5

Model Validation

1. QUANTIFIED STRATEGY MODEL (QSM)

We name the model that we have developed, the Quantified Strategy Model. It consists of a representation of a military strategy by a ranked tree where the following information is stored at the vertices:

- The relative contribution of any military strategy entity represented by the vertex $\langle \varphi i \rangle$ to its next higher entity represented by the predecessor vertex $\langle \varphi \rangle$, denoted $\upsilon_{\langle \varphi i \rangle}$.

- The actual or real contribution of the vertices $\langle ijklm \rangle$, associated with force design elements, to their respective predecessor vertices $\langle ijkl \rangle$ associated with their respective operating systems, denoted $\rho_{\langle ijklm \rangle}$.

- The effectiveness of force design elements, $E = A_O DC$, are stored on their associated vertices with labels $\langle ijklm \rangle$.

From the information stored on the vertices of the tree, we may, *inter alia*, calculate the following:

- The degree to which any entity associated with a particular vertex in the tree, contributes to some entity at a higher level of abstraction in the tree, $\tilde{\upsilon}_{\langle \varphi \rangle}$.

- The effectiveness of the force design to
  - operate as an operating system,
  - execute military tasks and missions,
  - achieve the military strategic ends, and to

- ° support a military strategy.

2. VALIDITY REQUIREMENTS

The final test for the validity of a system or model is whether or not it yields quality results. Often this determination may only be made after the systems has been developed and implemented. Sometimes, because of size and complexity, such a determination cannot be made. However, the following six questions will at least disclose weaknesses that may be corrected[1]:

- *Consistency*: Are results consistent when major parameters are varied?
- *Sensitivity*: Do input-variable changes result in output changes that are consistent with expectations?
- *Plausibility*: Are results plausible for special cases where prior information exists?
- *Criticality*: Do minor changes in the assumptions result in major changes in the results?
- *Workability*: Does the model require inputs or computational capabilities that are not available within the research bounds?
- *Suitability*: Is the model consistent with the objectives: that is, will it answer the right questions?

We shall now subject the model that we have developed to scrutiny in terms of these suggested questions in order to test its validity.

2.1. CONSISTENCY

In this section we answer the question: Are results consistent when major parameters are varied? In order to elicit a response, we have conducted four experiments.

First, we have found from Appendix B that, in the SANDF's case, the percentage contribution to their military strategy for the various services and divisions are as depicted in Figure 5.1.

By setting all the force design elements relating to a particular service's effectiveness to one and the non-related force design elements' effectiveness to zero for all of the above seven services and divisions and

[1] *Engineer Design Handbook - Systems Analysis and Cost-effectiveness*, Document AMCP 706-191, Washington: US Army Material Command, 1971, p. 2-27.

disregarding dependency and interdependency, E^R was consistent with the contributions of the services obtained from M.

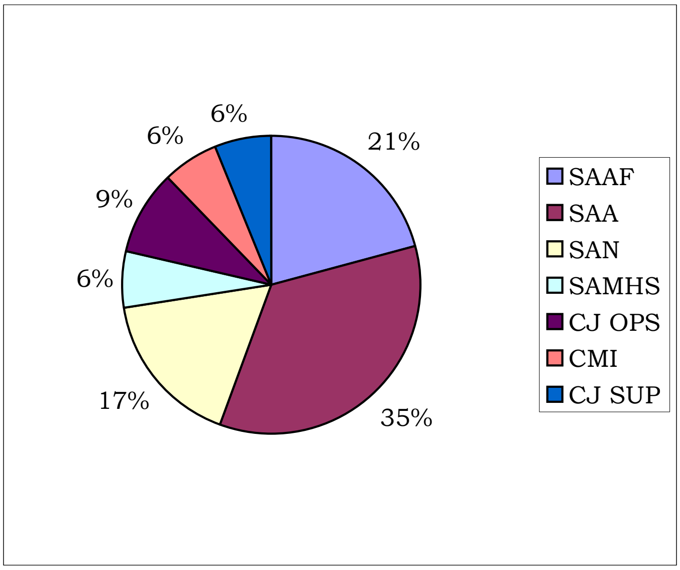

Figure 5.1: Force Design Contribution of Services and Divisions to the Military Strategy

Second, we have tested the model with fixed inputs, that is, we have set all effectiveness measurements at the same level and we have repeated the test over the interval [0,1] at increments of 0.1. The results are reported in Figures 5.2 and 5.3 respectively.

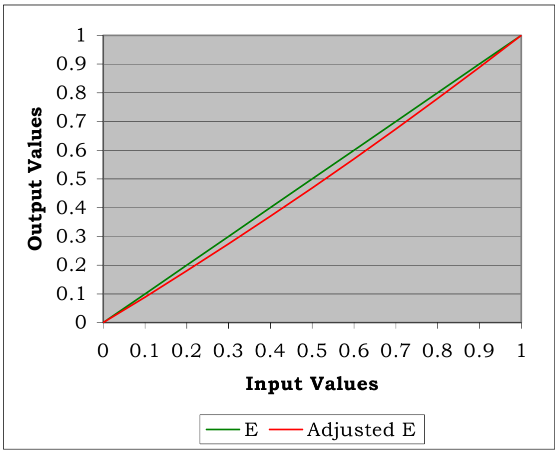

Figure 5.2: Absolute Impact of Dependency

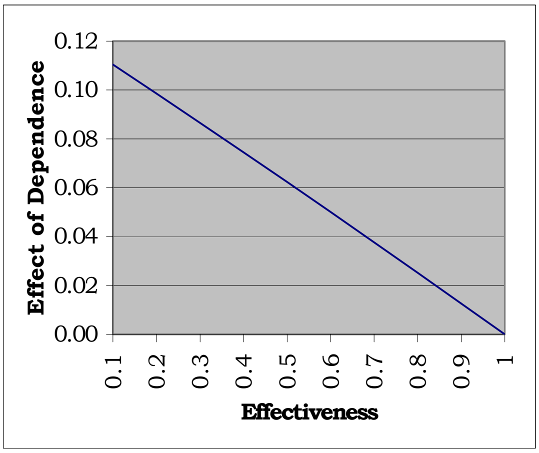

Figure 5.3: Relative Impact of Dependency

The model behaved consistently during these experiments. The absolute impact of effectiveness dependency, that is the direct impact on the force design's effectiveness to execute the military strategy, between force design elements is shown in Figure 5.2. We note that the impact of dependency or Adjusted E differs by about 0.06 where E = 0.5.

The relative impact of dependency was calculated by

$$I^{DEP} = \frac{E - E^{DEP}}{E} \tag{5.1}$$

where I^{DEP} is the relative impact of dependency on the model, E is the fixed effectiveness input and E^{DEP} is the model output regarding the effectiveness of the force design to execute the military strategy.

We note that as E becomes smaller, I^{DEP} becomes larger and *vice versa*. This is consistent with expectations. As the general effectiveness of the force design reduces the larger the effect on force design elements that are dependent on other force design elements will be. From Chapter 3, we know that, if a force design element is completely dependent on another, then its effectiveness with dependency taken into account is the product of its effectiveness and the effectiveness of the other force design element. This leads to the expectation that as E becomes smaller, I^{DEP} should become larger.

Third, we have assigned a random number in the interval [0,1) to the effectiveness of force design elements. Although E^R is a weighted sum of the effectiveness of the force design elements, if the experiment is repeated many times, from Figure 5.2, the expected value of E^R without taking dependency into account should be 0.5.

The experiment, taking dependency into account, was repeated fifty times. For this experiment we found $E^R = 0.460$. We want to know whether $E^R = 0.460$ is significantly different from 0.5 at the 1% level.

Now, we set the hypothesis

$$\mathrm{H}_0 : \bar{E}^R = 0.5$$

and the alternative hypothesis

$$\mathrm{H}_1 : \bar{E}^R \neq 0.5 .$$

A one-sample *t*-test calculates $\bar{E}^R \neq 0.460$ and gives a 95% confidence interval $\left[0.448 \leq \bar{E}^R \leq 0.472\right]$. The test statistic is t = -6.549. Therefore, we reject the null-hypothesis at the 1% level. Thus, we conclude that the impact of dependency is significant at the 1% level. This is consistent with our belief that dependency will impact significantly on the force design's effectiveness to execute the military strategy.

Likewise, we know that according to Table 3.4, a unit, operating system or task force may be placed in a combat readiness category in accordance with its appropriate measure of effectiveness as follows:

- Category CR1: Unit, Operating System or Task Force is fully combat ready. ($E \geq 0.5$)

- Category CR2: Unit, Operating System or Task Force needs minor adjustments to become fully combat ready. ($0.5 > E \geq 0.27$)

- Category CR3: Unit, Operating System or Task Force needs major adjustments to become fully combat ready. ($0.27 > E \geq 0.125$)

- Category CR4: Unit, Operating System or Task Force is not combat ready. ($E < 0.125$)

Fourth, by setting force design element effectiveness in a random manner in the intervals [0.5,1), [0.27,0.5), [0.125,0.27) and [0, 0.125) respectively we have achieved the mean results as reported in Table 5.1.

Serial	Category	Military Strategy	End	Mission	Task	Operating System	Force Design Element
	a	b	c	d	e	f	g
1	CR1	0.727	0.731	0.735	0.733	0.744	0.728
2	CR2	0.308	0.310	0.316	0.313	0.317	0.307
3	CR3	0.179	0.183	0.188	0.185	0.187	0.179
4	CR4	0.057	0.058	0.059	0.059	0.060	0.057

Table 5.1: Mean Simulated Values at the Various Levels of Abstraction

The reported results regarding the combat readiness categories at all levels were consistent with the inputs.

When major changes have been made in the effectiveness inputs such as setting large parts of the force design's effectiveness to zero and other parts to one we have found the results to be consistent. The same has been observed when we have chosen a middle of the road position where we have set effectiveness by means of random numbers. Also, when the inputs were chosen within the parameters for deciding on combat readiness, the model performed consistently. From the four aforementioned experiments, we conclude that the model delivers consistent results.

2.2. SENSITIVITY

In this section we answer the question: Do input-variables changes result in output changes that are consistent with expectations?

First, we consider the question from an effectiveness point of view. Recall that we have used both $\upsilon_{\langle\varphi\rangle}$ and E^{φ} to determine effectiveness at higher levels of abstraction. Specifically, we have used

$$E^{US} = A_O DC$$

at the force design elements level,

$$E^{OS} = \sum_{m=1}^{t} \upsilon_{\langle ijklm\rangle} E_m^{US}$$

at the operating system level,

$$E^{TF} = \sum_{l=1}^{s} \upsilon_{\langle ijkl\rangle} E_l^{OS}$$

at the task force level,

$$E^{M} = \sum_{k=1}^{r} \upsilon_{\langle ijk\rangle} E_k^{TF}$$

at the military mission level,

$$E^{E} = \sum_{j=1}^{q} \upsilon_{\langle ij\rangle} E_j^{M}$$

at the military strategy's ends level, and

$$E^{R} = \sum_{i=1}^{p} \upsilon_{\langle i\rangle} E_i^{E}$$

for the force design's effectiveness to execute a military strategy.

Suppose we set the effectiveness of all force design elements to one, then the expected value of $E^R = 1$. If we choose a force design element at random and we set its corresponding $E^{US} = 0$, then we find that the expected value of

$$E^{R} = 1 - w_f \,. \tag{5.2}$$

Also, if we set the effectiveness of all force design elements to ε, then the expected value of

$$E^{R} = \varepsilon - \varepsilon w_{f}\,. \tag{5.3}$$

More generally, the impact of change on the model is

$$I_{C} = f\left(\bar{E}, \delta_{f}\right)$$

where $\bar{E}$ is the mean effectiveness, of all force design elements, δ_{f} is the changes in the effectiveness of a particular force design element over time, $f \in F$, and F is the set of force design elements. Now, for change in one particular force design element we have that

$$I_{C} = \bar{E}\delta_{f} \tag{5.4}$$

and the new expected value of the effectiveness of an entity which is not at a terminal vertex, is

$$\hat{E}^{\varphi} = \bar{E}^{\varphi} + \bar{E}^{\varphi}\delta_{f}\,. \tag{5.5}$$

We note that (5.4) is a measure of the sensitivity of the model for changes in the effectiveness of force design elements. An upper limit for (5.4) is w_{f}. This upper limit is reached when $\bar{E} = 1$ and $\delta_{f} = w_{f}$.

If we consider changes in the relative contributions of entities represented on the vertices of M to their predecessor vertices, then we note that when we amend a particular $\upsilon_{\langle\varphi\rangle}$, it must impact on the other entities that also contribute to the entity represented by the same predecessor vertex.

Suppose we have n successor vertices that contributes $\upsilon_{\langle\varphi 1\rangle}$, ..., $\upsilon_{\langle\varphi n\rangle}$ to the vertex $\langle\varphi\rangle$ respectively and where $\upsilon_{\langle\varphi 1\rangle} + \ldots + \upsilon_{\langle\varphi n\rangle} = 1$. Then, under the assumption that the predecessor vertex is fully enabled, reductions in the contribution of the ith successor vertex will impact on the other vertices to the degree to which they have contributed prior to the change.

Suppose the ith vertex changes its contribution from $\upsilon_{\langle\varphi i\rangle}$ to $\upsilon^{N}_{\langle\varphi i\rangle}$, then the change to the contributions of the kth successor vertex of the set of n vertices excluding the ith vertex is

$$\upsilon^{N}_{\langle\varphi k\rangle} = \upsilon_{\langle\varphi k\rangle} + \upsilon_{\langle\varphi k\rangle}\frac{\upsilon_{\langle\varphi i\rangle} - \upsilon^{N}_{\langle\varphi i\rangle}}{1 - \upsilon_{\langle\varphi i\rangle}}\,. \tag{5.6}$$

The sensitivity of the model is described by (5.4) and (5.6) respectively. Because of the model size, the model will not be excessively sensitive to small changes in the input parameters. Furthermore changes in the model outputs as described by (5.5) will be proportional to changes in the model input. We conclude that, regarding sensitivity, the model will behave satisfactorily.

2.3. PLAUSIBILITY

In this section we answer the question: Are results plausible for special cases where prior information exists?

2.3.1. Prior Study

During an evolution to prioritise projects within the SANDF in 1998, the present military strategy as it is delineated in the South African Department of Defence's Strategic Plan[2] did not exist. It was then decided to analyse the relative contributions of force design elements in terms of a general consensus about the force design elements' contributions to defence capability. The results from that analysis and the analysis result from this study are shown in Figure 5.4.

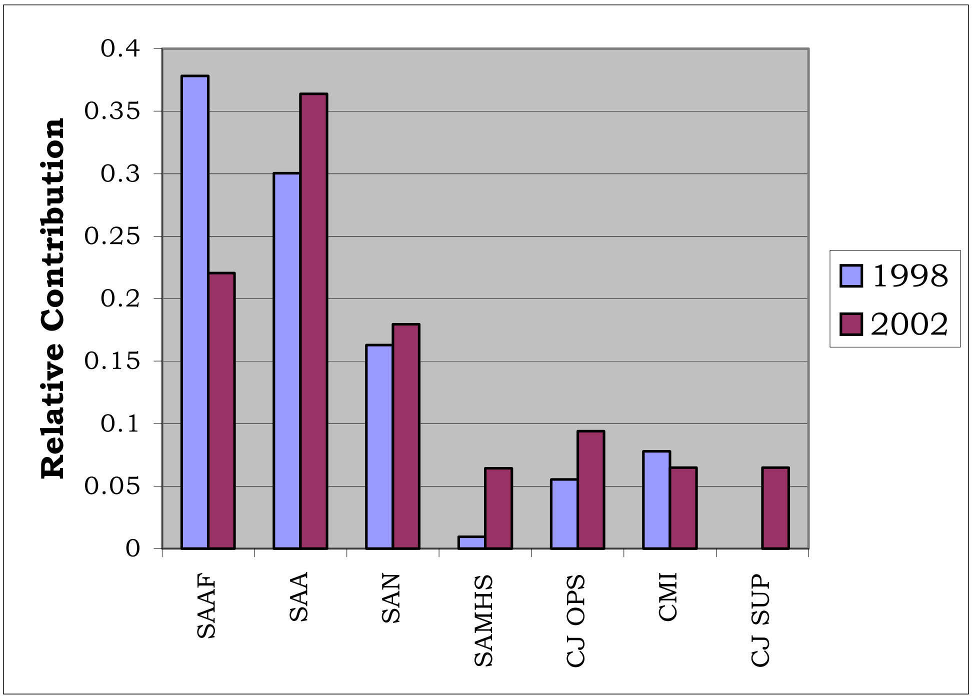

Figure 5.4. Comparative Statistics between Two Military Strategic Studies

At the time, the 1998 study was accepted with reservation. Major critique expressed by the then Chief of Joint Operations, Lt Gen D. Ferreira, was

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[2] *South African Department of Defence Strategic Plan for FY 2002/03 to 2004/05*, Pretoria: Department of Defence, 31 January 2002.

that the South African Air Force's contribution was overrated and that the support environment's contribution was underrated[3].

From the latter study, the general's concerns were vindicated. If the differences between the SAAF, CJ SUP and SAHMS contributions is brought into account, equation (5.6) explains the magnitude of the present estimates of the contributions by the various services and divisions rather accurately. However, the 1998 study shows that the model or framework for the South African military strategy might be plausible to some degree.

2.3.2. Scenario Tests

There is a dearth of prior quantifiable information to test the plausibility of the quantified military strategy model that we have proposed. However, given certain scenarios, there are valid qualitative thoughts that might be used in lieu of quantifiable information. We shall develop some further scenarios and test the model output for plausibility against the qualitative thoughts of professional military personnel.

2.3.2.1. *Scenario 1: Armour is No Longer a Requirement*

Suppose that the notion that is supported in some circles that armour is not a necessity for war and that the SANDF can go without such force design elements were to become reality. From Table 3.4, we know that an effectiveness level of 50% is necessary to consider any entity in the military strategy combat ready. Moreover, we know that to achieve an effectiveness level of 50%, operational availability, dependability and capability must be of order about 80%. Thus, the 50% requirement for effectiveness is an arduous requirement. Therefore, we assume that all force design elements are combat ready with effectiveness being about 0.6 and adjusted for dependency so that all force design elements' effectiveness is at least 0.5, whilst, as a result of doing away with them, the effectiveness of the armour is zero.

Given that the armour's effectiveness is in the interval 0.6 the model predicts that the SANDF's force design elements, operating systems and task forces will be combat ready for all tasks and missions in order to achieve its strategic ends. However, when the armour's effectiveness is set at zero, the following entities are not combat ready anymore:

- Task $\langle 111 \rangle$: to demonstrate own offensive capabilities are reduced as the task's associated manoeuvre and direct fire operating system is no longer combat ready.

[3] Ferreira, Lt Gen D., Chief of Joint Operations, Operations Staff Council, 1 Jul 1998, Pretoria.

- Task $\langle 113 \rangle$: show-of-force are reduced as the task's associated manoeuvre and direct fire operating system is no longer combat ready.

- Manoeuvre and direct fire operating system relating to task $\langle 126 \rangle$; neutralise enemy in the land battle space.

- Task $\langle 253 \rangle$: enforce the keeping of peace treaty provisions and its associated manoeuvre and direct fire operating system.

In general, the predictions by the model were supported during an interview with a professional general officer[4]. It was commented that the inherent protection offered by the armour within the manoeuvre and direct fire operating systems would be lost and the shock action that is brought about by armour in the battle field will no longer be possible. As these factors were taken into account in deciding on the contribution of armour in the manoeuvre and direct fire operating system, the model output was accepted.

2.3.2.2. *Scenario 2: The Navy is Decimated*

The question could be asked: How vulnerable is the South African military strategy to pre-emptive strike by an aggressor using a weapon of mass destruction against the SA Navy whilst they are all within their homeport?

Now, suppose an aggressor uses a weapon of mass destruction against the SA Navy whilst they are all within Simon's Town and as a result, the SA Navy's effectiveness reduces to zero. We assume levels of effectiveness for the remainder of the SANDF as set for for the previous scenario. The impact on the strategy, its end and ways is depicted in Table 5.2.

We note that the force design's effectiveness are now considered to be inadequate for the following five tasks:

- Task $\langle 127 \rangle$: Neutralise Enemy in the Maritime Battle Space.

- Task $\langle 242 \rangle$: Search and Rescue in the Southern Oceans.

- Task $\langle 252 \rangle$: Conduct Maritime Blockade Operations.

- Task $\langle 311 \rangle$: Antarctic Operations to support SANAE.

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[4] Gildenhuys, Brig Gen B.C., SM, MMM, General Officer Commanding, SA Army Armour Formation, Personal Interview, 25 April 2003, Pretoria.

- Task $\langle 315 \rangle$: Hydrography and Charting.

Legend for Table 5.2	
(green)	Combat Readiness Category CR1
(yellow)	Combat Readiness Category CR2
(red)	Combat Readiness Category CR3/4

Serial	E^R	Ends	E^E	Mission	E^M	Task	E^{TF}
	a	b	c	d	e	f	g
1	0.46531	1	0.46021	11	0.48044	111	0.47480
2						112	0.34134
3						113	0.52554
4				12	0.45616	121	0.60000
5						122	0.60000
6						123	0.59744
7						124	0.30724
8						125	0.49497
9						126	0.51422
10						127	0.26844
11		2	0.48548	21	0.59748	211	0.59723
12						212	0.59780
13				22	0.44487	221	0.59680
14						222	0.29293
15				23	0.51733	231	0.59798
16						232	0.35578
17				24	0.34875	241	0.52495
18						242	0.22272
19				25	0.53773	251	0.58612
20						252	0.13292
21						253	0.58641
22						254	0.59287
23						255	0.59293
24						256	0.59301
25		3	0.45436	31	0.43293	311	0.07500
26						312	0.58049
27						313	0.50917
28						314	0.59847
29						315	0.05400
30						316	0.30000
31						317	0.49212
32				32	0.58488	321	0.60000
33						322	0.60000
34						323	0.48000

Table 5.2. Results by the Quantitative Strategy Model for Scenario 2

Moreover, the force design's effectiveness to carry out eight other tasks does not meet the required level. The following tasks are at risk:

- Task $\langle 111 \rangle$: Demonstrate Own Offensive Capabilities.
- Task $\langle 112 \rangle$: Safeguard Diplomatic Personnel.
- Task $\langle 124 \rangle$: Strategic Interdiction.
- Task $\langle 125 \rangle$: Neutralise Enemy in the Air Battle Space.
- Task $\langle 222 \rangle$: Assist in Peace-making.
- Task $\langle 232 \rangle$: Distribution of Food and Shelter.
- Task $\langle 316 \rangle$: Pollution Control at Sea.
- Task $\langle 323 \rangle$: Presidential Protocol Requirements.

After having completed this analysis, no new intuitions emerged about the ranked tree, M. After consultation with a professional flag officer, we consider the Quantitative Strategy Model's output for this scenario to be adequate[5].

2.3.3. Stress Testing the Model

We have subjected the model to a series of stress tests where we have set a certain percentage of the effectiveness figures for force design elements to zero. We have then scrutinised the model output with the view to find inconsistencies in the prediction of effectiveness at higher levels of abstraction. None could be found.

2.3.4. Audit Requirements

We have shown in Chapter 3 that some E^{φ} in the model is inter-dependent. Also, incorrect values or values of lesser quality in the model will affect the reliance or plausibility that could be placed on the model adversely. To address this issue, the model, complete with all inputs should be subjected to internal audit in order to verify the veracity of the inputs.

2.4. CRITICALITY

In this section we answer the question: Do minor changes in the assumptions result in major changes in the results?

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[5] Retief, Vice Admiral J.F., SD, SM, MMM, Chief of the South African Navy, Personal Interview, 19 February 2003.

Suppose we have that all force design elements' effectiveness is uniformly distributed in the interval [0.53,0.73). We may generate E^R by means of generating $E^{US} = e^{US} \sim U[0.53, 0.73)$. By the nature of this distribution and taking dependency into account, we expect that $E(E^R) = 0.6$.

Now, if we change the values for all of E^{US} in successive simulations in the interval [0.53,0.73), we have generated 84 small changes to the values of all of the E^{US}. If we still find that $E(E^R) = 0.6$, then we may assume that the model is robust against such changes. As the model comprises the weighted sum,

$$E^R = \sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{r}\sum_{l=1}^{s}\sum_{m=1}^{t}\tilde{\upsilon}_{\langle ijklm\rangle}E_{\langle ijklm\rangle},$$

we expect it to be the case.

We have simulated the simultaneous change of the effectiveness of all eighty four force design elements 45 times. We set the hypothesis that

$$\mathrm{H}_0 : \bar{E}^R = 0.6$$

and the alternative hypothesis

$$\mathrm{H}_1 : \bar{E}^R \neq 0.6.$$

A one-sample *t*-test calculates $\bar{E}^R = 0.598$ and a 95% confidence interval to be $[0.595 \le \bar{E}^R \le 0.601]$. Thus, we accept H_0 on the 5% level. As such, we accept that small changes in effectiveness will not have a major effect on E^R.

When we have repeated the experiment at a lower level in the tree, that is, at the operating system level of abstraction we have found that for the hypothesis

$$\mathrm{H}_0 : \bar{E}^{OS} = 0.6$$

and the alternative hypothesis

$$\mathrm{H}_1 : \bar{E}^{OS} \neq 0.6$$

regarding the indirect fire operating system for task $\langle 126\rangle$, a one-sample *t*-test calculated $\bar{E}^{OS} = 0.599$ with a 95% confidence interval of $[0.591 \le \bar{E}^{OS} \le 0.606]$. Thus, again we accept $\mathrm{H}_0 : \bar{E}^{OS} = 0.6$.

However, whereas the standard deviation in the data set used for calculating $\bar{E}^{R}$ was 0.009, the standard deviation of the data set used for calculating $\bar{E}^{OS}$ was 0.026.

After further investigation is became clear that, as the measure of effectiveness is determined at higher and higher levels of abstraction, so the standard deviation in the experiments done above decreases. This phenomenon may be directly attributed to the influence of the depth of the tree at higher levels of abstraction. The deeper the tree, the larger the smoothing effect of the weighted sum becomes and the less the effectiveness at higher levels of abstraction is influenced by small changes in the effectiveness of force design elements.

Let us consider the impact of small changes in $\upsilon_{\langle ijklm \rangle}$ on the measures of effectiveness at the various levels of abstraction within M.

If we consider the distribution of the values allocated to the various $\upsilon_{\langle ijklm \rangle}$, we find the following summary statistics:

Minimum Value:	0.000217.
Maximum Value:	0.066479.
Mean:	0.012.
Median:	0.006.

The difference between the mean and median indicates the possibility that the density of the distribution of $\upsilon_{\langle ijklm \rangle}$ is skewed. Consider the bar-graph roughly depicting the distribution of $\upsilon_{\langle ijklm \rangle}$ at Figure 5.5.

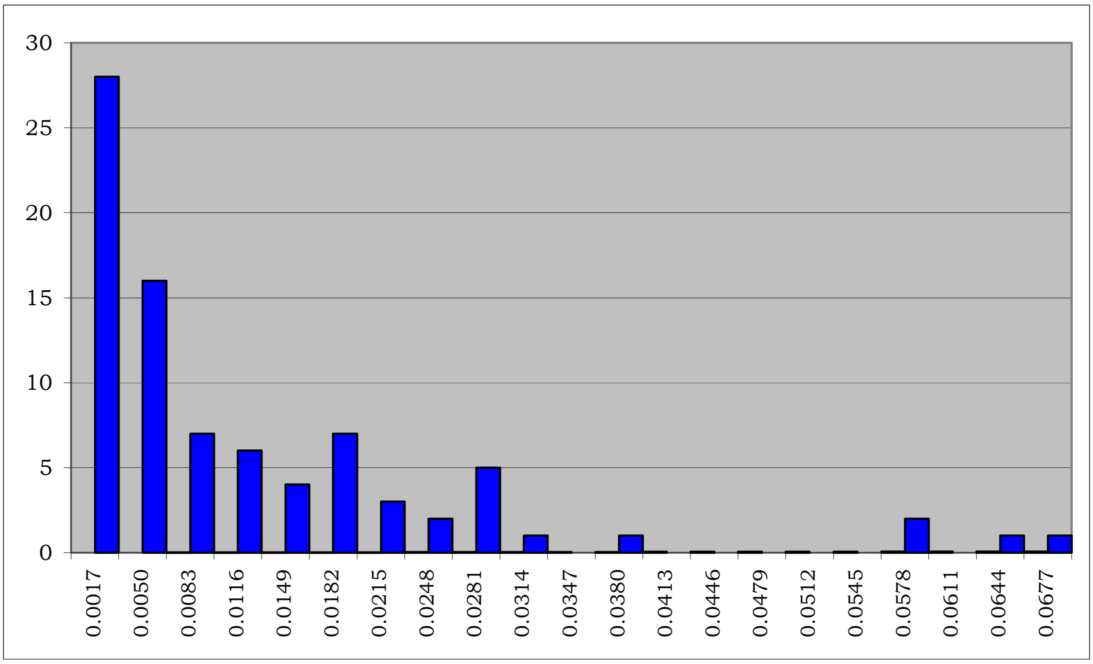

Figure 5.5: Histogram of Values Allocated to $\upsilon_{\langle ijklm \rangle}$

From Figure 5.5 and the summary statistics given above, we note that the larger majority of values that was allocated to the various $\upsilon_{\langle ijklm \rangle}$ is at least 50% less than the maximum allocated value. Thus, changes to the various $\upsilon_{\langle ijklm \rangle}$ may be considered very small.

From (5.6) we know that the impact of changes in one instance of $\upsilon_{\langle ijklm \rangle}$ will impact in proportion to the other entities' relative size to the entities that will be influenced.

We conclude by accepting that changes in the allocation of values to the various $\upsilon_{\langle ijklm \rangle}$ will have a proportionally small impact on the model.

2.5. WORKABILITY

In this section we answer the question: Does the model require inputs or computational capabilities that are not available within the research bounds?

The whole of the Quantified Strategy Model was fitted onto one Microsoft ® Excell 97 spreadsheet. All other computational requirements were adequately supported by the same spreadsheet. Within the bounds of our research, we have also made use of Expert Choice 2000 Professional 10.1 software to capture the judgement of professional officers regarding the contributions of entities to higher order entities in a military strategy and of the XA Callable Library Version 11.0 to solve linear programs regarding the scheduling of projects. The three software packages were found to be sufficient.

Thus, we conclude that the model does not require inputs or computational capabilities that are not available within the research bounds.

2.6. SUITABILITY

In this section we answer the question: Is the model consistent with the objectives: that is, will it answer the right questions?

The model was developed specifically with the South African military's needs in mind. To that end, it answers a wide variety of questions. The questions may be grouped in several fields of application. First, questions about the contributions that force design elements *et cetera* make to the attainment of the South African military strategy are answered. The following list of questions is representative of the typical questions appertaining to this application field:

- What are the relative and real contributions that force design elements make to the appropriate operating systems?

- What is the relative contribution that an operating system makes to a task force?

- What is the relative contribution that a task force makes toward achieving a military mission?

- What is the relative contribution that a military mission makes toward achieving a military strategic end?

- What is the relative contribution that a military strategic end makes toward achieving a military strategy?

- What is the relative contribution that a force design element makes toward achieving a military strategy?

- What is the relative contribution that an operating system makes toward achieving a military strategy?

- What is the relative contribution that a military task makes toward achieving a military strategy?

Second, questions about the effectiveness or combat readiness of the force design to execute a military strategy are answered. The following list of questions is representative of the typical questions appertaining to this application field:

- How combat ready is the military for achieving tactical, operational and strategic objectives?

- How effective are force design elements, operating systems and task forces?

- How effective is the force design to execute military tasks and missions?

- How effective is the force design to achieve the military strategic ends?

- How effective is the force design to implement a military strategy?

Third, questions about the quality of processes in the military are answered. At the least, insights are provided about the quality of these processes. The following list of questions is representative of the typical questions appertaining to this application field:

- To what extent is the logistic support system able to support the force preparation and force employment activities?
- To what extent is the human resource support system able to support the force preparation and force employment activities?
- To what extent does the design and production of main equipment comply with the military's needs?
- How apt is the maintenance philosophy?
- To what extent does the logistic supply process comply with the military's needs?
- What is the impact of the health status of personnel within the organisation?
- To what extent does integration training at force design element level comply with the military's needs?
- To what extent does the leave policy and the management thereof comply with quality requirements?
- Are the members of the military sufficiently disciplined?
- To what extent does the human resource supply chain inclusive of recruiting, training and timely appointment, comply with the military's needs?

Fourth, the model also answers, either partially or fully, questions emanating from the acquisition community. The following list of questions is representative of the typical questions appertaining to this application field:

- Are main equipment or user systems still functioning optimally?
- Is there a need to replace force design element hardware?
- Which supplier option best satisfies acquisition needs?
- What should the priority of projects be for scheduling purposes so as to maximise the force design's capabilities in terms of a military strategy?

Fifth, if we track changes in the values allocated to the various variables such as $v_{\langle\varphi\rangle}$, $\rho_{\langle ijklm\rangle}$, A_i, A_O, D, C *et cetera*, we shall be able to find trends in the changes of the values and forecast future values. In turn, this will allow for question about the future to be answered. The following list of questions is representative of the typical questions about the future that could be answered by the model:

- If we do not intervene in the status quo, when will the force design fail to be effective in executing a military strategy, military missions or tasks?

- By when must we replace or maintain main equipment in order to ensure an effective force design?

- What priority should we accord particular projects so as to manage the budget in such a manner that we optimise the effectiveness of the force design in the short term?

Members of the panel that have made inputs into the quantification of the various $v_{\langle\varphi\rangle}$ support the model and have stated that they regard the model, complete with the associated questions to be answered, as requisite[6].

3. OPPORTUNITIES FOR FURTHER RESEARCH

The research has focussed on a holistic information model that would present the decision-maker with quantifiable facts to be considered when making decisions about preparing for war against a military strategy for war. In this context, by war is meant the achievement of a military strategy's ends when called upon to do so. To that end, we have deliberately avoided issues that may detract from the research focus.

3.1. REFINING THE VALUES FOR $v_{\langle\varphi\rangle}$ AND $\rho_{\langle ijklm\rangle}$

Because of the research focus, the allocation of values to the various $v_{\langle\varphi\rangle}$ was restricted to what could be achieved by using the judgement of a panel of professional military officers only. Moreover, no attempt was made to allocate values to the various $\rho_{\langle ijklm\rangle}$. This aspect was deliberately avoided as it was assessed to be of little consequence to the eventual outcome of the research.

It is suggested that in the further development of the model as an aid to decision-making, analytical and heuristic methods should be investigated

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

to increase the quality of the values allocated to the various $\upsilon_{\langle\varphi\rangle}$. Also, the model has been sufficiently developed to allow for the quantification of the values reflecting the actual contributions of the force design elements so as to increase the quality of the decision aid worth of the model.

3.2. REDEFINING EFFECTIVENESS AT HIGHER LEVELS OF ABSTRACTION

Recall that we have stated that effectiveness at the higher levels of abstraction could be expressed by the equation

$$E^{\xi} = f\left(E_1^{\xi+1},\ldots,E_n^{\xi+1}\right)I^{\xi} \tag{5.7}$$

where E is a measure of effectiveness, ξ is the level of abstraction within M which have rank $\mu(\upsilon)=\xi$ and I is an integrator of the effectiveness inherited from the lower level of abstraction, $f\left(E_1^{\xi+1},\ldots,E_n^{\xi+1}\right)$.

We have argued that the effect of I^{ξ} is a function of command and control doctrine at the level of abstraction under consideration. We have modelled the command and control functions as force design elements or user systems, so that there are measures of effectiveness for them that are of the form $E^{\xi+1}$. Thus, (5.7) reduces to

$$E^{\xi} = f\left(E_1^{\xi+1},\ldots,E_n^{\xi+1}\right). \tag{5.8}$$

We have stated that

- finding values for I^{OS} in (5.7) might not be feasible as the capability of the operating system headquarters and its impact on the operating systems might prove to be too complex to determine;

- as (5.8) is a monotone non-decreasing function and it avoids the problem of having to find a value for I^{OS} it shall suffice as a measure of effectiveness; and

- we may consider I^{OS} a scaling factor and as we are interested in relative values only, we may set $I^{OS}=1$.

Now, as it is suitable and more readily implementable we have used (5.8) as an alternative to (5.7). It might be possible that, if values for I^{ξ} and the relationship between I^{ξ} and $f\left(E_1^{\xi+1},\ldots,E_n^{\xi+1}\right)$ could be found, a measure of E^{ξ} could be deduced that may suit the model better. As a result, such research may lead to an improvement in the quality of the model.

4. SUMMARY

In this chapter, we have

- first, described the newly developed model in general terms;
- second, have shown that, by-and-large the model may be considered valid; and
- finally, have proposed new areas for further research to improve the model quality.