Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 499907
UNCLASSIFIED	

TITLE

SATISFYING REQUIREMENTS AT MINIMUM COST: METHODOLOGY WITH AN APPLICATION TO UNIT LEVEL STANO REQUIREMENTS

System Number:

Patron Number:

Requester:

Notes:

DSIS Use only:

Deliver to:

DEPARTMENT OF NATIONAL DEFENCE
CANADA

OPERATIONAL RESEARCH DIVISION

DIRECTORATE OF OPERATIONAL RESEARCH (JOINT & LAND)

JSORT RESEARCH NOTE RN 9605

SATISFYING REQUIREMENTS AT MINIMUM COST: METHODOLOGY WITH AN APPLICATION TO UNIT LEVEL STANO REQUIREMENTS

by

Dr. Phil O'Neill

OCTOBER 1996

OTTAWA, CANADA

National Defence Défense nationale

OPERATIONAL RESEARCH DIVISION

CATEGORIES OF PUBLICATION

ORD Reports are the most authoritative and most carefully considered publications of the DGOR scientific community. They normally embody the results of major research activities or are significant works of lasting value or provide a comprehensive view on major defence research initiatives. ORD Reports are approved personally by DGOR, and are subject to peer review.

ORD Project Reports record the analysis and results of studies conducted for specific sponsors. This Category is the main vehicle to report completed research to the sponsors and may also describe a significant milestone in ongoing work. They are approved by DGOR and are subject to peer review. They are released initially to sponsors and may, with sponsor approval, be released to other agencies having an interest in the material.

Directorate Research Notes are issued by directorates. They are intended to outline, develop or document proposals, ideas, analysis or models which do not warrant more formal publication. They may record development work done in support of sponsored projects which could be applied elsewhere in the future. As such they help serve as the corporate scientific memory of the directorates.

ORD Journal Reprints provide readily available copies of articles published with DGOR approval, by OR researchers in learned journals, open technical publications, proceedings, etc.

ORD Contractor Reports document research done under contract of DGOR agencies by industrial concerns, universities, consultants, other government departments or agencies, etc. The scientific content is the responsibility of the originator but has been reviewed by the scientific authority for the contract and approved for release by DGOR.

DEPARTMENT OF NATIONAL DEFENCE

CANADA

OPERATIONAL RESEARCH DIVISION

DIRECTORATE OF OPERATIONAL RESEARCH (JOINT & LAND)

JSORT RESEARCH NOTE RN 9605

SATISFYING REQUIREMENTS AT MINIMUM COST: METHODOLOGY WITH AN APPLICATION TO UNIT LEVEL STANO REQUIREMENTS

by

Dr. Phil O'Neill

Recommended by: R. Kluchert, JSORT

Approved by: G. Lafond, DOR(J&L)

Directorate Research notes are written to document material which does not warrant or require more formal publication. The contents do not necessarily reflect the views of ORD or the Canadian Department of National Defence.

OTTAWA, ONTARIO

OCTOBER 1996

ABSTRACT

This report summarises a methodology for selecting equipment to accomplish a set of mission elements according to prescribed task standards. The main idea is to model the problem as a generalisation of the classic "Minimum Cover Problem", which is solvable by standard techniques of integer linear programming. The methodology uses defined configurations of equipment to address the mission elements. The solution it provides is the lowest cost set of equipment that satisfies all of the requirements for the mission elements. An example problem is discussed, that of selecting unit level STANO equipment. While the discussion is mainly in terms of equipment selection, the methodology can be applied to other classes of selection problems.

TABLE OF CONTENTS

PAGE

SATISFYING REQUIREMENTS AT MINIMUM COST: METHODOLOGY WITH AN APPLICATION TO UNIT LEVEL STANO REQUIREMENTS

BACKGROUND

1. This report describes an approach to analysing military requirements. Although the description of the methodology is given in terms of equipment requirements, other kinds of requirements can be addressed as well. The method can be used to minimise the cost of satisfying requirements to achieve prescribed performance standards for defined missions and tasks.

2. The work was motivated by a particular equipment acquisition problem for Surveillance, Target Acquisition and Night Observation (STANO) at the unit level. Thus, and for the sake of example, the method is applied to the unit level STANO problem. However, in anticipation of actual data for existing STANO systems in the CF and in anticipation of data for potential acquisitions of STANO systems by the CF, representative data will populate the example problem used in this report. The results of the completed analysis will be documented in a future report.

3. The purpose of this report is to present the methodology and to illustrate its use, rather than to solve any particular selection problem. Indeed, the primary objective is to provide those who will ultimately provide data with enough background information to meaningfully accomplish the task.

4. The main idea of the methodology is to model the selection problem as a generalisation of the *Minimum Cover Problem* [1], a combinatorial optimisation problem in the class of NP-complete 0-1 linear programming problems. An example of the Minimum Cover Problem is to find the smallest collection of *links* in a network that connect the *set* of all *nodes* in the network. The generalisation, for the network example, is to find the smallest set of links to connect the nodes by selecting among defined *sets* of links rather than just *individual* links, where either *all* or *none* of any group can be selected.

THE MODEL

5. For "equipment" selection, the main components of the model are:

- mission elements
- equipment
- configurations of equipment
- costs of equipment

6. The equipment selection problem can be stated as follows:

> given a set of mission elements and a collection of equipment configurations such that each configuration is adequate to accomplish one or more of the mission elements according to prescribed task standards, determine the lowest cost set of equipment that can accomplish all of the missions.

MISSION ELEMENTS

7. Mission elements describe the intended use of STANO equipment, conditions under which it is to be used and the intended goals of using the equipment. There are many ways of defining mission elements for purposes of the model. For unit level STANO, a mission element will consist of a "task" and a "range" plus at least one "target type" and at least one set of "light level" and "visibility conditions". Alternatively, a mission element could consist of a "task" and a "range", plus all "target types", plus all "light levels" and all "visibility conditions".

8. The level of detail captured in the description of each mission element is a matter of choice on the part of the analyst. The goal is to identify configuration options that suffice across the full spectrum of all tasks, target types, visibility conditions, and ranges that are being considered in the analysis.

EQUIPMENT

9. The term "equipment" is used to refer to all of the individual systems that can be employed to assist with at least one of the mission elements. Both existing systems and proposed acquisitions should be included in the master list of equipment.

10. It may be the case that for analysis of new acquisitions, certain pairs of equipment types or pairs of specific equipment models under consideration would not both be acquired. This might result from some basic incompatibility in operating the equipment items together or it may result from the desire to use and maintain as few types of equipment as possible due to maintenance and inventory considerations. In such cases, constraints can be added to exclude forbidden pairings of equipment items. The section entitled "Forbidden Pairings (Exclusive Disjunction)" discusses this further.

CONFIGURATIONS OF EQUIPMENT

11. Typically, a mission element requires more than one type of equipment in order to be performed to task standards. For this reason, the model allows equipment types to be grouped into configurations. An equipment configuration is a collection of equipment items, specified by number and type, that can satisfactorily accomplish a mission element. Note, however, that equipment options consisting of only one piece of equipment or one equipment type are perfectly valid in the model. Both existing systems and potential acquisitions should be considered when defining the configurations, bearing in mind the prescribed task standards.

12. The identification of suitable configurations may be a nontrivial matter. In particular, validating options that involve the acquisition of new equipment may require field trials, advice from subject matter experts on the new equipment, simulation, war gaming or other analyses in order to satisfactorily establish capability benchmarks. However, this validation process should be carried out regardless of whatever method is ultimately used to make the selection; therefore, the methodology proposed here does not generate additional work.

SENSITIVITY ANALYSIS

13. A significant advantage of the methodology is that direct associations are made between specific mission elements, configurations and task standards. This provides insight into the relative worth of configurations and individual items of equipment, as well as the relative degree of difficulty of the mission elements. Useful information can be obtained by doing sensitivity analysis on mission elements and standards.

14. If small changes in task standards cause large changes in the inventory of selected equipment then other options and possibly other items of equipment should be considered. Alternatively, it may be that the task standards are not well defined for the selection problem being studied.

15. If dropping one mission element causes a large change in the optimal selection, then it is advisable to re-examine configurations which can address that particular mission element with a view to revising and enlarging upon the number of options which are adequate for that mission element and then re-solving the problem. Alternatively, the particular mission element that is problematic might actually be inappropriate for inclusion in the selection problem being analysed.

FORBIDDEN PAIRINGS (EXCLUSIVE DISJUNCTION)

16. For some applications, it may be necessary to exclude the selection of certain pairs of options or certain pairs of equipment types. For example, it may be the case that certain types of equipment are mutually incompatible in terms of functioning together. If it is the case that for the mission elements being addressed, such equipment must be used simultaneously, then any pairings of configurations that combine incompatible equipment should be excluded from the solution.

17. In other cases, a study of options for acquisition of new equipment might consider a number of potential systems of which at most one will actually be purchased. For this type of problem, pairings of configurations that combine more than one of the new systems should be excluded since such pairings are not viable options. By using additional constraints, forbidden pairings (referred to as exclusive disjunction) can be eliminated from the set of feasible selections.

EQUIPMENT COSTS

18. Equipment costs should include all costs that are relevant to the systems under consideration and the intent of the analysis. Such costs might include acquisition costs, O&M costs, or life cycle costs, whatever is appropriate to the particular application at hand.

19. Alternatively, weight or volume can be used instead of cost, or "1"s can be used to count items of equipment in the "cost" function if it is desired to minimise the total number of items of equipment. As well, a preference or utility ranking can be used instead of a "cost" function. One might even use a probabilistic approach to evaluating the utility of configurations. If the unit cost of each equipment type were replaced by the probability of failure of each configuration averaged over the mission elements for which it could be employed, then the methodology would select a minimal set of the most effective configurations which are adequate to accomplish all of the mission elements.

20. Set-up costs, or any other fixed costs associated with equipment acquisition, can be included in the model by using additional variables and constraints. In the statement of the model at paragraph 24, the variables z_i, $1 \le i \le n$, and the constraints labelled, "*fixed cost inclusion for equipment types*", enable fixed costs to be included, if they are required.

STATEMENT OF THE MODEL

21. Let us suppose that m mission elements have been identified for unit level STANO together with defined task standards. Suppose further that for each mission element, one or more equipment configurations have been proposed and that each of the proposed configurations has sufficient capability to accomplish its assigned mission elements, to the prescribed task standards, at minimum.

22. The Selection Problem can be formally stated as a 0-1 integer linear programming problem. Consider first, the constants:

l the number of equipment configurations;

m the number of mission elements;

n the number of equipment types;

F_i the total of all fixed costs incurred by acquiring any equipment type i;

C_i the total of any variable costs per unit of equipment i;

Q_{ik}, $1 \le i \le n$, $1 \le k \le l$, the number of units of equipment i in configuration k;

M $\max_{\substack{1 \le i \le n \\ 1 \le k \le l}} \{Q_{ik}\}$, the largest number of units in any configuration;

U_{jk}, $1 \le j \le m$, $1 \le k \le l$, the utility of configuration k in mission element j;

$$U_{jk} = \begin{cases} 1 & \textit{if configuration k suffices for mission element j} \\ 0 & \textit{otherwise} \end{cases}$$

$$S = \bigcup_{1 \le i < j \le l} \{(i,j) \ni \neg\,(\textit{configuration } i \vee \textit{configuration } j)\}$$

S is the set of exclusive disjunction for all forbidden pairs.

23. Consider next, the variables:

x_k, $1 \le k \le l$ include/exclude configuration k

$$x_k = \begin{cases} 1 & \textit{if configuration k is selected} \\ 0 & \textit{otherwise} \end{cases}$$

y_i $1 \le i \le n$, the minimum number of units of equipment j required to satisfy each of the individual mission elements, taken over all of the mission elements;

z_i, $1 \le i \le n$, include/exclude fixed costs for equipment type i;

$$z_i = \begin{cases} 1 & \textit{if } y_i > 0, \\ 0 & \textit{otherwise} \end{cases}$$

24. The Selection Problem is defined as follows:

$$\textit{minimize} \sum_{i=1}^{n} C_i y_i + \sum_{i=1}^{n} F_i z_i \textit{ (total cost of equipment)}$$

subject to:

$$Q_{ik} x_k \leq y_i,\ 1 \leq i \leq n,\ 1 \leq k \leq l \textit{ (minimum quantity of equipment);}$$

$$\sum_{k=1}^{l} U_{jk} x_k \geq 1, 1 \leq j \leq m \textit{ (adequate capability of equipment for each mission element);}$$

$$z_i \geq \frac{y_i}{M},\ 1 \leq i < n \textit{ (fixed cost inclusion for equipment types);}$$

$$x_i + x_j \leq 1,\ \forall (i,j) \in \tilde{S} \textit{ (exclusive disjunction)}$$

$$\left.\begin{array}{l} x_k \in \{0,1\},\ 1 \leq k \leq l; \\ z_i \in \{0,1\},\ 1 \leq i \leq n \end{array}\right\} \{0-1 \textit{ integer decision variables}\}$$

25. Note that it is not necessary to put explicit integrality constraints on the variables y_i, $1 \leq i \leq n$. Because the values of Q_{ik}, $1 \leq i \leq n$, $l \leq k \leq 1$, are integers, the other constraints and the objective function force, y_i, $1 \leq i \leq n$, to take on only integer values.

26. A matrix view of the Selection Problem appears in Figure 1. The structure of the problem is emphasised by the use of boxes to outline matrices. For some readers, this view might reveal structural features of the 0-1 integer linear programming problem that might not have been evident in the formal statement of the problem given at paragraph 24.

COMPUTATIONAL COMPLEXITY OF THE SELECTION PROBLEM

27. Because the Minimum Cover Problem is in a class of problems whose solution time grows exponentially in the number of variables [1], it is to be expected that the required solution time for the Selection Problem, a generalisation of the Minimum Cover Problem, will also grow exponentially in the number of variables. Thus, instances of the Selection Problem will ultimately become intractable as more configurations and equipment types are added.

28. However, because of the relatively simple role played by the z variables in controlling the addition of fixed costs, it is reasonable to expect that the most significant determining factor in the size of selection problems that can be practicably solved will depend on the x variables. In other words, the number of configurations will be the actual barrier on the size of the selection problems that can be solved in an acceptable amount of time.

29. In addition to the time complexity, the number of constraints can also be a limiting factor. For the Selection Problem, the number of constraints grows quadratically in the number of equipment types and linearly in the number of mission elements. Thus, for the selection problem, the growth in constraints is much less restrictive than the time complexity.

30. Acquisitions planning and operations planning in the CF typically involve a relatively small set of potential configurations, a relatively small set of equipment types and a relatively small set of mission elements. Therefore, in the context of CF planning, it is reasonable to expect that the size of actual Selection Problems will be tractable by using the standard "branch-and-bound" approach of linear programming [2].

EXAMPLE PROBLEM

31. The model has been coded in EXCEL using the SOLVER "tool" in order to provide a quick proof-of-concept demonstrator and also to test the timing requirements. The inherent limitations of SOLVER permit only very small cases of the model to be "solved". An example is shown in Figure 2. The example has 12 equipment types in 5 configurations. Configuration 2 and Configuration 3 are mutually exclusive. There are 26 mission elements. Fixed costs are not included in this example because of the limits on the number of constraints in SOLVER.

minimize

$$C_1 y_1 + C_2 y_2 + \dots + C_n y_n$$
$$(+ F_1 z_1 + F_2 z_2 + \dots + F_n z_n)$$

variable costs + (fixed costs)

subject to

configuration 1 — include/exclude x_1 — minimum required

$$\begin{matrix} \text{equipment item 1} \\ \text{equipment item 2} \\ \vdots \\ \text{equipment item n} \end{matrix} \quad \begin{bmatrix} Q_{11} \\ Q_{21} \\ \vdots \\ Q_{n1} \end{bmatrix} x_1 \le \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

configuration 2 — include/exclude x_2

$$\begin{matrix} \text{equipment item 1} \\ \text{equipment item 2} \\ \vdots \\ \text{equipment item n} \end{matrix} \quad \begin{bmatrix} Q_{12} \\ Q_{22} \\ \vdots \\ Q_{nk} \end{bmatrix} x_2 \le \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

$\vdots$

$$\begin{matrix} \text{equipment item 1} \\ \text{equipment item 2} \\ \vdots \\ \text{equipment item n} \end{matrix} \quad \begin{bmatrix} Q_{1l} \\ Q_{2l} \\ \vdots \\ Q_{nl} \end{bmatrix} x_l \le \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

$$\begin{matrix} \text{mission 1} \\ \text{mission 2} \\ \vdots \\ \text{mission m} \end{matrix} \quad \begin{bmatrix} U_{11} \\ U_{21} \\ \vdots \\ U_{m1} \end{bmatrix} x_1 + \begin{bmatrix} U_{12} \\ U_{22} \\ \vdots \\ U_{m2} \end{bmatrix} x_2 + \dots + \begin{bmatrix} U_{1l} \\ U_{2l} \\ \vdots \\ U_{ml} \end{bmatrix} x_l \ge \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}$$

x_1 = 0 or 1
x_2 = 0 or 1
$\vdots$
x_l = 0 or 1

for any pairs of configurations i and j which are mutually exclusive add a constraint of the form

$$x_i + x_j \le 1$$

if equipment i has a one-time fixed cost of F_i add $z_i \ge y_i/M$, with $z_i = 0$ or 1

utility matrix U_{jk} = 1 if configuration k suffices for mission j
= 0 otherwise

quantity matrix Q_{ik} = units of equipment of item i contained in config j — let $M = \max_{\substack{1 \le i \le n \\ 1 \le k \le l}} \{Q_{ik}\}$

include/exclude variables x_k = 1 if config k is included in the acquisition
= 0 otherwise

equipment totals y_i = minimum required units of equipment item i

equipment costs C_i = unit acquisition cost of equipment item i
F_i = one-time fixed cost of equipment item i

Figure 1: The Selection Problem

NOTE:
pairing of config2 + config3 is excluded

QUANTITY MATRIX

cost	equipment types	config 1	config 2	config 3	config 4	config 5	y variables	
	x variables	1	0	1	1	0		
27	AN/PVS-4	1	3	1	2	6	2	AN/PVS-4
95	AN/PVS-5	0	2	0	0	3	0	AN/PVS-5
38	AN/PVS-6	0	7	0	4	0	4	AN/PVS-6
98	AN/PVS-7A	3	0	3	5	0	5	AN/PVS-7A
41	AN/PVS-7B	0	1	0	0	1	0	AN/PVS-7B
95	AN/TAS-5	0	5	5	0	5	5	AN/TAS-5
50	AN/PAS-7A	3	0	1	9	0	9	AN/PAS-7A
28	AN/PAQ-4A	2	0	9	0	2	9	AN/PAQ-4A
13	AN/PAQ-4B,4C	0	1	3	5	0	5	AN/PAQ-4B,4C
28	AN/UAS-12	0	5	0	0	5	0	AN/UAS-12
17	GCP-1A	4	0	6	0	4	6	GCP-1A
7	Phoenix Beacon	0	5	0	0	5	0	Phoenix Beacon
							total cost	2045

UTILITY MATRIX

MISSION ELEMENTS	config 1	config 2	config 3	config 4	config 5
clear a road	0	0	1	0	1
clear a village	1	1	0	0	0
clear a wood	1	1	0	0	0
conduct a fighting patrol	0	0	1	1	0
conduct a patrol	0	1	1	1	0
conduct a reconnaissance	1	1	1	0	1
control civilian movement	0	1	0	1	0
cordon & search	1	1	1	0	1
est. a blocking position	0	1	1	1	0
est. a defensive position	0	0	1	1	0
est. a sentry post	0	1	0	1	0
est. a strong point	0	0	1	1	0
est. an ambush	1	0	0	0	1
est. and op. a check point	1	1	0	0	0
est. and op. an OP	0	1	1	0	1
establish a listening post	1	0	0	0	1
gain a lodgment	0	1	1	1	0
protect a convoy	1	0	1	1	0
protect a VIP	0	0	1	1	0
protect a vital point	0	1	1	1	1
provide assault force	1	1	0	0	0
provide a cut-off force	0	1	1	0	1
provide a fire base	0	1	0	1	0
react to an ambush	0	1	1	0	0
search a building	0	1	1	1	1
secure a route	1	0	0	1	0

Figure 2: Example Case of STANO Equipment Selection

32. The optimal solution for the example in Figure 2, is to select Configurations 1,3 and 4. Note, that Configuration 2 was rejected and therefore the disjunction between Configurations 2 and 3 is satisfied. The minimum equipment requirements are 2 x AN/PVS-4, 4 x AN/PVS-6, 5 x AN/PVS-7A, 5 x AN/TAS-5, 9 x AN/PAS-7A, 9 x AN/PAQ-4A, 5 x AN/PAQ-4B, 6 x GCP-1A, with a total cost of $2,045,000.

33. About 24 trials were generated by populating the matrices with random data and solving the problem using EXCEL SOLVER. All of the trials were solved within 2 minutes of elapsed time. Using 2 minutes as a "worst case" benchmark, it is estimated that problems involving 15 configurations could be solved within 24 hours on a PC486. Based on this observation, it is reasonable to expect that by using special purpose linear programming software such as LINDO or LINGO, actual instances of the Selection Problem for the CF could be solved.

FEASIBILITY CHECKS

34. An examination of Figure 2 reveals feasibility checks on the data. In the "QUANTITY MATRIX", each row is associated with an equipment type and each column is associated with a configuration; therefore, a row of 0's indicates that the corresponding equipment type is never used in any configuration and a column of 0's indicates the corresponding configuration contains no equipment. Any type of equipment that is not used in any configuration can be removed from the problem. A valid configuration contains at least one type of equipment and therefore a column of 0's indicates an error.

35. In the "UTILITY MATRIX", each row is associated with a mission element and each column is associated with a configuration; therefore a row of 0's indicates that the corresponding mission element is not adequately performed by any of the configurations. If such is the case, then the integer linear programming problem is infeasible. A column of 0's indicates that the corresponding configuration is ineffective against any of the mission elements and therefore the corresponding configuration should be removed from the problem.

MAIN FEATURES OF THE METHODOLOGY

36. The methodology has a number of features that make it appropriate for many applications in the context of CF planning:

- the methodology corresponds well with the actual processes of equipment acquisition in the CF insofar as it allows capabilities to be examined in terms of pinpointing capability deficiencies and gauging the impact of augmenting existing equipment with new or upgraded equipment or the impact of other options that consist entirely of new or upgraded equipment;

- the methodology provides a framework for identifying requirements for test and evaluation of equipment;

- in CF operations, tasks and missions are addressed by configurations of equipment and not just single types of equipment; the methodology captures this "ensemble" approach to military capability;

- if the integer linear programming problem is solved, then the list of equipment that results is the *global* optimum for the "*cost*" function; selection methods based on heuristics that aggregate information about structured sub-problems into an overall solution for the Selection Problem do not necessarily find the minimum cost solution

- if the size of an application renders optimisation impracticable, heuristics can be used to find a "good" feasible solution; alternatively, the branch-and-bound method can be allowed to proceed for an acceptable time interval and the best feasible solution found can be taken as a good solution.

37. Note that the method can be applied to much broader classes of *selection problems* than the STANO problem. Other such problems include:

- selection of personnel by rank and MOC to be included in a military unit to minimise total personnel costs or total number of personnel;

- selection of military units to be included in a formation to minimise the total number of personnel or the total number of units;

- selection of equipment to minimise the total number of pieces of equipment, the total weight or the total volume;

- selection of alternative activities to achieve personnel training or equipment maintenance objectives with minimum cost.

This list is by no means complete. Rather, it is intended as a sample of the sort of selection problems that the methodology can address.

38. Military planners frequently estimate the minimum number of items of such things as equipment, supplies or personnel that suffice to meet defined requirements. Unsophisticated estimation techniques typically do not distinguish between multiple uses of the same item and often overestimate the minimum requirement by naively including such items more than once in the estimation process. This phenomenon is referred to as “double counting”. Enumeration using the proposed linear programming methodology eliminates “double counting”. Thus, for example, double counting associated with current methods of constructing Tables of Organisation and Equipment (TO&E) can be overcome by applying this approach.

39. The model has been described in terms of “equipment” selection. As previously stated, for “equipment” selection, the main components of the model are:

- mission elements
- equipment
- configurations of equipment
- costs of equipment

For personnel selection, “personnel” would replace “equipment” in the above list; for selection of military units, “units” would replace “equipment”. For minimising total weight of equipment, “weights” would replace “costs”. To minimise the total number of items, take the “cost” of each item as “1”.

SUMMARY AND CONCLUSIONS

40. This note has described a methodology for selecting equipment in order to accomplish a set of mission elements. The selection is based on “configurations” of equipment types rather than just individual types. The methodology finds the lowest cost set of equipment that meets the minimum requirements for all of the mission elements.

41. The computational complexity of the methodology is potentially onerous. However, within the context of CF planning, it is expected that PC based software will adequately address most problems in a feasible amount of time.

42. In order to apply the methodology, there is as well, the non-trivial matter of identifying equipment configurations that can perform mission elements according to given task standards. However, this part of the equipment selection problem must be solved in any case, and therefore the methodology proposed here does not impose an additional burden of analysis.

43. While this research note has been written mainly in terms of equipment selection, the methodology can be applied to a broad class of selection problems. Furthermore, it can be used to eliminate overestimates of requirements that result from "double counting".

REFERENCES

1. Garey, Michael R and Johnson, David S., "Computers and Intractability: A Guide to the Theory of NP-Completeness", W.H. Freeman and Company, San Francisco, 1979.

2. Bradely, Stephen P., Hax, Arnold C. and Magnanti, Thomas L., "Applied Mathematical Programming", Addison-Wesley Publishing Company, Reading, Massachusetts, 1977.

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared e.g. Establishment Sponsoring a contractor's report, or tasking agency, are entered in Section 8). Operational Research Division Department of National Defence Ottawa, Ontario K1A 0K2	2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable) UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title)

SATISFYING REQUIREMENTS AT MINIMUM COST: METHODOLOGY WITH AN APPLICATION TO UNIT LEVEL STANO REQUIREMENTS

4. AUTHORS (last name, first name, middle initial)
O'Neill, Dr. Phil

5. DATE OF PUBLICATION (month Year of Publication of document) October 1996	6a. NO OF PAGES (total containing information. Include Annexes, Appendices, etc.) 20	6b. NO OF REFS (total cited in document) 2

7. DESCRIPTIVE NOTES (the category of document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Research Note

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address).

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) 3551-20201-4	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written.) ---
10a. ORIGINATOR's document number (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) JSORT RESEARCH NOTE RN 9605	10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor.) ---

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification.)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors: further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

13. **ABSTRACT** (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the test is bilingual).

This report summarises a methodology for selecting equipment to accomplish a set of mission elements according to prescribed task standards. The main idea is to model the problem as a generalisation of the classic "Minimum Cover Problem", which is solvable by standard techniques of integer linear programming. The methodology uses defined configurations of equipment to address the mission elements. The solution it provides is the lowest cost set of equipment that satisfies all of the requirements for the mission elements. An example problem is discussed, that of selecting unit level STANO equipment. While the discussion is mainly in terms of equipment selection, the methodology can be applied to other classes of selection problems.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified . If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

decision support
equipment selection
integer linear programming
mathematical modelling
operations research
requirements analysis
unit level STANO

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

Canada

NO. OF COPIES NOMBRE DE COPIES	COPY NO. COPIE Nº	INFORMATION SCIENTIST'S INITIALS INITIALES DE L'AGENT D'INFORMATION SCIENTIFIQUE
1	1	BA

AQUISITION ROUTE FOURNI PAR ▶	DRD
DATE ▶	7 Nov 96
DSIS ACCESSION NO. NUMÉRO DSIS ▶	

DND 1158 (6-87)

#499907

National Defence / Défense nationale

PLEASE RETURN THIS DOCUMENT TO THE FOLLOWING ADDRESS:

DIRECTOR
SCIENTIFIC INFORMATION SERVICES
NATIONAL DEFENCE
HEADQUARTERS
OTTAWA, ONT. - CANADA K1A 0K2

PRIÈRE DE RETOURNER CE DOCUMENT À L'ADRESSE SUIVANTE:

DIRECTEUR
SERVICES D'INFORMATION SCIENTIFIQUES
QUARTIER GÉNÉRAL
DE LA DÉFENSE NATIONALE
OTTAWA, ONT. - CANADA K1A 0K2