2.1.   War Gaming

Jaiswal[15] has provided the flow diagram in Figure 2.11 that depicts the flow of information within a war game. He maintains that the methodology is, in the main, the same for games in the land, air and maritime battle spaces.

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[14] Golden, B., Bodin L., Doyle, T and Steward, W., Approximate Travelling Salesman Algorithms, *Operations Research* 28, 1980, pp. 694-712.
[15] Jaiswal, *op. cit.*, p 96-102.

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                    ┌─────────────────────┐
                    │ Organisational Data │
                    │    Equipment/       │
                    │     Weapon/         │
                    │  Ammunition Data    │
                    │   Terrain Data      │
                    │ Environmental Data  │
                    └─────────────────────┘
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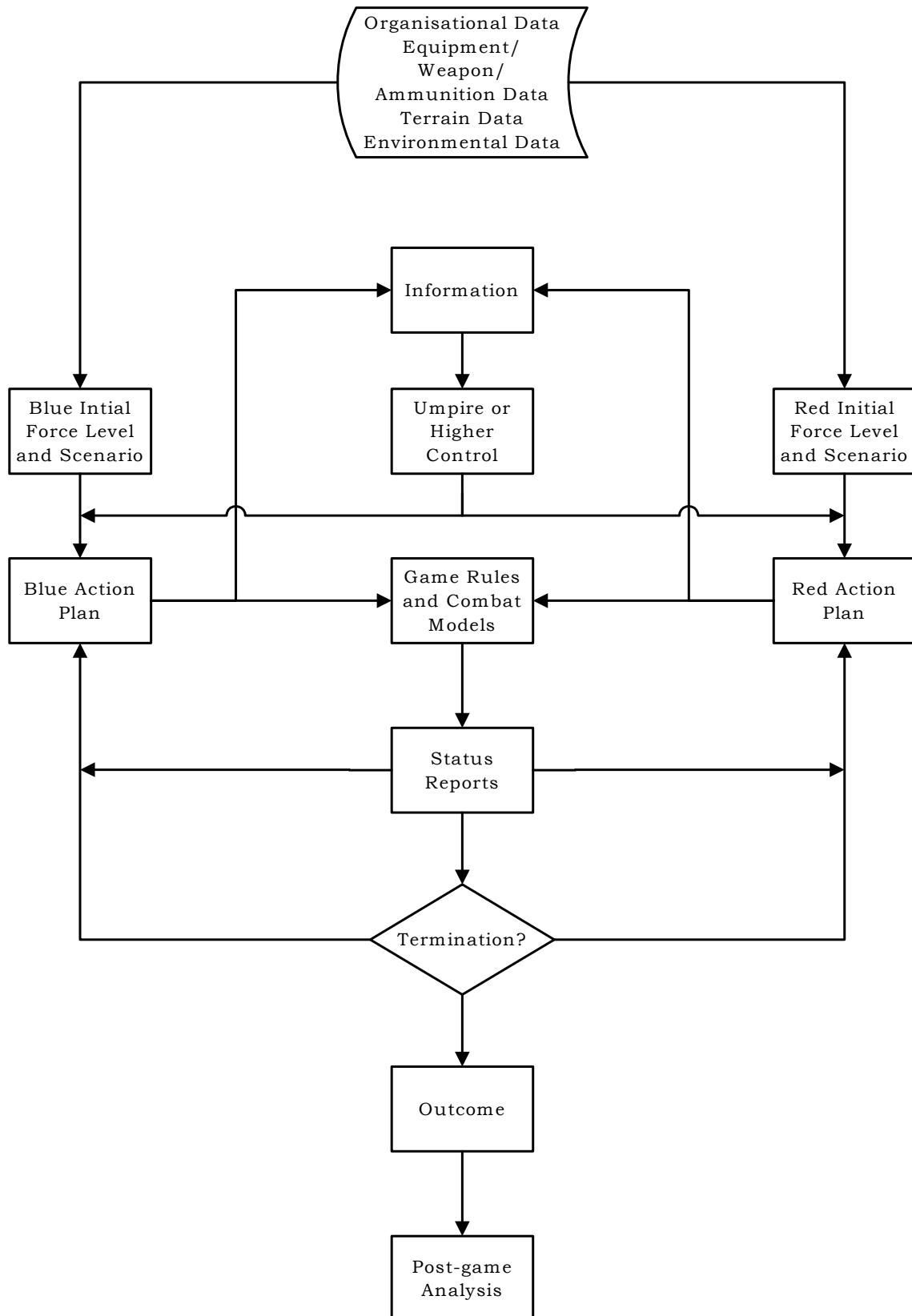
Figure 2.11: Flow Diagram for a War Game

Although the basic war gaming methodology is the same for the land, air
and maritime battle spaces, the array of weapons, sensors, organisational

structure, environmental parameters and terrain vary significantly. A war game consists of a database, a set of game rules and combat resolution models. The outcome of a game is normally expressed in terms of the accomplishment of military objectives that could include one or more of the following non-exhaustive list:

- Gain of Territory.

- Delay of Opposing Force Action.

- Defence of a Locality.

- Casualties.

- Damage.

The database is organised to input and retrieve data about the organisational structure, equipment, weapons, ammunition, terrain and the environment. It is to be noted that, in order to support the war game, the data requirements are comprehensive and complex.

After receipt of their scenarios, the players, normally called *Blue Force* and *Red Force*, draw up their action plans to achieve their objectives. The plans are now simulated by means of game rules and combat resolution models. The output from the simulation is relayed back to the players by means of status or situation reports. On receipt of these, the players might modify their action plans so as to take the run of the war into account. Also, the status reports may indicate that the desired objectives were reached and the war game will be terminated.

On termination the outcome documentation for the post-game analysis is prepared. Pre-defined measures of effectiveness are calculated so as to allow for the comparison of successive games and the quantification of the findings. In terms of our requirement to quantify the degree to which force design elements, operating systems and task forces contribute to their next higher vertices in M, these measures of effectiveness would address the force design elements, operating systems and task forces regarding rates of advance, percentage casualties, exchange ratios, number and depth of penetrations of the opposing force's defence, number and size of forces held in reserve, proportion of the reserve committed to action, time required to reconstitute a reserve, time delays imposed on the opposing force, force totals and force ratios.

Note that the concerns voiced in Chapter 1 are still regarded as valid. A war game represents only one game theoretical strategy amongst a vast array of other strategies. Thus, a war game quantifies that one strategy only and as such, little confidence can be placed in the measures of effectiveness that was generated. Only after many war games were played, can some reliance be placed on the findings. The problem is that

war games are manpower and time intensive and for that reason, not many replications of the game will be generated.

3.2.2. Simulation

Law and Kelton[16] makes the case that although analytical methods deliver exact solutions, they are often not able to handle real world complex problems. They state that many systems are highly complex so that valid mathematical models are themselves complex, precluding any possibility of an analytical solution. They propound that in these cases, simulation might be a better technique.

Against the background of the simulation process diagram in Figure 2.12, we[17] suggest a ten-point simulation methodology.
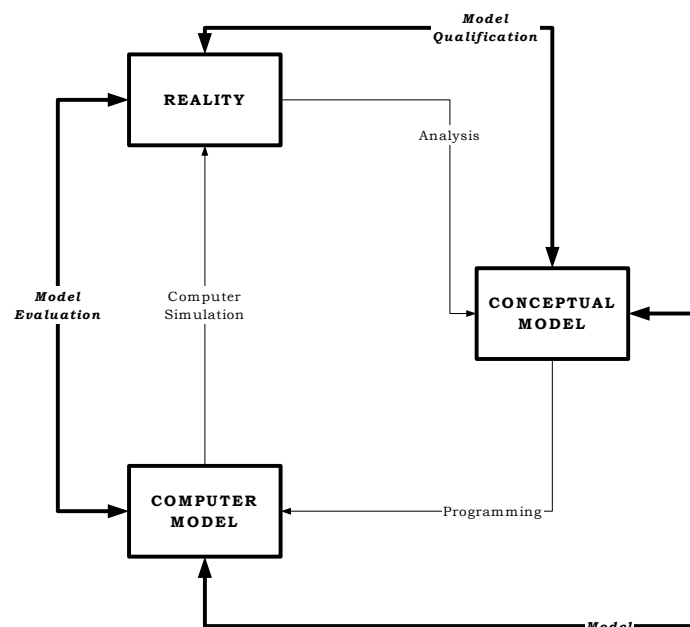
Figure 2.12: The Simulation Process

The ten-point simulation methodology is given in Figure 2.13. Note that in the building of the model, the model parameters and the validation of the model should take place against a real-life data benchmark. Also, the methodology is iterative. Whenever the sub-system does not deliver an output of the required quality, the methodology takes you back to the appropriate sub-system. For example, if the computerised model does not pass the program verification process, the analyst is required to go back to the programming of the model on a computer.

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[16] Law, A.M. and Kelton, W.D., *Simulation Modeling & Analysis.* 2 ed., New York: McGraw-Hill, 1991, p. 6.

[17] Engelbrecht, G.N., *Simulation: study guide 1 for OPS303-Q.* Revised edition, Pretoria: University of South Africa, 2001, p. 6.

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┌─────────────────────────┐
│   Formulate the problem │
│    and plan the study   │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│  Build a conceptual model│ ◄──
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│     Find the model      │
│      parameters         │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│  Program the model on a │
│       computer          │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│  Verify the computerised│
│        model            │
└─────────────────────────┘
            │
            ▼
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│     Validate the model  │ ◄──
└─────────────────────────┘
            │
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│  Design experiments to be│
│   used by the model     │
└─────────────────────────┘
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            ▼
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│   Carry out experiments │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│   Analyse the results and│
│     write a report      │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│    Implement results    │
└─────────────────────────┘
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Real life and data

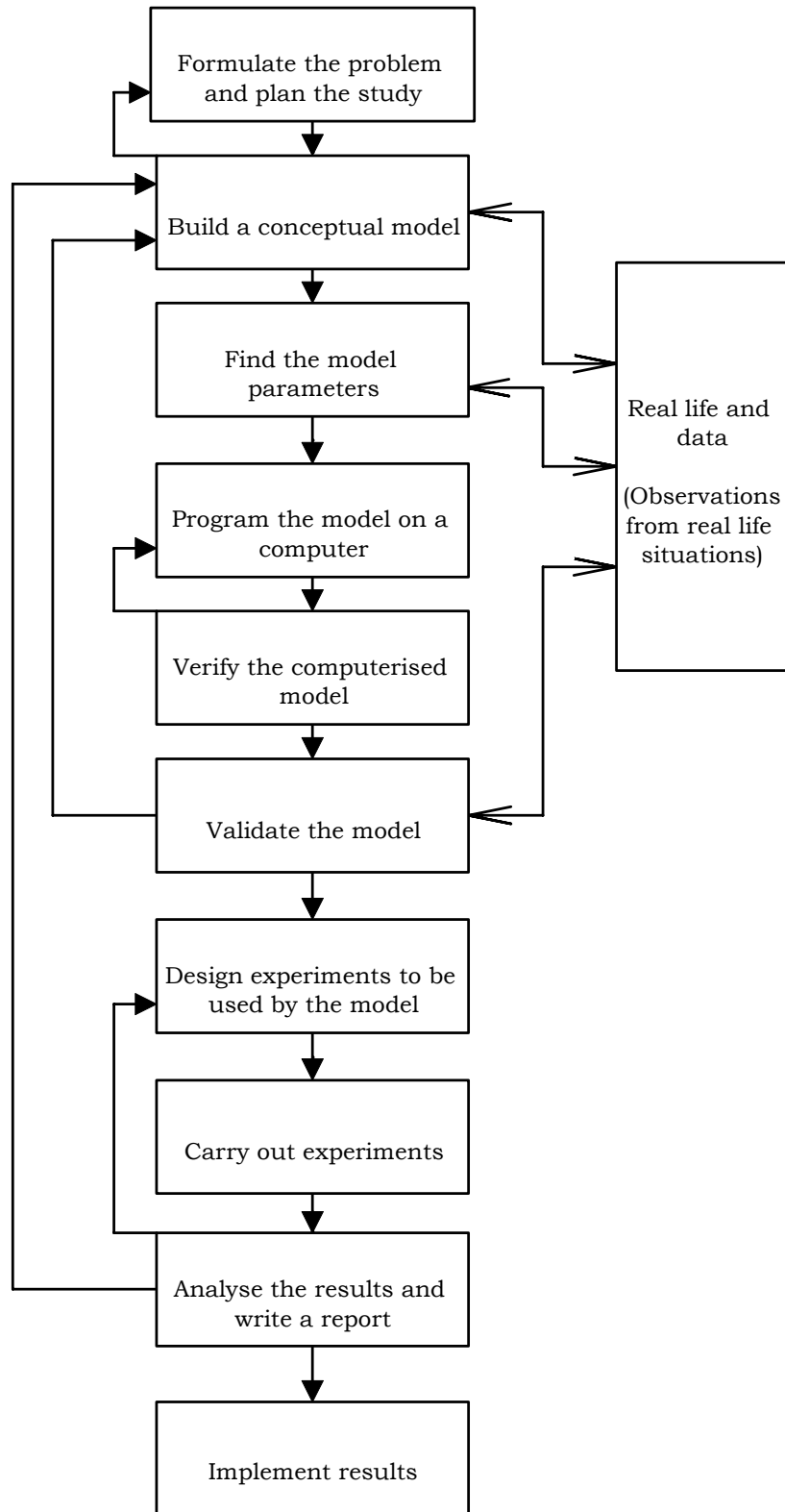(Observations from real life situations)

Figure 2.13: A Ten-point Simulation Methodology

Likewise, if the model does not pass validation, the process requires the analyst to re-look the conceptual model. Two examples follow.

3.2.2.1.   *Warship Simulation Model*

The Institute for Maritime Technology[18] has developed a warship simulation model to compare the combat effectiveness of various types of ships or ships with different combat suites on board. The simulation model was aptly named COMPARE.

The programming of a scenario based on some naval task did the evaluations. This scenario was then repeatedly simulated for *n* times. The simulation model contained a mixture of deterministic and Monte Carlo techniques. By setting up combat measures of effectiveness for the entities under consideration and incrementing their respective values at the *n* iterations of the model, estimates of these measures of effectiveness may be determined.

In developing COMPARE, all of the relevant objects had to be modelled. In order to ascertain the scope of the simulation, the non-exhaustive list of objects and sub-objects *et cetera* relating to a surface ship are given directly below.

```
Surface Ship
        Movement
                Course
                Speed
                Alter Course
                        Rate
                        Advance
                        Transfer
        Detection
                Visual
                Radar
                        Surface Search
                        Air Early Warning
                        Navigation
                Sonar
                Electronic Warfare Equipment
                        Electronic Intelligence Equipment
                        Communications Intelligence Equipment
        Action Information
        Weapons
                Surface-to-Surface Missiles
                Surface-to-Air Missiles
                Guns
                        Medium range guns
                        Close range guns
```

---

[18] Kidd, M., *Software Requirement Specification for Warship Effectiveness Model*, Document: P0036-000000-423, Simon's Town: IMT, 2001.

COMPARE allows for the evaluation of a wide variety of surface ships, submarines, maritime patrol aircraft and maritime strike aircraft.

The output from COMPARE can readily be used to find estimators of $\upsilon_{\langle ijklm \rangle}$ and $\rho_{\langle ijklm \rangle}$. The nature of the software also allows for the determination of confidence intervals for $\upsilon_{\langle ijklm \rangle}$ and $\rho_{\langle ijklm \rangle}$.

3.2.2.2.   *Higher Level Military Simulations*

Military simulations can be classified into weapon or sensor system, single platform, task group, mission analysis and theatre level simulations[19]. Hoebner[20] describes a simulation of strategic bomber penetration, the Advanced Penetration Model, hereinafter APM. This very complex model was aimed at simulating the mission of the strategic bomber and took about ten years to be developed.

APM allows for offensive as well as defensive systems and operates at the operating system and military task level. In order to improve the reliability of its outputs, even force design elements were included in the simulation. Thus, in terms of M, the APM would theoretically allow for the finding of $\upsilon_{\langle \varphi \rangle}$ and $\rho_{\langle \varphi \rangle}$ at the force design element, operating system and military task level.

The scope of APM is such that it allows for the following numbers of force design elements:

Offensive Systems

650 × Bombers
650 × Tankers
5,000 × Cruise Missiles
5,000 × Nuclear Devices
5,000 × Precursor Vehicles

Defensive Systems

3,500 × Air Early Warning Aircraft as well as Surface-to-Air Missile, Ground Control of Interceptor and Electronic Warfare sites
4,000 × Target Complexes
Unlimited Fighter Interceptors

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[19] Jaiswal, *op. cit.*, p. 81.
[20] Hoebner, *op. cit.*, pp. 84–105.

According to a briefing at the USAF headquarters[21] during 1978, APM simulates the mission in seven main phases. These phases are depicted in Figure 2.14.
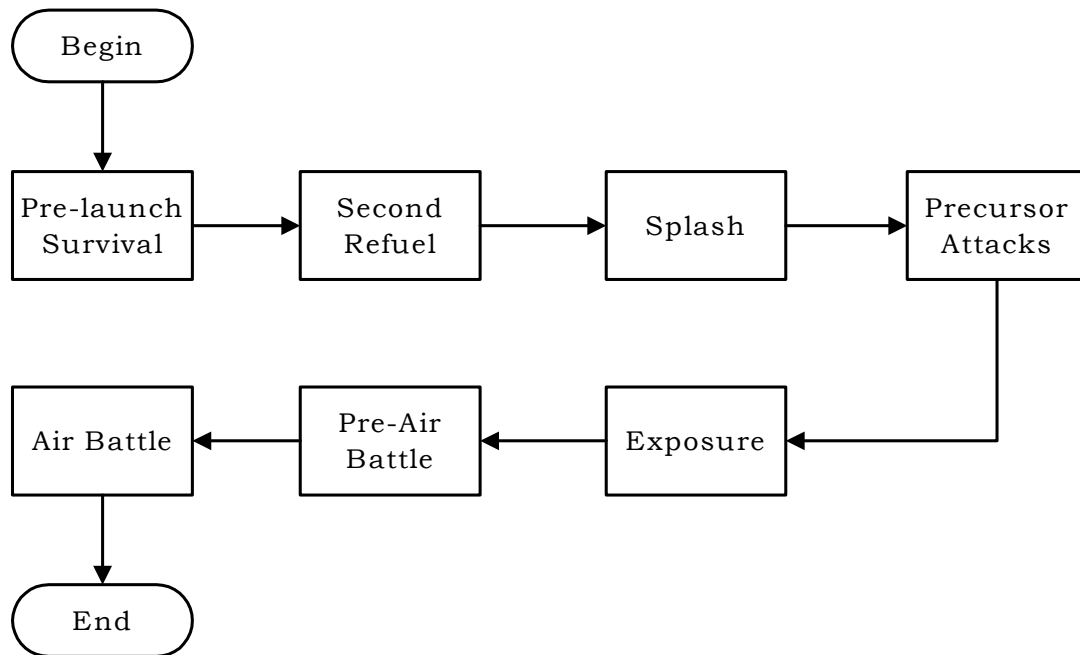

Figure 2.14: APM Simulation Phases

In the pre-launch survival phase, intercontinental cruise ballistic missiles, cruise missiles and even saboteurs attack the bomber base. The model takes into account the user-specified alert status of forces, characteristics of the attack and the warning received by the bomber aircraft. The pre-launch survivability figure of merit, P_{LS}, is a function of the aircraft's take-off time, fly-out speed and hardness to nuclear effects.

The second refuel phase matches surviving bomber's fuel requirements with surviving tanker's offload capabilities. The splash phase computes the point in the planned flight path at which each incompletely refuelled bomber will run out of fuel. Note that the events in the second refuel phase and the splash phase are directly influenced by P_{LS}.

The precursor phase allows the user to assign ballistic missiles to degrade the opposing force's air defences before the bombers arrive. The user specifies the types of missiles, numbers to be fired and yields. The simulation calculates weapon effects and determines which defences were neutralised.

During the exposure phase the planned flight path of each of the penetrating bombers is pre-processed to calculate its exposure to detection and attack during the flight towards its target area. It includes detection by the opposing force's Air Early Warning aircraft, radar and

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[21] Hoebner, *op. cit.*, p. 94.

electronic warfare and attack by the opposing force's air defences including, *inter alia*, combat air patrols, interceptors and surface-to-air missiles. The penetrator's altitude, stealth and electronic warfare capabilities are weighed up against the opposing force's detection and electronic warfare capabilities.

The pre-air battle phase generates no new events, but consolidates all the events that were previously generated so as to position the penetrating bombers and the opposing force's air defences. It is a fully automated system for the time-ordering of all bomber events from point of entry to the defended air space to point of exit and the tabulation of the identification, characteristics and capabilities of all offensive and defensive elements.

The air battle phase simulates the interaction of the bombers and the air defences over the opposing force's defended air space. It is a time-sequenced process of the events planned by the mission planner and modified by the various simulation phases and associated processors. Each event will generate subsequent events on the appropriate deterministic or probabilistic basis. For example, the detection of a bomber on radar or *detection event* by the opposing force will trigger a request for interceptors or *fighter-request event*. This phase continues until all surviving bombers have left the defended airspace.

In order to simulate the air battle phase, seven air battle event processors support the simulation. They are as follows:

- Command and Control.

- Radar.

- Air Early Warning.

- Interceptor.

- Surface-to-Air Missile.

- Nuclear Effects.

- Penetrator.

Each of these processors generates figures of merit or measures of effectiveness for all force design elements, operating systems and the military task itself. Thus, we note that the finding of values for $v_{\langle \varphi \rangle}$ and $\rho_{\langle \varphi \rangle}$ at the force design element, operating system and military task level becomes feasible. However, note that such a simulation requires a vast amount of man-hours, computers, consultation, preparation and cost. At

the same time, as in most such cases, these simulation models are so complex that their proper validation becomes problematic.

3.2.3. Conclusions about Heuristic Methods

The following conclusions about heuristic methods are made:

- Because of the complexity of real-life situations, it is more likely that heuristic methods may be employed in determining values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$ as insufficient modelling techniques are available for analytic methods.

- War games and simulation techniques produce statistics that can be readily used in determining values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$.

- Because there are little or no replications of war games, it is very likely that little or no confidence may be placed on the determined values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$.

- Simulation generally allows for sufficient replication to construct confidence intervals for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$.

- Complex simulation models are difficult to validate.

3.3. JUDGEMENTS

When the situation mitigates against the use of analytical or heuristic methods, such as when time or funding constraints prohibit this or when the complexity of the problem is such that it cannot be modelled, the judgement of professional sailors, soldiers or airman may be used to determine values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$. For example, if one were to ask a soldier what contribution to the command and control operating system is made by the Brigade HQ (Tactical), Regional Task Force HQ (Operational) and the HQ at Chief of Joint Operations (Strategic) respectively, he may, based on his experience, make such a judgement. If one found that, in general, soldiers do not differ significantly in their views about this, the judgements may be accepted as the values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$. In general, there are many methods that may be used to facilitate quantifying the judgements of professional men in determining values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$. We shall investigate the following three such methods:

- Simple Multi-factor Decision Process.
- Simple Multiple-attribute Rating Technique.
- Analytic Hierarchy Process (AHP).

3.3.1. Simple Multi-factor Decision Process[22]

Suppose we have to decide to what extent some force design elements enable an operating system. We label the n force design elements F1, ..., Fm and the operating system O$_S$. In this process we shall consider m factors in order to rate the force design elements. We label the factors or considerations C1, ..., Cn.

Now, we rate every force design element according to factor C1 against some predetermined scale and we normalise the result afterwards. Then we write the normalised values in the first column of an $m \times n$ matrix, A. We repeat the process for the remainder of the force design elements and write the results in the successive columns of A. In the process we fully populate A.

On completion we rate the factors, C1, ..., Cn, for their contributions against some predetermined scale and we normalise the result afterwards. This result is written in the vector x. Now we determine the vector y so that

$$Ax^{\mathrm{T}} = y \tag{2.29}$$

The elements of

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix} \tag{2.30}$$

contains the values for $v_{\langle ijklm \rangle}$.

We note that as the various scales may differ significantly for the various factors, normalisation in the columns of A is necessary in order to allow for the relative importance of the m factors to be taken account of correctly. This method judges every force structure element against every factor on its own. Thus, the judgements themselves are not relative to one another. The comparison relative to one another is achieved by the use of (2.29).

We have previously used a variation on this method where, for every factor, a hundred points were divided between the alternatives (force structure elements in our case) simultaneously. This was done because the panel found it difficult to judge every option on its own. They were

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[22] Render, B. and Stair, R.M., *Quantitative Analysis for Management.* 4 ed., Boston, Ma: Allyn and Bacon, c1991, pp.199–200.

more comfortable to weigh the various alternatives against each other. It is suggested that to employ pair-wise comparisons might have been more fruitful as it would have allowed for the determination of inconsistency as described in paragraph 3.3.3.

The Simple Multi-factor Decision Process underlies both the Simple Multiple-attribute Rating Technique and the Analytic Hierarchy Process to some extent. However, this method is useful in that it does not require sophisticated software and it may even be gainfully employed as a back-end process for both the analytical and heuristic methodologies.

3.3.2. Multiple-attribute Rating Technique

During 1986, Von Winterfeldt and Edwards[23] first described the Multiple-attribute Rating Technique (SMART). SMART is a multi-criteria decision analysis tool whereby we evaluate a finite number of decision alternatives (n) under a finite number of performance criteria (m) [24].

SMART relies on simple additive models, numerical estimation techniques for eliciting single-attribute values and ratio estimation of weights. The technique was initially justified by its simplicity. Later studies demonstrated the robustness of additive multi-attribute models. Still later, it was given theoretical support because of the inclusion of difference measurement. By 1986, SMART had developed into a collection of techniques rather than a single process. The main communality between the techniques is their reliance on direct numerical estimation methods. However, the use of more sophisticated swing weights and single-attribute curve-drawing procedures are becoming common[25].

A method for finding values for $v_{\langle ijklm \rangle}$ could, based on the generally accepted SMART methodology[26], comprise the following steps:

- Identify the vertex $\langle \varphi \rangle$ in M that must be enabled.

- Identify the n vertices, $\langle \varphi 1 \rangle$, …, $\langle \varphi n \rangle$, in M that enable the vertex $\langle \varphi \rangle$.

- Identify the relevant dimensions of value or factors to be considered.

- Rank the dimensions in order of importance.

[23] Von Winterfeldt, D. and Edwards, W., *Decision Analysis and Behavioural Research,* Cambridge: Cambridge University Press, 1986, pp. 278–287.

[24] Lootsma, F.A., *Multi-Criteria Decision Analysis via Ratio and Difference Judgement.* Dordrecht: Kluwer, c1999, p. 15.

[25] Lootsma, F.A., Mensch, T.C.A. and Vos, F.A., Multi-criteria Analysis and budget reallocation in long-term research planning, *European Journal of Operations Research* 47, 1990, pp. 293–305.

[26] Lootsma, c1999, *op. cit.,* p. 278.

- Make ratio estimates of the relative importance of each dimension relative to the one rank lowest in importance.

- Normalise the dimension importance weights.

- Measure the relative contribution of the various $\langle \varphi i \rangle$ for every dimension on an appropriate scale.

- Normalise the relative contributions for every dimension.

- Calculate the values for the various $v_{\langle ijklm \rangle}$.

Note that an appropriate scale means a scale that may be easily interpreted by the participants and that is relevant to the situation. For example, when evaluating the maximum continuous speed of a ship, an appropriate scale is expressed in knots. Metres per second or kilometres per hour would not suffice for sailors. However, taking the utility of the various speeds into account, a transformation by means of an exponential utility function, (2.17), may lead to an evaluation of superior quality, as a difference of one knot at ten knots would be evaluated as having more utility than same difference at thirty knots. Such a scale would classify as a single-attribute curve-drawing procedure.

3.3.3. Analytic Hierarchy Process

Thomas L. Saaty[27] first described the Analytic Hierarchy Process (AHP) during 1980. It is based on the notion of the Simple Multi-factor Decision Process. The main difference is that every alternative is compared with every other alternative regarding every factor. This method is referred to as pair-wise comparisons. Suppose we have n alternatives, then, when making pair-wise comparisons, we record the comparisons in a matrix, B where because of the assumption of complete consistency

$$
B = \begin{bmatrix}
1 & b_{12} & b_{13} & \cdots & b_{1n} \\
\frac{1}{b_{12}} & 1 & b_{23} & \cdots & b_{2n} \\
\frac{1}{b_{13}} & \frac{1}{b_{23}} & 1 & \cdots & b_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\frac{1}{b_{1n}} & \frac{1}{b_{2n}} & \frac{1}{b_{3n}} & \cdots & 1
\end{bmatrix}.
$$

The diagonal elements in B are all equal to 1. Moreover, B displays a "symmetry" around its diagonal elements where the ijth entry is the inverse of the jith entry. Saaty makes use of this phenomenon to

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[27] Saaty, T.L., *The Analytic Hierarchy Process*, New York: McGraw-Hill, c1980.

calculate the eigenvector of the matrix in the following relatively simple two step manner[28].

- Step 1: Normalise the column vectors in B and denote the elements of $B_{\text{Normalised}}$ as β_{ij}.

- Step 2: Write down the eigenvector, ε, of B such that

$$\varepsilon = \begin{bmatrix} \dfrac{1}{n}\sum_{j=1}^{n}\beta_{1j} \\[2ex] \dfrac{1}{n}\sum_{j=1}^{n}\beta_{2j} \\[2ex] \vdots \\[2ex] \dfrac{1}{n}\sum_{j=1}^{n}\beta_{nj} \end{bmatrix}. \tag{2.31}$$

The vector (2.31) can now be inserted into the appropriate elements of (2.29) for final computation. Saaty has also prescribed a figure of merit, the consistency index, for checking consistency in the making of entries into B.[29] To find the consistency index value, the following three-step method is used:

- Step 1: Compute $\chi = B\beta^{\mathrm{T}}$.

- Step 2: Compute $\lambda_{\max} = \dfrac{1}{n}\sum_{i=1}^{n}\dfrac{\chi_i}{\beta_i}$.

- Step 3: Compute the Consistency Index by $\mathrm{CI} = \dfrac{\lambda_{\max} - n}{n - 1}$.

As a general rule, if the CI is below 0.1, then the inconsistency in the model is acceptable. If not, the pair-wise comparisons should be revisited until CI < 0.1.

In order to use the AHP for the purpose of finding values for the various $v_{\langle \varphi i \rangle}$ we use the following method:

- Step 1: Compare all the vertices $\langle \varphi i \rangle$ in a pair-wise manner with due regard for the degree to which they enable $\langle \varphi \rangle$ against the factor under consideration. In the process, complete B.

- Step 2: Find the eigenvector of B.

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[28] Winston, *op.cit.*, p. 801.
[29] Saaty, *op. cit.*, pp. 83–84.

- Step 3: Calculate CI. If CI < 0.1, then go to Step 1, else go to Step 4.

- Step 4: Place the eigenvector of B in its correct context within (2.29).

- Step 5: If more factors need to be considered, go to Step 1, else go to Step 6.

- Step 6: Repeat the method to find the eigenvector to be placed within y in (2.29).

- Step 7: Solve (2.29).

In order to facilitate the pair-wise comparison process, the benchmark in Table 2.3 can be used to determine the relative importance, likelihood or preference for one entity over another.

Value of b_{ij}	Interpretation
1	Entities i and j are of equal importance, likelihood or preference.
3	Entity i is weakly more importance, likely or preferred to entity j.
5	Entity i is strongly more important, likely or preferred to entity j. Experience and judgement supports the view.
7	Entity i is very strongly more important, likely or preferred to entity j. The view is supported by demonstration.
9	Entity i is absolutely more important, likely or preferred to entity j. There is extensive evidence to support this view.
2,4,6,8	Intermediate values that can also be assigned.

Table 2.3: Interpretation of values assigned in pair-wise comparisons

The AHP has been the centre of wide academic debate. A number of authors have criticised the AHP for a variety of reasons. Amongst others, Belton, Stewart, Dyer and Lootsma have all criticised the AHP[30].

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[30] Belton, V. and Stewart, T.J., *Multiple Criteria Decision Analysis - An Integrated Approach*. Boston, Ma: Kluwer, 2002, pp. 157–159; Stewart, T.J., A Critical Survey on the Status of Multiple Criteria Decision Making Theory and Practice, *Omega, International Journal of Management Science*, Vol 20, No 5/6, 1992, pp. 573–575; Dyer, J.S., Remarks on the Analytic Hierarchy Process, *Management Science*, Vol. 36. No. 3, 1990, pp. 249–258; Lootsma, F.A., Letter to the Editor, ORiON, Vol. 5, No. 1, 1988, pp. 52–54.

Harker and Vargas[31] list the following four areas of concern regarding the AHP:

- No axiomatic foundations.

- Ambiguity of the questions asked.

- The ratio scale in Table 2.3 is questionable.

- Possibility of rank reversal amongst present alternatives when new alternatives are added to the problem.

Jaiswal[32] sums up the view of the proponents of AHP regarding the concerns raised by Harker and Vargas in the following manner:

- The first criticism is no longer valid as Saaty has given the axiomatic foundations of the AHP[33].

- The ambiguity of the questions asked is a failure of the analyst or facilitator to frame meaningful questions rather than a failure of the AHP.

- The use of a ratio scale in AHP is a departure from traditional methods. Normally decision analysts will employ interval measures or direct assessment methods. Jaiswal considers the scale adequate to capture the preferences in most cases. Also, nothing prohibits the analyst, when required, from expanding on the scale.

- The proponents of AHP defend rank reversal as natural.

However, the debate still continues and Jaiswal[34] reports that despite this, the AHP is being used in many decision-making problems in which alternatives are to be ranked based on some criteria of performance. The AHP has been used as a decision support tool in the military for

- war games;

- analysis of conflicts;

- Star Wars;

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[31] Harker, P.T. and Vargas, L.G., Theory of Ratio Scale Estimation: Saaty's Analytic Hierarchy Process, *Management Science*, Vol. 33, No. 11, 1987, pp. 1383–1403.
[32] Jaiswal, *op. cit.*, pp. 227–230.
[33] Saaty, T.L., Axiomatic Foundations of the Analytic Hierarchy Process, *Management Science*, Vol. 32, No. 7, 1986, pp. 841–855.
[34] Jaiswal, *op. cit.*

- nuclear disarmament; and

- arms requirements programmes for defence forces.

3.3.4.   Conclusions on Judgement Methods

The use of military judgement in determining values for $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$ in lieu of analytical or heuristic methods is prescribed when the latter methods are not available or the problem is of such a nature that the cost of the research and other related factors prohibit their use. However, obtaining valid scores from judgements by professional officers may prove to be difficult. They may experience the questions to be ambiguous or simply misunderstand them, which, in turn, may lead to much less than optimal results.

3.4.   CONCLUSIONS ABOUT QUANTIFYING RELATIONSHIPS WITHIN A MILITARY STRATEGY

We have shown that there are three distinct categories of methods that may be used to quantify $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$. They are analytical methods, heuristic methods and the use of judgements. From the discussion in this section we conclude that analytical methods are the preferred way of quantifying $v_{\langle\varphi\rangle}$ and $\rho_{\langle\varphi\rangle}$. However, for a variety of reasons heuristic methods may be used. The main reason being that very often the ability to model complex environments mathematically does not exist. Finally, if heuristic methods are not viable, the judgement of professional officers may be considered to be an adequate substitute.

4.   THE QUANTIFICATION OF A MILITARY STRATEGY

The aim of this section is to demonstrate the use of the concepts and the methodology for finding the values of the variables described in section 2. We shall proceed by

- developing a theoretical military strategy based on the South African example;

- determining values for the relations (2.3) and (2.4) by obtaining the judgements of a panel of professional SANDF officers;

- use $v_{\langle\varphi\rangle}$ to calculate (2.6), (2.8), (2.9) and (2.10); whilst at the same time,

- present the importance of these figures to management.

4.1. DEVELOPING A MILITARY STRATEGY FOR SOUTH AFRICA

In developing a theoretical military strategy for South Africa, we shall take cognisance of South Africa's constitution and the Department of Defence's strategic plan for the financial years 2002/03 and 2004/05. The development was undertaken under the leadership of the author and by a panel of professional SANDF senior officers from all the Services. A list of these officers is at Appendix E.

The strategy was developed in line with the relationship diagram in Chapter 1, Figure 1.3. Therefore, we shall develop a military strategy by developing its ends, ways and means and the relationships between them. When the strategy's ways are developed, military missions and their associated military tasks will be defined and when the strategy's means are developed operating systems or capabilities together with their associated force design elements will be defined.

Linking the ends of the strategy to the military missions links the strategic ends and ways whilst linking the military tasks to the operating systems links the strategic ways and means.

4.1.1. The Ends of a military strategy

The Department of Defence's Strategic Plan[35] defines the following military strategic ends:

- Defence against Aggression.

- Promoting Security.

- Supporting the People of South Africa.

According to the plan, by defence against aggression is meant the provision of self-defence according to international law against any threat of aggression that endangers the stability of South Africa. To promote security is to provide internal and external deployment of military forces to enhance security in support of decisions by parliament. Also, by support to the people of South Africa is meant the provision of support to the population or other state departments in operations other than war by using the SANDFs collateral utility.

Recall that, in accordance with South Africa's Constitution[36], only the President, as head of the national executive, may authorise the employment of the defence force in

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[35] *South African Department of Defence Strategic Plan for FY 2002/03 to 2004/05*, Pretoria: Department of Defence, 31 January 2002, p. 4.
[36] South Africa. *Constitution of the Republic of South Africa,* Act 108 of1996, (as amended). Pretoria: Government Printer, p. 113.

- co-operation with the police service;

- defence of the Republic; or

- fulfilment of an international obligation.

We note that a military strategy's ends, as depicted in the Department of Defence's strategic plan are, in part, an interpretation of the Constitution. However, an analysis of the strategy's ends gives rise to the following concerns:

- The wording of the ends does not describe a required output. It simply states what must be done and not what must be achieved. For example, suppose the SANDF defends South Africa against an aggressor, and the country's territorial integrity is compromised. Does that then constitute an achieved military strategic end?

- The plan elucidates the second military strategic end by stating that to promote security is to provide internal and external deployment of military forces to enhance security in support of decisions by parliament. If this is read with the necessity to ensure the stability of South Africa, this military strategic end may lead to a specious argument that the military is responsible for the internal stability or law and order in South Africa. This should clearly not be the case. The international common practice is for defence forces to safeguard the sovereignty and territorial integrity of their countries with law and order being the domain of the police.

- South Africa's international obligations are not implied in the military strategic ends. For example, the country's commitments to the United Nations for the charting of the navigable waters in the region are not implied.

Bearing the aforesaid into account, we formulate, in M, the following South African military strategic ends:

$\langle 1 \rangle$:   South Africa's sovereignty remains intact.

$\langle 2 \rangle$:   South Africa's international obligations are fulfilled.

$\langle 3 \rangle$:   The SANDF's obligations internal to South Africa are fulfilled.

4.1.2.   The Ways of the Military Strategy

We shall handle the military strategy's ways in two steps. Firstly we shall define and link military missions to the military strategy's ends. Thereafter, we shall define and link military tasks to the military missions.

4.1.2.1.   *Military Missions*

Military missions are broad statements of how the strategic ends should be realised.

Priority	Missions
1	Co-operation with the South African Police Service. Borderline Control. Support Military Diplomacy. Special Operations. Disaster Relief and Humanitarian Assistance. Defence against an Information Onslaught. Maritime Support. VIP Transport. Regional Peacekeeping. Support to Government Departments. Regional Peace-making.
2	Regional Peace-building. Regional Humanitarian Intervention. Repelling of Non-conventional Onslaught. Presidential Tasks. Regional Disaster Relief and Humanitarian Assistance. Show-of-Force. Protection of Foreign Assets. Regional Peace Enforcement. Search-and-Rescue. Regional Search-and-Rescue. Repelling of Unconventional Onslaught.
3	Defence against Biological and Chemical Onslaught. International Peacekeeping. Pre-emptive Operations. International Humanitarian Intervention. International Peace-making. Regional Peace Observers. Repelling of Conventional Onslaught. International Peace Enforcement. International Peace-building. International Disaster Relief and Humanitarian Assistance. International search-and-Rescue. International Observers.

Table 2.4: Missions in the South African Military Strategy

The Department of Defence's strategic plan[37] defines 34 such missions. These missions have been prioritised in terms of risk where *risk* is defined an exposure to danger owing to the impact of the onslaught on the security of South Africa and the probability of the onslaught being encountered by South Africa[38]. The missions are listed in Table 2.4.

A careful analysis of these missions reveals some areas of concern. First, the stated missions are not of consistent complexity or order. This may prove to be problematic in that some of the missions could be regarded as tasks or even as lower order entities. For example, the observers referred to may well be some sub-set of a force design element and it would therefore be unwise to try and model it as a mission to accomplish some end.

Second, within the context of the plan, some of the missions might appear for completeness sake only. The repelling of conventional, unconventional and non-conventional onslaughts is a case in point. Whereas the necessity for the repelling of a conventional onslaught is supported, the necessity for repelling unconventional or non-conventional onslaughts is questioned.

In the case of unconventional onslaught; as the government of South Africa has the support of the majority of its people, such an event is highly unlikely. The sporadic bombings in the Cape and Gauteng attributed to People against Gangsters and Drugs and the Extreme Right respectively is a police task and they are able and willing to undertake this task. Moreover, given the ten-year span of the strategy, an unconventional onslaught cannot be foreseen. Also, it must again be emphasised that international common practice is for defence forces to safeguard the sovereignty and territorial integrity of their countries and to leave law and order to the police.

The same argument may be made for a so-called non-conventional onslaught. Organised crime in South Africa, unlike the situation in, for example, Columbia, is not a threat to the country's sovereignty and likewise, the police should deal with organised crime. Recall that, if required, the president may place the SANDF in service to co-operate with the police service. The latter may prove to be a substantial mission or task.

Third, some of the stated missions refer to aspects of the same mission concept. For example, when war is waged to repel an aggressor, it would, by necessity include pre-emptive operations, the defence against biological and chemical agents as well as defence against an information attack. These missions could be regarded as military tasks relating to the same mission.

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[37] *South African Department of Defence Strategic Plan. op. cit.,* pp. 4–5.
[38] *Ibid.*

Fourth, from the Department of Defence's strategic plan, the relationships between the strategic ends and ways or missions are not clear. These relationships are not stated explicitly within the plan. In fact, the plan suggests that the priorities for the 34 missions were derived by determining the mission's risk as an autonomous entity and that the relative importance of the military strategy's ends were not considered. If this is true, it could be considered a major flaw in the development of the military strategy as the requirements of multi-criteria decision analysis theory[39] indicates that the relevance of the strategy's ends must be taken into account.

We shall attempt to address these issues in the formulation of M at the mission and task levels. The following nine military missions relate to the three military ends:

Missions relating to $\langle 1 \rangle$: South Africa's sovereignty remains intact.

$\langle 11 \rangle$: Conduct Military Diplomacy.

$\langle 12 \rangle$: Wage War against an Aggressor.

Missions relating to $\langle 2 \rangle$: South Africa's international obligations are fulfilled.

$\langle 21 \rangle$: Conduct Disaster Relief in Africa.

$\langle 22 \rangle$: Conduct General Peace Diplomacy.

$\langle 23 \rangle$: Conduct Humanitarian Operations.

$\langle 24 \rangle$: Conduct International Search and Rescue.

$\langle 25 \rangle$: Conduct UN Charter Operations.

Missions relating to $\langle 3 \rangle$: The SANDF's obligations internal to South Africa are fulfilled.

$\langle 31 \rangle$: Support other Government Departments.

$\langle 32 \rangle$: Support the President of South Africa.

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[39] Belton, V. and Stewart, T.J., *op.cit.*, pp. 13–77.

4.1.2.2. *Military Tasks*

Military tasks define military missions in more detail and are required in order to assign means to the strategy's ways. The following 34 military tasks relate to the nine military missions:

Military Tasks relating to ⟨11⟩: Conduct Military Diplomacy.

⟨111⟩: Demonstrate Own Offensive Capabilities.

⟨112⟩: Safeguard Diplomatic Personnel.

⟨113⟩: Show-of-Force.

Military Tasks relating to ⟨12⟩: Wage War against an Aggressor.

⟨121⟩: Defence against Information Attack.

⟨122⟩: Defence against Psychological Attack.

⟨123⟩: Defence against Weapons of Mass Destruction.

⟨124⟩: Interdiction Strategic.

⟨125⟩: Neutralise Enemy in the Air Battle Space.

⟨126⟩: Neutralise Enemy in the Land Battle Space.

⟨127⟩: Neutralise Enemy in the Maritime Battle Space.

Military Tasks relating to ⟨21⟩: Conduct Disaster Relief in Africa.

⟨211⟩: Combating Natural Disasters.

⟨212⟩: Curtailing Spread of Disease in Livestock.

Military Tasks relating to ⟨22⟩: Conduct General Peace Diplomacy.

⟨221⟩: Assist in Peace-building.

⟨222⟩: Assist in Peace-making.

Military Tasks relating to ⟨23⟩: Conduct Humanitarian Operations.

⟨231⟩: Combating Epidemics in Africa.

⟨232⟩: Distribution of Food and Shelter.

Military Tasks relating to ⟨24⟩: Conduct International Search & Rescue.

⟨241⟩: Landward Search-and-Rescue in Africa.

⟨242⟩: Search-and-Rescue in the Southern Oceans.

Military Tasks relating to ⟨25⟩: Conduct UN Charter Operations.

⟨251⟩: Conduct Landward Blockade Operations.

⟨252⟩: Conduct Maritime Blockade Operations.

⟨253⟩: Enforce the Keeping of Peace Treaty Provisions.

⟨254⟩: Observe Keeping of Peace Treaty Provisions.

⟨255⟩: Police Population Movement.

⟨256⟩: Safeguard Key Points.

Military Tasks relating to ⟨31⟩: Support other Government Departments.

⟨311⟩: Antarctic Operations to support SANAE.

⟨312⟩: Borderline Control.

⟨313⟩: Conduct Search-and-Rescue within South Africa.

⟨314⟩: Disaster Relief and Humanitarian Assistance.

⟨315⟩: Hydrography and Charting.

⟨316⟩: Pollution Control at Sea.

⟨317⟩: Support the South African Police Service.

Military Tasks relating to ⟨32⟩: Support the President of South Africa.

⟨321⟩: Presidential Air Transport.

⟨322⟩: Presidential Health Support.

⟨323⟩: Presidential Protocol Requirements.

4.1.3.   The Means of the Military Strategy

The means of the military strategy may be divided into operating systems at the higher level and force structure elements at the lower level. The operating systems link the military tasks to the force design elements in the ranked tree representation, M.

4.1.3.1.   *Operating Systems*

Recall from chapter 1 that United States Army doctrine[40] prescribes six operating systems at the operational level of war. The military missions may be considered to exist at the strategic level of war whereas military tasks exist at the operational level of war. Moreover, the Task Forces charged with execution of the military tasks exist at the tactical level of war.

According to the referred to doctrine, the following operating systems should exist:

- Movement and Manoeuvre.

- Fires.

- Protection.

- Command.

- Intelligence.

- Logistics.

These operating systems contain the various force design elements that must be grouped together into higher order systems that should be considered at the operational level of war. The concept of operation systems relates to the notion of required capabilities for fighting the war. In this thesis we regard operating systems and military capabilities to be similar concepts.

Although these conceptual operating systems may be considered adequate for planning and execution at the operational and strategic levels within the US armed forces, their scope is too extensive for the more detailed requirements of preparing for war. The staff of the Chief of Joint Operations within the SANDF has decided on defining the following set of thirteen operating systems so as to manage the department's military capabilities in order to prepare for war:

- <u>Command and Control</u>. Command and Control embodies the leadership function within the war.

- <u>Manoeuvre and Direct Fire</u>. Manoeuvre and Direct Fire is the operating system that delivers firepower directly and it places itself in a position to deliver firepower by manoeuvre.

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[40] *Decisive Force: The Army in Theater Operations.* FM 100-7, Washington: Department of the Army, 1995, p. 5-0.

- Indirect Fire. Indirect Fire embodies all indirect weapons and fighter aircraft in the ground support role.

- Information Warfare. Information Warfare is the operating system that deals with the war in the cyber space. For convenience sake, Information Warfare includes psychological force design elements.

- Lift in the Battlefield. Lift in the Battlefield relates to the operating system that enables the movement of forces and commanders in the battle.

- Lift in the Theatre of Operations. Lift in the Theatre of Operations relates to the operating system that enables the movement of forces between battlefields in the same theatre of operations.

- Lift Strategic. Lift Strategic relates to the operating system that enables the movement of forces between the theatres of operations.

- Protection – Combat Search and Rescue. Combat Search and Rescue encompasses the operating system that, under combat conditions, search for and rescue own forces.

- Protection – Deployed Forces. The Protection of Deployed Forces operating system protects own forces that are deployed in the theatre of operations.

- Protection – Rear Areas. The Protection of the Rear Areas operating system ensures a safe rear area for own forces.

- Situational Awareness – Information Operations. Information Operations embodies the force design elements that collate and order information in order to compile the tactical, operational and strategic pictures.

- Situational Awareness – Reconnaissance, Surveillance and Intelligence. Reconnaissance, Surveillance and Intelligence constitute the operation system that provides information to the Information Operations operating system. It includes all sensors in and around the battlefield.

- Sustainment. The Sustainment operating system links the task force to the rear area in order to sustain the war effort.

All, or at least a sub-set, of these operating systems should link to all of the military tasks. Consider the vertex *Neutralise Enemy in the Land*

Battle Space, $\langle 126 \rangle$. By analysing this military task, we note that all of the operating systems relate to it. On the other hand, consider the vertex *Search-and-Rescue in the Southern Oceans*, $\langle 242 \rangle$. An analysis of this task indicates that the Command and Control and Combat Search and Rescue operating systems only might be sufficient.

The panel of officers exercised their judgement in deciding which operating systems are related to which military tasks. The result is contained in Appendix B.

4.1.3.2. *Force Design Elements*

The panel has identified 84 force design elements, most of which are currently part of the South African order of battle. To ensure a requisite force design in the model in terms of Assumption 2.1, some force design elements were added to the order of battle. These included, *inter alia*, maritime patrol aircraft, air early warning aircraft, and maritime unmanned aerial vehicles, swing role fighters and corvettes.

The force design elements were then linked to the appropriate conceptual operating systems. From experience, we know that not all of the force design elements would always be necessary to make up an operating system. For example, when the military task is to neutralise an enemy in the maritime battle space, a corvette would be a valid inclusion in the manoeuvre and direct fire operating system whereas a main battle tank might not be.

Moreover, some force design elements enable more than one operating system. This is especially true of multi-role force design elements. A swing role fighter is a component of the manoeuvre and direct fire operating system against an enemy in the air battle space but is also a component of the indirect fire operating system where the enemy is in the land battle space.

The above factors were taken into account fully when the linking between the various operating systems, as they appertain to the various military tasks, and the force design elements, were made. The linking of the various force design elements to their respective operating systems as they appertain to neutralising the enemy in the air, land and maritime battle spaces is shown in Appendix A. The complete ranked tree is at Appendix B.

4.2. DETERMINING VALUES FOR $v_{\langle \varphi \rangle}$

Values for $v_{\langle \varphi \rangle}$ was determined by the panel with the aid of the AHP. The AHP allowed for a faster pace of work as the vertices were directly addressed and not via a set of attributes as would be required for using

SMART. Moreover, suitable software was available, the panel preferred the method and judged that the resultant $v_{\langle\varphi\rangle}$ would be sufficiently accurate. The complete result is also contained in Appendix B.

4.3. MANAGEMENT INFORMATION DERIVED FROM THE MODEL

The aim of the quantified model of the military strategy is to allow for better fact based decision making in managing the prepare for war strategy in order to execute the war proper strategy when called upon to do so. Thus far, we have defined a ranked tree, M, allocated rank orders to the vertices, labelled them and have assigned values to all $v_{\langle\varphi\rangle}$.

We shall now demonstrate how these values for $v_{\langle\varphi\rangle}$ can be used to improve management's understanding of the military strategy and aid them in identifying their more important key performance areas. We shall deal with these aspects under the following headings:

- Force Design Elements' contribution to the Military Strategy.

- Operating Systems' contribution to the Military Strategy.

- Military Tasks and Missions and their contributions to the Military Strategy.

- Contributions by vertices of higher rank order to vertices lower rank order.

4.3.1. Force Design Elements' contribution to the Military Strategy

The force design elements' contribution to the Military Strategy is calculated by using (2.9). These calculations for the constructed model of the military strategy, M, were conducted and the results are at Appendix C.

This information is of value to the decision-maker as it indicates the relative worth of the various force design elements. In turn, the relative worth of the various force design elements aids in prioritising the managers expenditure of effort.

By inspection of the relative worth of the various force design elements we note that the five most important force design elements, in order of importance, to the military strategy are the motorised infantry, tactical level headquarters, swing role fighters, corvettes and the mechanised infantry. From participating in the building of the model, the reasons for this are apparent. In the main, the two most important factors the panel of professional military officers considered were

- the likelihood that the force design element would be used in the related type of military task; and

- the importance of the force design element to conclude the associated military task successfully.

In the case of the motorised infantry, the likelihood of their use in most of the military tasks made them the obvious choice for the first position whereas the other force design elements in the top five positions were evaluated to be there by their relative importance to conclude associated military tasks successfully. The decision-maker is now focussed on the fact that his/her short term peacetime requirements dictate that the motorised infantry be kept combat ready. Also, in the case of the other four force design elements, their combat readiness is important if, at any time, South Africa must face an aggressor. In peacetime, this is especially true for the military diplomacy missions. We deduce that w_f will certainly shape decisions on combat readiness.

4.3.2. Operating Systems' contribution to the Military Strategy

By using (2.10), it is possible to find the relative worth of the various operating systems. This can be considered to be of value to the decision-maker regarding the next level of abstraction. Values for w_s were calculated from the constructed model of the military strategy and are depicted in Table 2.5.

Serial	Operating System	$100\,w_s$
	a	b
1	Command and Control	11.0
2	Manoeuvre and Direct Fire	31.8
3	Indirect Fire	6.8
4	Information Warfare	6.1
5	Lift Battlefield	1.0
6	Lift Theatre	4.1
7	Lift Strategic	1.6
8	Search and Rescue	6.4
9	Protect Own Forces	8.9
10	Protect Rear Area	2.1
11	Information Operations	2.9
12	Reconnaissance and Intelligence	5.6
13	Sustainment	11.6

Table 2.5: Operating Systems' contribution to the Military Strategy

From this table we may deduce that problems in the force design elements that provide manoeuvre and direct fire capabilities have potentially the most adverse effect on the support of the military strategy. Furthermore, the continued sustainment of deployed forces is as

important as their command and control. Finally, the protection of the deployed forces is an important factor.

4.3.3. Military Tasks and Missions and their contributions to the Military Strategy

As we have anticipated, the model had no replications of vertices within M_3 and M_2. Therefore, we may find the relative importance of the various missions and military tasks directly from $v_{\langle\phi\rangle}$; $\langle\phi\rangle \in \{M_2, M_3\}$. The importance of the missions and tasks in order to achieve the military strategic ends can be deduced from these values.

4.3.4. Contributions by Vertices or Higher Rank Order to Vertices of Lower Rank Order

Suppose that in order to set priorities in the short term a decision-maker wishes to know what the relative contributions to the strategy would be if, for the time being, only the achievement of South Africa's international obligations are important and that the military must be ready in five years only to achieve the strategic end of maintaining South Africa's sovereignty. Also, he wishes to express the priorities in terms of the following aspects:

- Command and control, including the command and control and situational awareness operating systems.

- Fighting elements including the direct fire and manoeuvre operating system and the indirect fire operating system.

- Information warfare.

- Battlefield, theatre and strategic lift.

- Protection operating systems.

- Sustainment.

By setting $v_{\langle 2\rangle} = v_{\langle 3\rangle} = 0$ and $v_{\langle 1\rangle} = 1$ we use (2.10) to calculate w_s for all of the force design elements. These values will represent the required situation in five years time. By using the constructed model of the military strategy, we have calculated these values and present it in a pie-chart at Figure 2.15.

Now, By setting $v_{\langle 1\rangle} = v_{\langle 3\rangle} = 0$ and $v_{\langle 2\rangle} = 1$ we use (2.10) to calculate w_s for all of the force design elements. These values will represent the required situation for the moment. Again, by using the constructed model of the

military strategy, we have calculated these values and present it in a pie-graph at Figure 2.16.
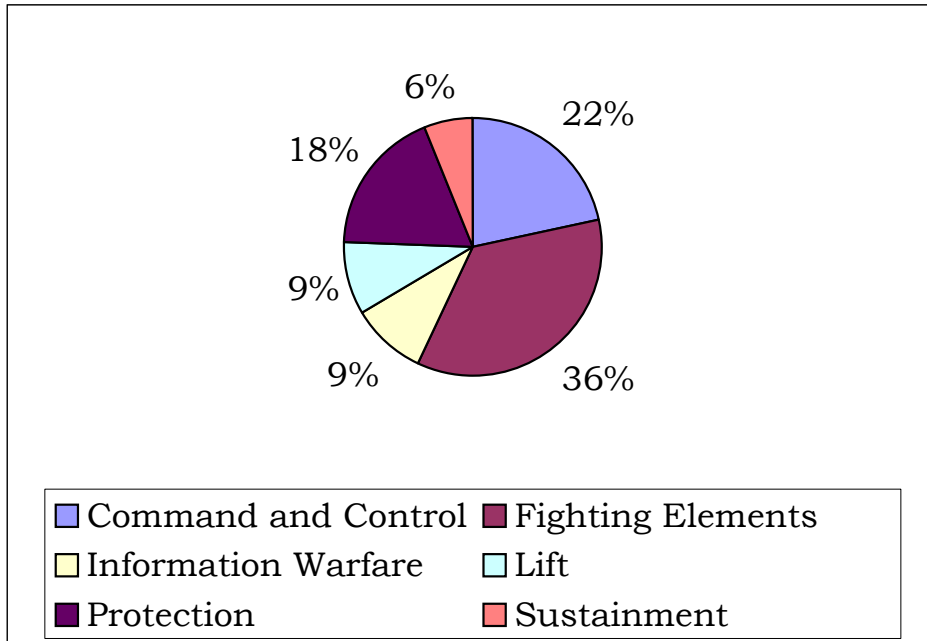

Figure 2.15: Computed values for setting $v_{\langle 2 \rangle} = v_{\langle 3 \rangle} = 0$ and $v_{\langle 1 \rangle} = 1$

By comparing the two graphs in Figure 2.15 and Figure 2.16, we note that command and control requirements are of the same importance in both scenarios. However, in the short term more emphasis should be placed on the fighting elements at the cost to information warfare, lift and sustainment.
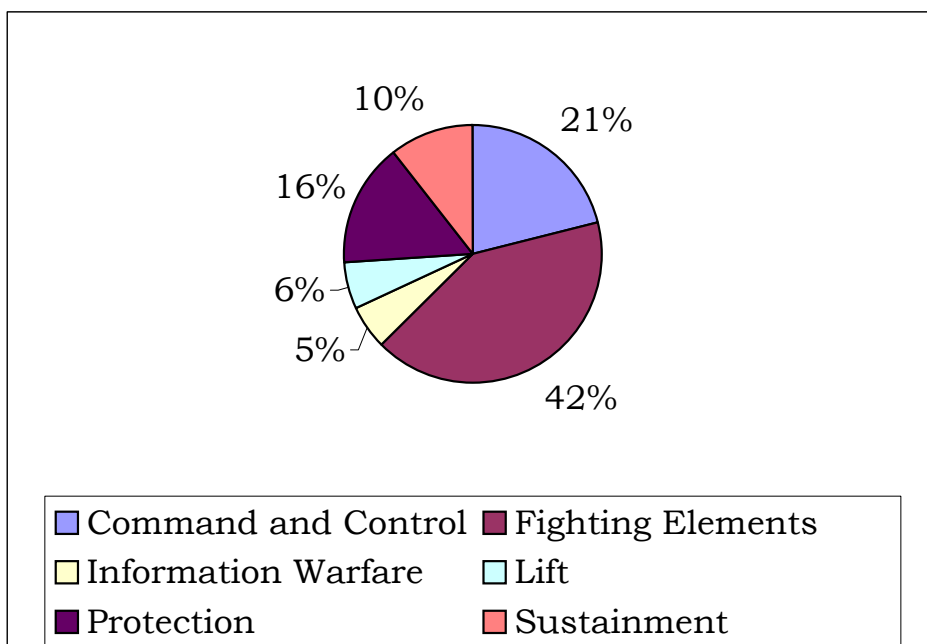

Figure 2.16: Computed values for setting $v_{\langle 1 \rangle} = v_{\langle 3 \rangle} = 0$ and $v_{\langle 2 \rangle} = 1$

By further analysis it is evident that the differences between the today and the five-year hence scenario are not very large. Thus, the pronouncements above might not hold. The differences should be treated with circumspection and it would be of more value to model the problem at the force design level.

5. CONCLUSION

We have researched the question:

> How can the extent of the many-to-many relationships that exist between a military strategy, its ends, ways and means be quantified?

In order to structure the research, we have made three assumptions, *viz.*, the model is requisite, the various relationships exist relative to one another and the force design elements are all fully effective.

We have shown that the relationships between the succeeding vertices in M exist in the form depicted in (2.3) and (2.4). Moreover, we have found the relationships between all vertices in M and the root of M. They are depicted in (2.7).

We have further found the contribution of sets of vertices in the various sub-sets, M_ς, of M and have depicted them in (2.9) and (2.10).

In M_5 and under conditions where it does not hold that the relationships between the various vertices are relative, we have defined an actual contribution, $\rho_{\langle ijklm \rangle}$. We have indicated that (2.16) can be used to transform $\rho_{\langle ijklm \rangle}$ into $\upsilon_{\langle ijklm \rangle}$. Moreover, we have shown that the problem of finding values for $\rho_{\langle ijklm \rangle}$ and $\upsilon_{\langle ijklm \rangle}$ is a complex one, but we have indicated how one could use analytic, heuristic and judgement methods to obtain these values.

Finally, we have developed a military strategy for South Africa and used it to demonstrate the use of the aforementioned relationships and formulae in the management information environment. In doing so, we have gained significant insight into the military strategy and are more capable than ever to participate in the dialectic process of formulating strategy.

Chapter 2