Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 510032
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TITLE

TARIFF ESTIMATION FOR THE NEW LIGHTWEIGHT THERMAL UNDERWEAR

System Number:

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DSIS Use only:

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TECHNICAL MEMORANDUM

3776 6ke12 (HES)

26 January, 1998

TARIFF ESTIMATION FOR THE NEW
LIGHTWEIGHT THERMAL UNDERWEAR

References:
A. Meeting held in Hull, January 7, 1998
B. Results of fit testing trials of the lightweight thermal underwear performed by Capt S. Boyne and Mr R. Marinelli
C. Chamberland, A., Carrier, R., Forest, F., & Hachez, G. (1998). *Anthropometric survey of the Land Forces (LF97)* (Contractor report 98-CR-15). Toronto: DCIEM.
D. Dillon, W. R., & Goldstein, M. (1984). *Multivariate analysis*. New York: John Wiley & Sons.

EXECUTIVE SUMMARY

Fit trial data were collected by CTS (Clothe the Soldier) and DSSPM (Director of Soldier System Project Management) personnel on a sample of 54 men and 25 women from CFB Petawawa. The subjects were measured for height, weight, chest circumference and waist circumference. The subjects were given an initial undergarment size and asked to perform a series of range of motion tests such as reaching overhead, touching toes, etc. Subjects were instructed to try-on neighboring sizes so as to select the best fitting garment. After a trial and error period, subjects settled on their preferred garment size. DCIEM was requested to analyze the results and provide tariff estimates for Land Forces males and females based on these fit trial results. Two methods were used to analyze the data: traditional bivariate classification and multivariate discriminant function analysis. Clothing size classification rules were established from the fit trial results and subsequently applied to the Land Forces 97 anthropometric survey data to provide tariff estimates. Both methods were applied to the fit trial results to generate the best possible tariff estimates.

BACKGROUND

The method used for establishing tariffs usually revolves around a small set of key dimensions and pre-established limits for each dimension. For instance, a trouser size might be 7032, where 70 is the stature in inches and 32 is the waist circumference. Direct application of these measures to an anthropometric database would yield the number of individuals that would meet the criteria of this size, and tariffs could be generated. This system may break down when other factors come into play. One can see, for example, that crotch height may be more pertinent to trouser selection than stature, and particular features of the trouser design may cause other limiting factors to enter into size selection.

Ignoring those factors during tariffing may cause significant overstocking and understocking of sizes in the supply system.

Many of the factors affecting size selection can only be determined through fitting trials. A fitting trial requires the participation of test subjects spanning, to the extent possible, the full range of the anthropometric dimensions of interest, and having them perform representative tasks. One of the best ways of obtaining a good range of test subjects is by using global body size criteria such as stature and weight in the selection process. Figure 1 gives a global view of the fit trial subjects relative to each other and the 95% equiprobability ellipse derived from the Land Forces anthropometric survey of 1997 (Reference C).

The objective of a fitting trial is to collect pertinent anthropometric data on the subjects, and arrive at the best fitting size of garment for each individual. Determination of the best fitting size of garment is achieved through a test protocol requiring subjects to perform representative or worst case tasks to help them make an informed subjective assessment of fit. Once the fit data have been collected, the next task is to determine which anthropometric dimensions govern the selection of a size, and at what value the transition takes place from one size to the other.

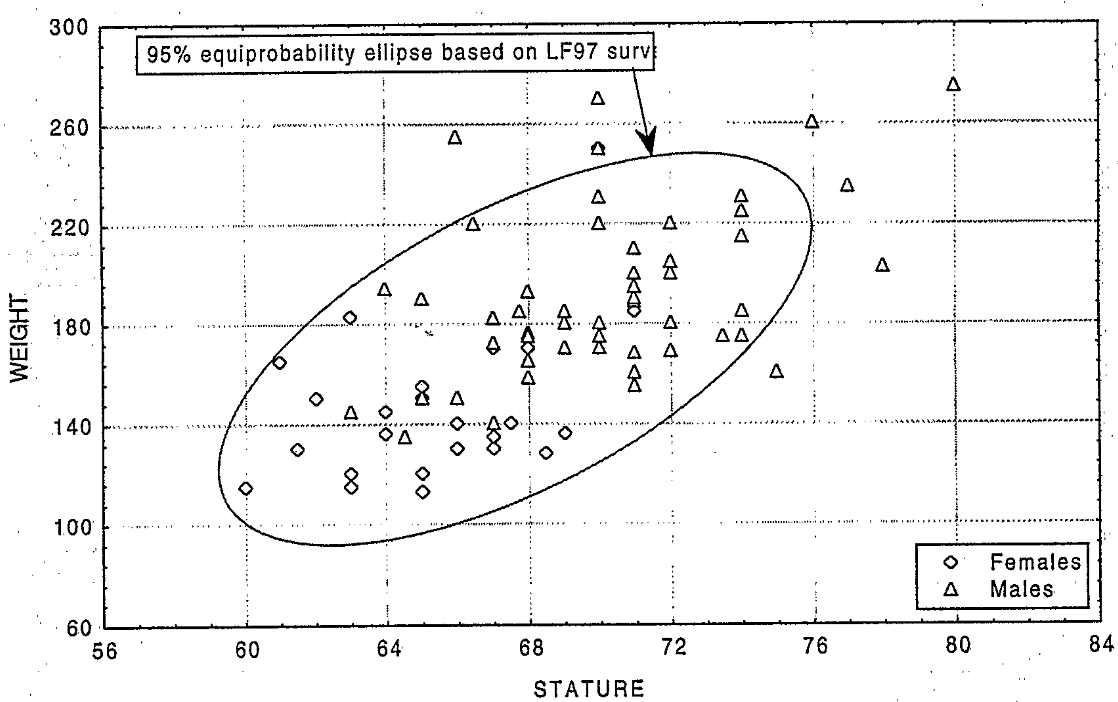

Figure 1 Fit test sample relative to LF97 survey data

The objective of the work described in this paper was to arrive at the most accurate estimate of tariffs based on fit trial data provided at reference B. Two methods of generating tariffs were used: a multivariate analysis technique called "discriminant function analysis" and the more traditional bivariate methods. The relative merits of the results obtained using both methods are discussed.

DATA

Fit trial data were collected by CTS (Clothe the Soldier) and DSSPM (Director of Soldier System Project Management) personnel on a sample of 54 men and 25 women from CFB Petawawa, reference B. The subjects were measured for height, weight, chest circumference and waist circumference. They were given an initial undergarment size and asked to perform a series of range of motion tests such as reaching overhead, touching toes, etc. Subjects were instructed to try-on neighbouring sizes so as to select the best fitting garment. After a trial and error period, subjects settled on their preferred underwear size.

REPRESENTATIVENESS OF THE TEST SAMPLE

The anthropometric data of the fitting trial were compared with those of the Land Forces anthropometric study in order to detect differences in landmarking and/or measurement technique and correct the biases where possible. The results of t-tests (Appendix A) show that for males, subjects in the fit testing sample were taller ($p=0.03$) and heavier ($p=0.06$) than the subjects measured in the Land Forces 97 survey (LF97). A look at Figure 1 confirms that several individuals were clearly outside the 95% probability ellipse for height and weight. Significant differences would therefore be expected in chest and waist circumference. The fact that chest circumference was larger by 1.5 inches in the test sample ($p=0.005$) but waist circumference was not ($p=0.61$), is highly suspect, and suggests that the trial measurements could have been taken substantially differently than those of the Land Forces survey.

Definitions for waist circumference vary substantially depending on the application. In anthropometry, two standard waist circumference measurements are widely accepted: waist circumference at omphalion, and waist circumference natural indentation. The former is taken at the navel level while the latter is taken at the greatest indentation at the side of the torso. Both were taken during the LF97 survey. Unfortunately, neither of these measures coincides with tailor's measures of waist whose definition depends on personal preference and on the garment being worn. In essence, the anthropometric measurements are repeatable on individuals but not necessarily pertinent for garments; tailor measurements are pertinent to garments but rely on "preferred" waist. There hasn't been, to date , an accepted definition for "preferred waist" circumference. Because the definitions of waist circumference are not comparable between the fit test sample and the LF97 survey, the tariffs generated will be biased. From recent work, it is possible to state that "preferred waist" will almost always be smaller than waist at omphalion, which explains the above results. Therefore, one can expect the tariffs to overestimate the percentage of larger size underpants required.

Similar t-tests were performed comparing the female fit test sample with the LF97 female data. The results indicate that stature, weight and chest circumference were not significantly different. Females in the fit testing sample were significantly smaller in waist circumference by 3.3 inches ($p=0.005$) than those measured in the LF97 survey. Since the samples were similar in stature and weight, this indicates that the landmark definitions were again probably different. In this case, however, the test sample was comparable in stature and weight to the LF97 survey, which means that it should be possible to use a 3.3 inch correction factor, assuming a high correlation between the two.

This correction should eliminate some of the bias, and allow the analysis to proceed with the generation of ballpark figures.

BIVARIATE ANALYSIS

The bivariate method is simple and efficient, as it considers only the two most important dimensions. The choice of dimensions is basically determined from experience or tradition. The down side is that it ignores all other "factors" that could affect size selection. The accuracy of this method is contingent upon the material characteristics and the design of the garments. Variations in materials and design may bring in a number of additional "factors" in the fit "equation".

The preferred sizes were plotted against stature-waist circumference (for the underpants) and stature-chest circumference (for the undershirt) bivariate plots shown in Appendix B. "Cut-off" values that could best explain individual choices of undergarments were found by inspection. The choice of cut-off values was not always straight forward due to the fact that subjects of similar dimensions appeared to prefer different sizes of undergarment. This difference in choice may be the result of additional factors acting on size selection. Some would argue that personal preference, which is an intractable construct, plays a major role in size selection. However, it is hypothesized that a big part of personal preference has its roots in unaccounted body shape and size factors. It is conceivable that given all of the pertinent anthropometric information, the "preferred" size could be predicted with a high degree of certainty. Given only two variables, this was not possible. Figure B-1 in Appendix B shows a set of separation lines between sizes that was attained after several attempts to achieve a balance between included and excluded personnel. It seems apparent, from the data, that waist circumference is the driving factor in the subjects' choices of size. However, there is a point where stature (or, more appropriately, crotch height) becomes the limiting factor. This can clearly be seen for subjects over 76 inches in stature who selected XL undergarments rather than the large size that their waist circumference would suggest. The same is true of the single XXL and for XS in the women's underwear.

Tables 1 and 2 show the prediction accuracy obtained for underpants using the bivariate method. Individual prediction rates varied from 29% to 75% accuracy for males, while they were between 50% and 100% for females. The global prediction success was 62% and 83% for males and females respectively.

The undershirt results reflect a greater importance being placed on stature than in the case of the underpants. In the case of males, a very clear transition is evident around 74 inches of stature: both the Medium and Large sizes seem inadequate for individuals taller than 74 inches. The female results appear to show that size selection is strictly a function of chest circumference.

Tables 3 and 4 show the prediction accuracy obtained for undershirts using the bivariate method. Individual prediction rates varied from 62.5% to 100% accuracy for males, while they were between 66.7 and 91.7% for females. The global prediction success was 79.6% and 80% for males and females respectively.

Table 1. Observed versus predicted classification of fit test sample males: underpants.

UNDERPANTS	Percent Correct	S	M	L	XL	Total Observed
S	75	6	2	0	0	8
M	75	3	18	3	0	24
L	50	0	4	7	3	14
XL	29	0	1	4	2	7
Total Predicted	62	9	25	14	5	54

Table 2. Observed versus predicted classification of fit test sample females: underpants.

UNDERPANTS	Percent Correct	XS	S	M	L	Total Observed
XS	100.0	2	0	0	0	2
S	92.9	0	13	1	0	14
M	50.0	0	2	2	0	4
L	75.0	0	0	1	3	4
Total Predicted	83.3	2	15	4	3	25

Table 3. Observed versus predicted classification of fit test sample males: undershirt.

UNDERSHIRT	Percent Correct	S	M	L	XL	Total Observed
S	62.5	5	3	0	0	8
M	81.8	1	18	3	0	22
L	75.0	0	2	12	2	16
XL	100.0	0	0	0	8	8
Total Predicted	79.6	6	23	15	10	54

Table 4. Observed versus predicted classification of fit test sample females: undershirt.

UNDERSHIRT	Percent Correct	XS	S	M	L	Total Observed
XS	66.7	4	2	0	0	6
S	91.7	1	11	0	0	12
M	75.0	0	1	3	0	4
L	66.7	0	0	1	2	3
Total Predicted	80.0	5	14	4	2	25

DISCRIMINANT ANALYSIS

Discriminant analysis is a multivariate statistical technique used to classify individuals into mutually exclusive and exhaustive groups based on a set of independent variables (Ref. D). The independent variables, in this case, are the anthropometric measurements. The discriminant analysis uses a linear combination of these variables in such a way as to minimize the misclassification error rates. The analysis determines which anthropometric variables are useful in discriminating between individuals belonging to different clothing size categories and at what value a transition occurs.

The approach used in this study made use of the fit test trial sample to define the relationship between anthropometric variables and the preferred clothing size. It is assumed that the subjects were representative of the population in their way of selecting the best fitting undergarment. Based on that assumption, one can expect the relationship between the anthropometry and the choice of undergarment to be relatively stable provided that the sample was large enough. If this is the case, then, the discriminant functions can be used to infer the choices made by a larger population such as that of the Land Forces.

In the case of the underpants, the discriminant function analysis results (shown in Table 5) showed that, for men, waist circumference was a strong contributor to the discriminant function (p-level=0.003), while the contributions of stature (p-level=0.06) and weight (p-level=0.07) were more moderate. In the case of females, waist circumference was also a significant contributor (p=0.03) while stature and weight were not.

Table 5. Discriminant function analysis summary for underpants, males.

No. of variables in model: 3; Grouping: 4 groups (S, M, L, XL)
Wilks' Lambda: .23861 approx. F (9,114)=10.204 p< .0000

N=53	Wilks' Lambda	Partial Lambda	F-remove (3,47)	p-level	Toler.	1-Tol. (R-Sqr.)
Weight	.278	.862	2.50	.070	.624	.376
Height	.280	.853	2.69	.057	.785	.214
Waist Circ.	.322	.741	5.47	.003	.555	.445

Table 6 shows the accuracy with which males were classified into small, medium, large and extra-large underpants. It shows, for example, that 42.9% of males who selected the large underpants were classified in the "large" size category. Five of them were "misclassified" as medium, and three as extra-large. Figure B-1 shows that a similar misclassification occurred by inspection as well. Other factors may be at play, in this instance, which could explain these surprising choices of garment size.

Table 7 shows the same results for females. It is interesting to note that the two females who preferred extra-small underpants were classified as "small" in the analysis. The discriminant analysis ignored the role that stature may have played in the choice of this size of garment. This is not surprising since there were only two subjects (the bare minimum for conducting a discriminant analysis) from which to derive a classification pattern. This shows that discriminant analysis results based on a small number of subjects should be interpreted with caution.

Table 6. Observed versus predicted classification of fit test sample males: underpants.

UNDERPANTS Group	Percent Correct	S p=.15	M p=.45	L p=.26	XL p=.13	Total Observed
S	62.5	5	3	0	0	8
M	95.8	0	23	1	0	24
L	42.9	0	5	6	3	14
XL	57.1	0	0	3	4	7
Total Predicted	71.7	5	31	10	7	54

Table 7. Observed versus predicted classification of fit test sample females: underpants.

UNDERPANTS Group	Percent Correct	XS p=.08	S p=.58	M p=.17	L p=.17	Total Observed
XS	0.0	0	2	0	0	2
S	100.0	0	14	0	0	14
M	50.0	0	2	2	0	4
L	100.0	0	0	0	4	4
Total Predicted	83.3	0	18	2	4	25

In the case of the undershirts, stature ($p<0.001$) and chest circumference ($p<0.001$) were found to be significant contributors to the discriminant function for males, while none of the four anthropometric variables for the women stood out. A look at Figure B-4 confirms the lack of pattern with respect to stature and chest circumference. A larger sample of females would be required to bring out the size selection patterns more clearly. A possible explanation could be that some design features of the undershirt may affect females differently than males.

The prediction of undershirt size selection was somewhat more successful than in the case of the underpants. Tables 8 and 9 show overall classification success rates of 79.6% for males and 88% for females vice 71.7% and 83.3% respectively for the underpants.

Table 8. Observed versus predicted classification of fit test sample males: undershirt.

UNDERSHIRT Group	Percent Correct	S p=.15	M p=.41	L p=.30	XL p=.15	Total Observed
S	75.0	6	2	0	0	8
M	77.3	2	17	3	0	22
L	81.3	0	3	13	0	16
XL	87.5	0	0	1	7	8
Total Predicted	79.6	8	22	17	7	54

Table 9. Observed versus predicted classification of fit test sample females: undershirt.

UNDERSHIRT Group	Percent Correct	XS p=.24	S p=.48	M p=.16	L p=.12	Total Observed
XS	83.3	5	1	0	0	6
S	100.0	0	12	0	0	12
M	75.0	0	1	3	0	4
L	66.7	0	0	1	2	3
Total Predicted	88.0	5	14	4	2	25

TARIFF ESTIMATES

Tariff estimates were generated using the rules established by both methods and the raw data from the LF97 survey data. The rules were applied directly to the LF97 data to determine, on an individual basis, the size of undergarment each of the survey's 708 subjects would prefer. The results are shown in Table 10 for the underpants, and in Table 11 for the undershirt.

Table 10. Tariff estimates for the underpants: percentage per size category

	Discriminant		Bivariate	
Size	Males	Females	Males	Females
XS		2.9		21.8
S	15.1	68.7	14.6	46.9
M	45.4	14.4	32.0	14.0
L	34.4	14.0	34.2	17.3
XL	5.2		19.1	

Table 11. Tariff estimates for the undershirt: percentage per size category

	Discriminant		Bivariate	
Size	Males	Females	Males	Females
XS		14.4		14.0
S	21.9	51.0	14.4	48.6
M	55.1	22.2	66.2	30.0
L	20.2	12.3	16.1	7.4
XL	2.8		3.2	

DISCUSSION

Two fundamental issues affected the outcome of the size prediction accuracy of both methods. The first issue had to do with the number of subjects per garment size being evaluated, while the second issue had to do with the number of anthropometric variables collected.

The question of how many subjects to include in a study is applicable to several fields of activity. The objective is usually to obtain a satisfactory degree of accuracy with the smallest possible number of subjects. Careful subject selection is the key to minimizing the cost-benefit ratio. Thus, where pre-selection is possible, subjects should be selected on the basis of stature and weight, and should be uniformly distributed across the 95% equiprobability ellipse. Based on this strategy, and the results of this study, a sample size of 8 to 10 individuals per garment size would probably be ideal.

The selection of anthropometric dimensions is also of critical importance to the determination of tariffs. Firstly, it is important to measure fit trial individuals in accordance with the measurement definitions of the LF97 survey. Secondly, it is important to measure all of the pertinent variables. As far as fit trials are concerned, it is better to take too many measures than too few. Again, the same type of trade-off applies as in the case of the number of subjects. Furthermore, some of the pertinent dimensions may only be identified after testing a few or all of the subjects. In the case of the LWTU, the discriminant analysis method would probably have benefited from the knowledge of dimensions such as crotch height, waist-back length, sleeve length, etc. Perhaps a system such as ICESS (Intelligent Clothing and Equipment Sizing System) could be used as a data-gathering tool in the future and integrated into the garment development process. ICESS not only takes a good number of standard dimensions but the images it takes can be re-analysed to extract a new list of variables after the trial.

Although prediction accuracy is one of the measures of performance, the acceptability of the misclassifications may be another. If, for example, an individual were located on the cut-off value between two sizes, then an error in prediction accuracy would be of little consequence. If, on the other hand, a garment two sizes too small was attributed to an individual, customer satisfaction may be adversely affected. The acceptability of the classification errors committed by the use of bivariate cut-off values versus discriminant analysis cannot be assessed properly using the current data set, since the rules were not in place to be tested. However, given the elasticity of the fabric and the results of the tests, one would expect satisfaction to be high in either case.

Discriminant analysis determines, by statistical means, which anthropometric dimensions enter into individual size selection and what the cut-off values are between sizes. Given all of the necessary input variables, this method could offer a highly successful size prediction and therefore highly accurate tariff estimates. Reducing the classification equations to practice at the point of issue would require more sophisticated means than are currently available. In the end, however, it is argued that individuals would select the size they prefer irrespective of the garment's scale of measurement. Therefore, fit testing followed by discriminant analysis are likely to provide the best tariff estimates since they are based on what individuals would actually draw from clothing stores.

Overall, the discriminant analysis results were slightly better than bivariate cut-off values. Thus, the classification rules of the discriminant analysis should be used to determine the purchasing tariffs with one notable exception: the female underpants. Although both methods have the same overall prediction accuracy, the discriminant analysis ignored the influence of stature on garment selection. The highlighted percentages in Table 12 represent the recommended methods to be used for tariff estimation for each undergarment.

Table 12. Overall prediction accuracy of both methods relative to undergarment type.

	Males		Females	
	Discriminant	Bivariate	Discriminant	Bivariate
Underpants	72%	62%	83%	83%
Undershirt	80%	80%	88%	80%

CONCLUSIONS

Fit testing is an important part of the clothing development and/or acquisition process. The results of such tests are the only ones that can be used to predict, with some accuracy, how the users will select the best fitting size. This enables the procurement system to anticipate the needs and purchase quantities that reflect this preference in the most efficient manner.

Discriminant analysis is a powerful multivariate technique that can be used in the determination of tariffs based on fit testing data. It brings out the limitations of the garments themselves by simply identifying those anthropometric variables that have a significant role in the selection of the preferred garment size. This feedback can also be valuable during the development of garments.

In order to be most effective, however, discriminant analysis requires:

a) a minimum of 8 to 10 subjects per clothing size category would be adequate, and

b) a complete set (as complete as possible) of the relevant anthropometric variables.

The number of anthropometric dimensions to take during a fit trial is not as easy to specify since the determination of relevant anthropometric variables depends, in part, on the characteristics of the garment itself; they cannot always be identified in advance of fit testing. To prevent the problem of ignoring important dimensions, it is preferable to err on the safe side and take more than needed. Automatic anthropometric measurement systems (such as the Intelligent Clothing and Equipment Sizing System (ICESS)) could be useful in future fit trials.

RECOMMENDATIONS

The tariffs recommended on the basis of the fit trial information are as shown in tables 13 and 14.

Table 13. Suggested tariffs for the Lightweight Thermal Underpants.

Underpants	Females (Percent)	Males (Percent)
XS	21.8	
S	46.9	15.1
M	14.0	45.4
L	17.3	34.4
XL		5.2

Table 14. Suggested tariffs for the Lightweight Thermal Undershirt.

Undershirt	Females (Percent)	Males (Percent)
XS	14.4	
S	51.0	21.9
M	22.2	55.1
L	12.3	20.2
XL		2.8

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APPENDIX A

Results of t-tests comparing the Light Weight Thermal Undewear (LWTU) trial subject anthropometry with the Land Forces anthropometric study (LF97) data

Table A-1. Comparison of fit test sample with LF97 survey data (Males)

	Means (in.)		t separ.	p-value	Std.Dev. (in.)		F-ratio	p-value
	LWTU	LF97	var.est.	2-sided	LWTU	LF97		
Stature	70.2	69.1	2.23	0.030	3.57	2.58	1.91	0.00
Weight	189.7	180.1	1.87	0.066	36.79	27.48	1.79	0.00
Chest circ.	43.1	41.6	2.89	0.005	3.62	2.82	1.65	0.01
Waist circ.	35.8	36.4	-1.01	0.317	3.85	4.09	1.12	0.61

Table A-2. Comparison of fit test sample with LF97 survey data (Females)

	Means (in)		t separ.	p-value	Std.Dev. (in)		F-ratio	p-value
	LWTU	LF97	var.est.	2-sided	LWTU	LF97		
Stature	65.4	64.4	1.68	0.104	2.83	2.24	1.59	0.09
Weight	145.6	149.0	-0.53	0.598	29.88	26.90	1.23	0.43
Chest circ.	37.8	37.5	0.29	0.773	4.15	3.68	1.27	0.38
Waist circ.	30.7	34.1	-3.03	0.005	5.27	5.07	1.08	0.73

APPENDIX B

Bivariate analysis graphs.

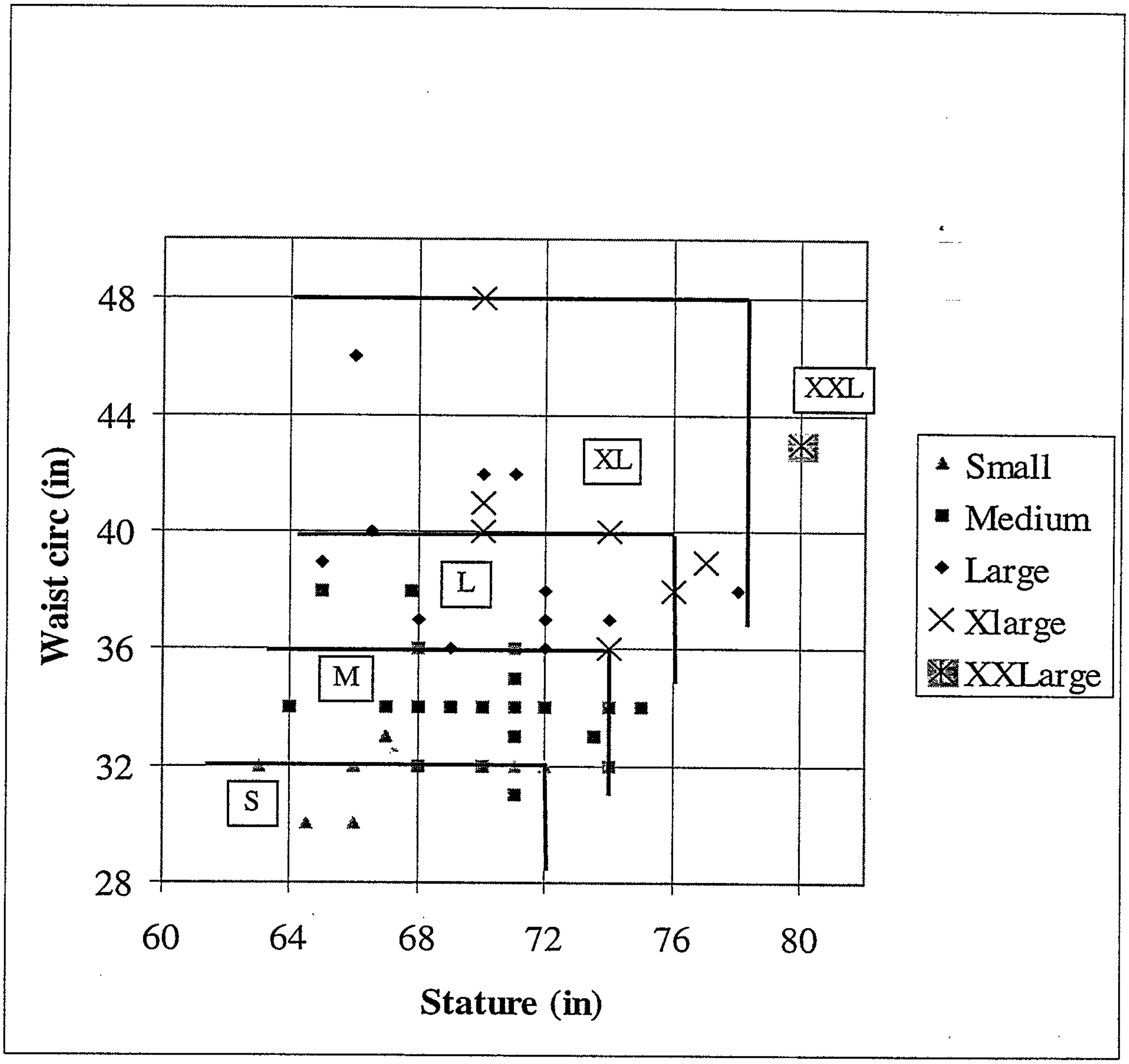

Figure B-1. Preferred underpants size in relation to stature and waist circumference, males.

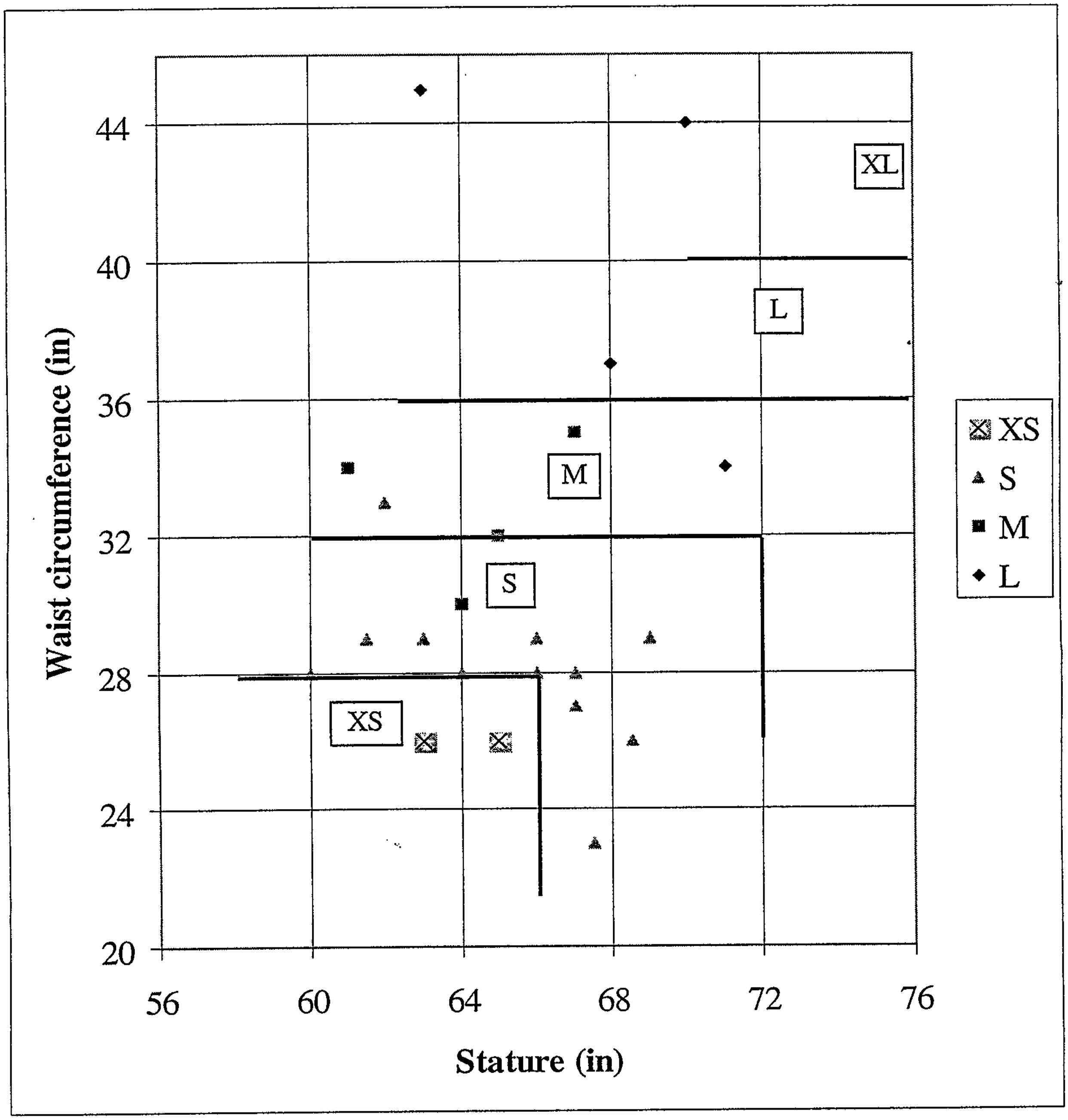

Figure B-2. Preferred underpants size in relation to stature and waist circumference, females.

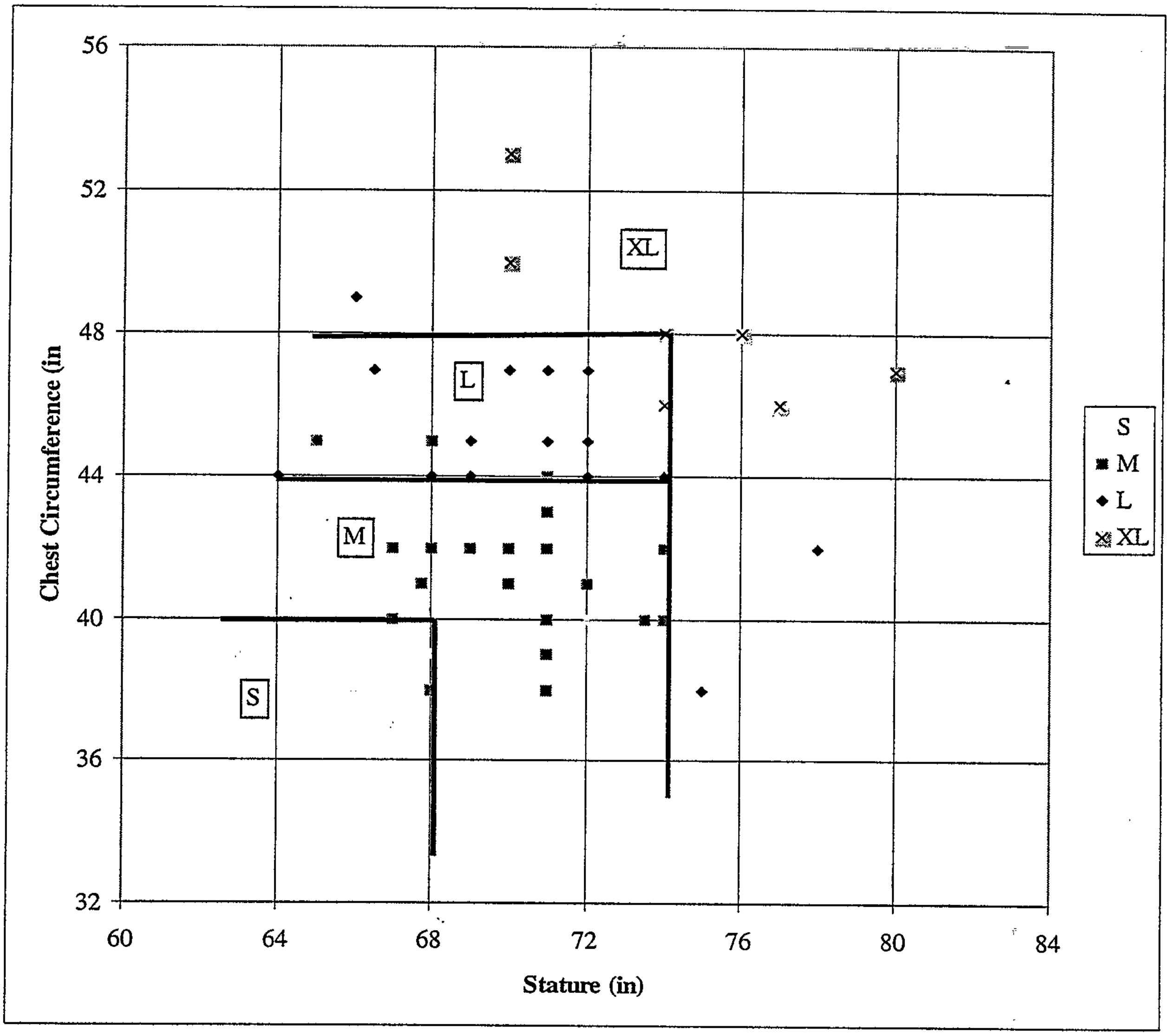

Figure B-3. Preferred undershirt size in relation to stature and chest circumference, males.

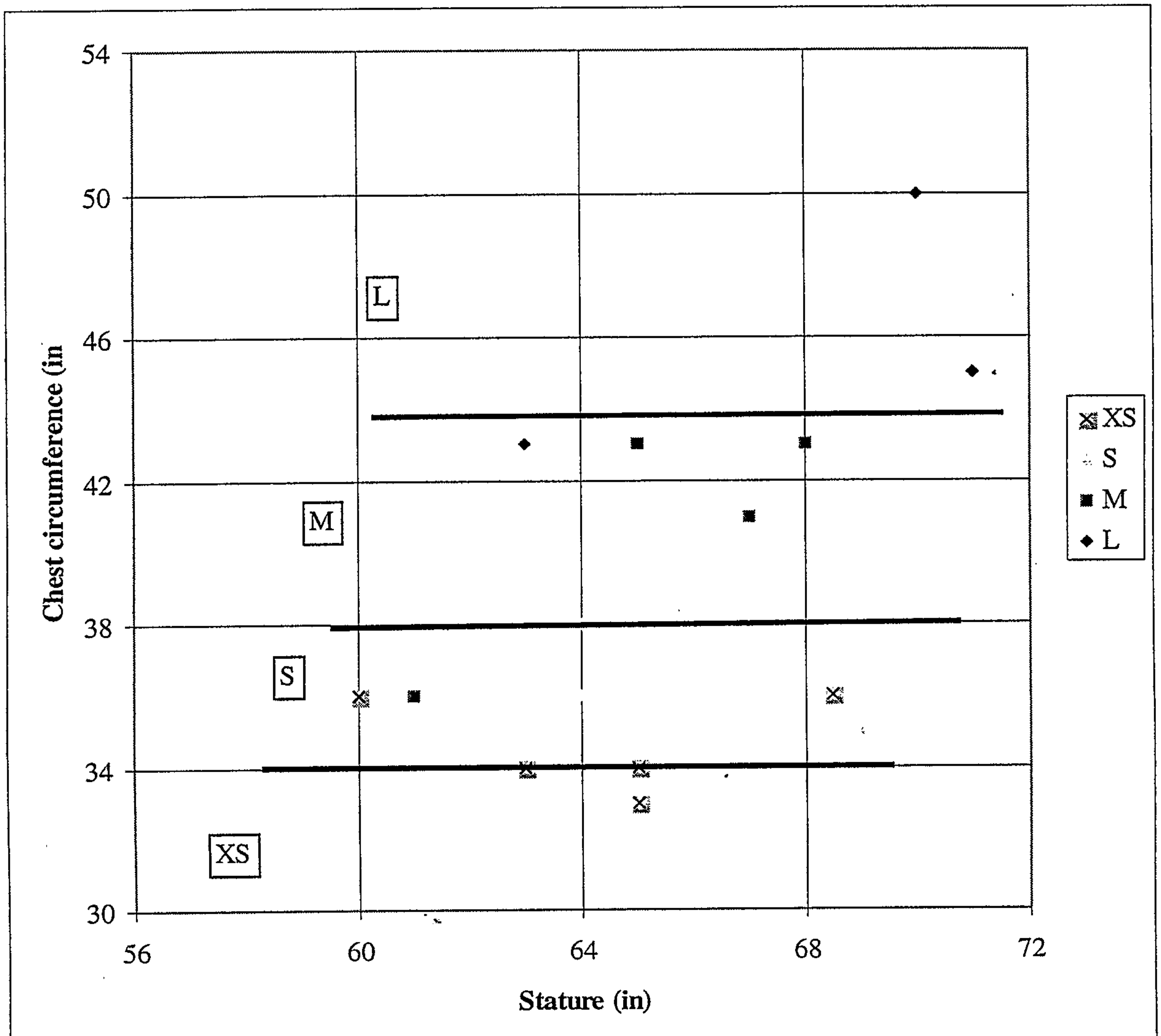

Figure B-4. Preferred undershirt size in relation to stature and chest circumference, females.

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Meunier, P.

6. DOCUMENT DATE (month and year of publication of document) 26 January, 1998	7.a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 16	7.b. NO. OF REFS. (total cited in document) 4

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Fit trial data were collected by CTS (Clothe the Soldier) and DSSPM (Director of Soldier System Project Management) personnel on a sample of 54 men and 25 women from CFB Petawawa. The subjects were measured for height, weight, chest circumference and waist circumference. The subjects were given an initial undergarment size and asked to perform a series of range of motion tests such as reaching overhead, touching toes, etc. Subjects were instructed to try-on neighboring sizes so as to select the best fitting garment. After a trial and error period, subjects settled on their preferred garment size. DCIEM was requested to analyze the results and provide tariff estimates for Land Forces males and females based on these fit trial results. Two methods were used to analyze the data: traditional bivariate classification and multivariate discriminant function analysis. Clothing size classification rules were established from the fit trial results and subsequently applied to the Land Forces 97 anthropometric survey data to provide tariff estimates. Both methods were applied to the fit trial results to generate the best possible tariff estimates.

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.)

Tariff, anthropometry, fit testing, sizing, multivariate, discriminant analysis, clothing

#510032

DSIS DCD03
HFD 07/94

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