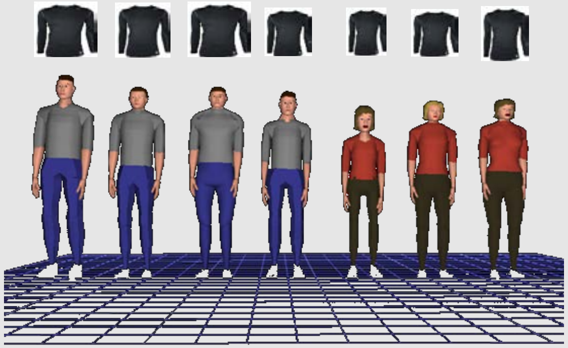
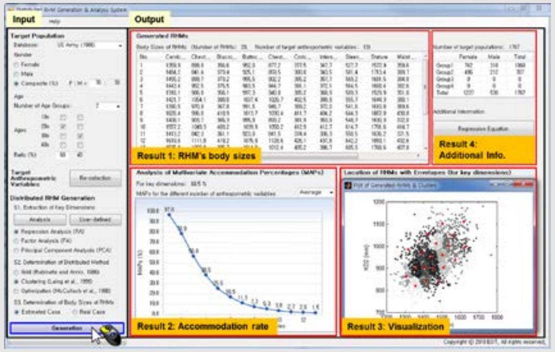
포항공과대학교 산업경영공학과

Ergonomic Design Technology Lab

Development of a Distributed Representative Human Model (DRHM) Generation and Analysis System for Multiple-Size Product Design





2013. 10. 3

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Agenda

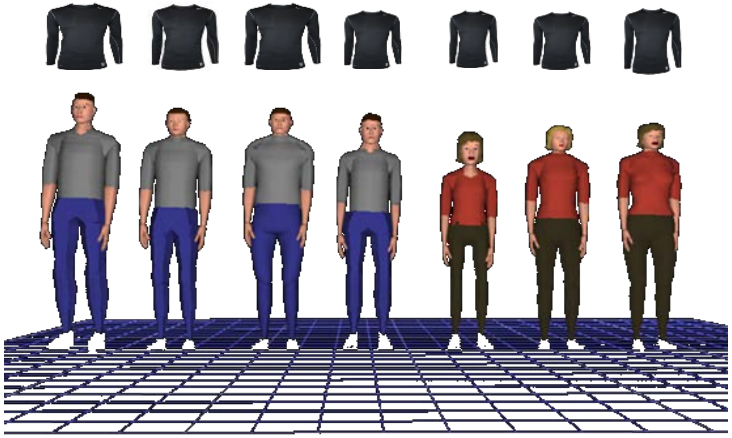
- Introduction
  - Background
  - Objective of the Study
- Literature Review
- System Development
- Application: Flight Suit Sizing System
- Discussion

Sizing System of Multiple-Size Product

- Multiple-size product: *n* sizes to fit *n* groups of people within a designated percentage (e.g., 90%) of the population (Winks, 1997; Ashdown, 2003; Jung et al., 2010)

Clothing

Gloves



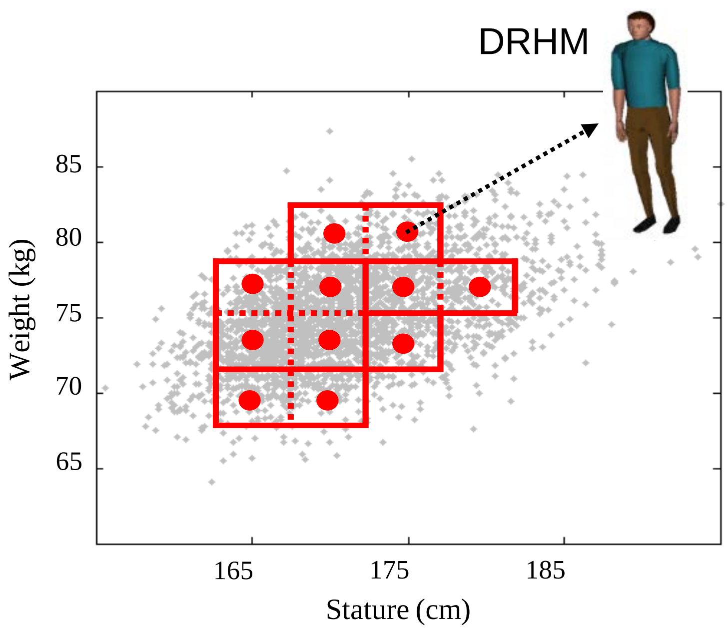
Sizing system of a multiple-size product

⇒ Sizing system of multiple-size product: Need to be properly designed to accommodate the anthropometric characteristics of a target population

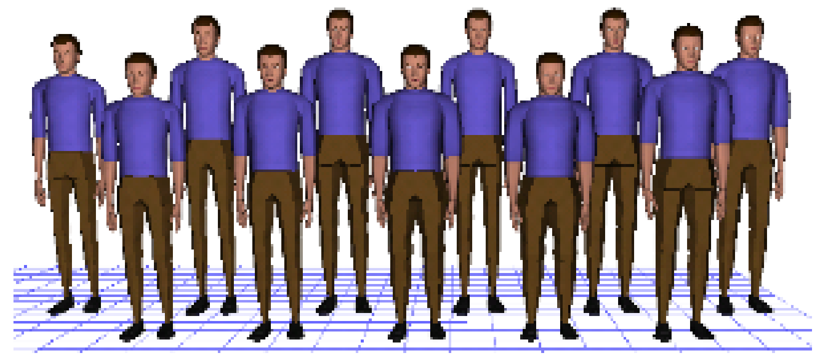
Distributed Representative Human Model (DRHM)

- DRHMs: Human models chosen over a set of grids which accommodate a designated percentage (e.g., 90%) of the population in the distribution of anthropometric dimensions

(Robinette and Annis, 1986; Kwon et al., 2009; Jung et al., 2010)



DRHM generation method: Grid method
(accommodation percentage = 90%)

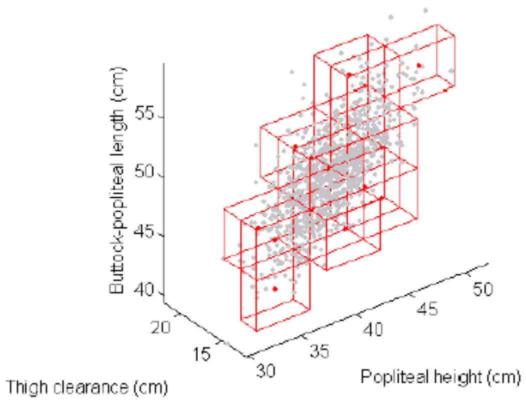


Generated DRHMs
(body sizes → sizing system)

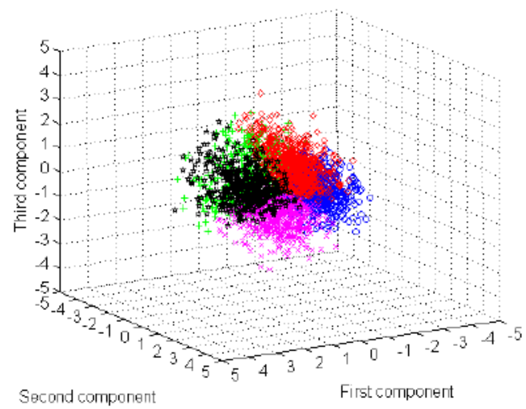
⇒ Body sizes of DRHMs: Applied for the design and evaluation of a sizing system

DRHM Generation Methods & Limitations

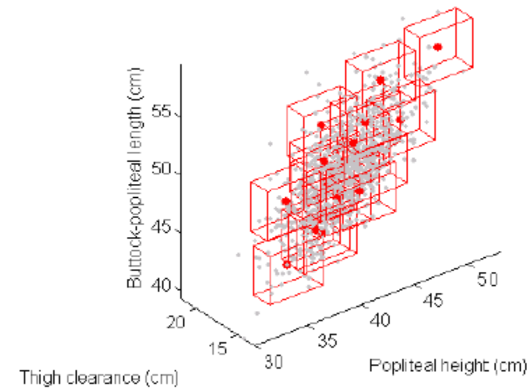
- DRHM generation method: Form a set of grids to accommodate a designated percentage (e.g., 90%) of the target population (Jung et al., 2010)



Grid method
(Robinette and Annis, 1986)



Clustering method
(Laing et al., 1999)



Optimization method
(McCulloch et al., 1998)

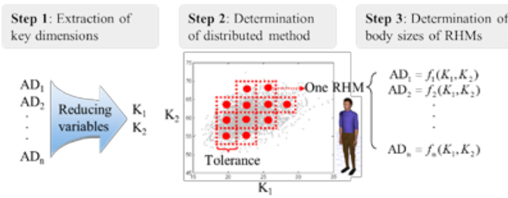
- Limitations: (1) unavailability of computerized systems, (2) time demand, (3) complexity

⇒ Not easy to choose an optimal sizing system out of a variety of sizing system alternatives without computerized systems

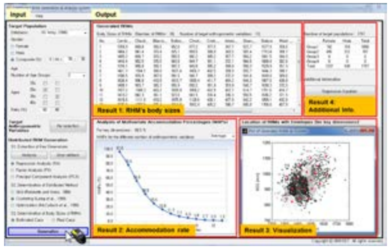
Objectives of the Study

Development of a Distributed Representative Human Model (DRHM) Generation and Analysis System for Multiple-Size Product Design

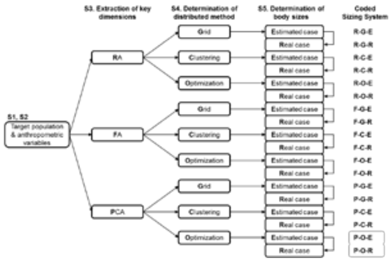
1. Analyze the DRHM generation process and methods



2. Develop a computerized system for DRHM generation and analysis



3. Examine the effectiveness of the DRHM computerized system by applying to flight suit design



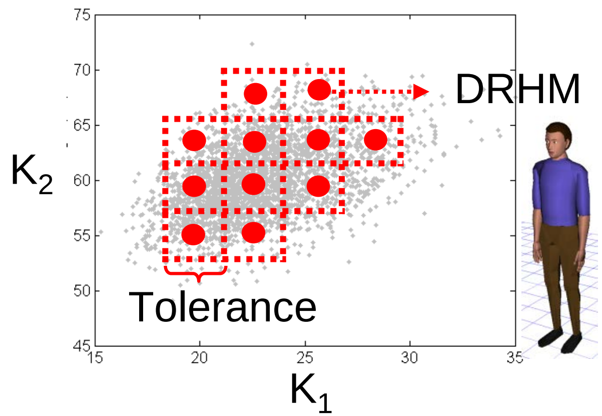
DRHM Generation: Process & Methods

- Jung et al. (2010): established the DRHM generation process and methods based on a comprehensive literature review

	S1: Determination of key dimensions/factors	S2: Application of DRHM generation method	S3: Determination of body sizes of DRHMs

Process

AD_1, AD_2, . . ., AD_n → Reducing variables → K_1, K_2



$$\begin{cases} AD_1 = f_1(K_1, K_2) \\ AD_2 = f_2(K_1, K_2) \\ \vdots \\ AD_n = f_n(K_1, K_2) \end{cases}$$

(note) AD = anthropometric dimension, K = key dimension/factor

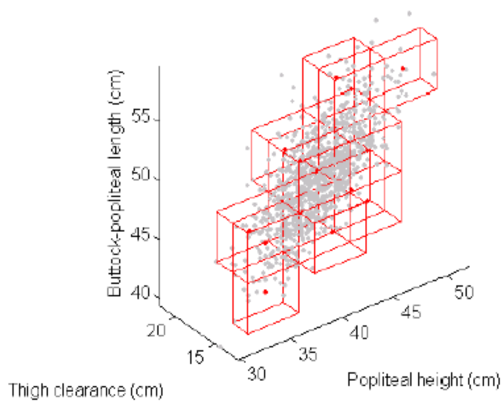
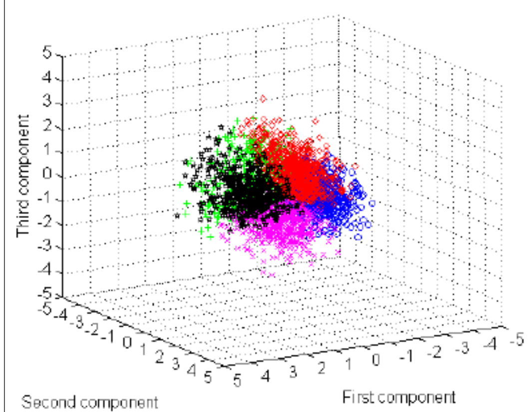
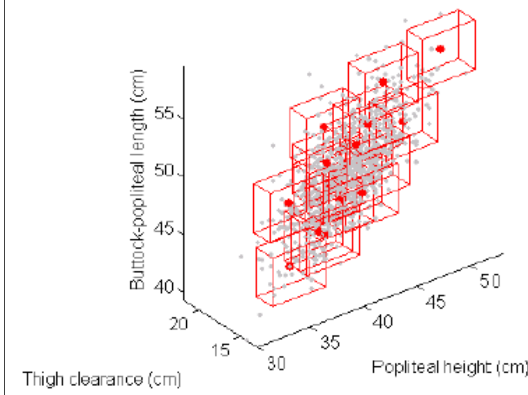
Methods

- Regression analysis (RA)
- Factor analysis (FA)
- Principal component analysis (PCA)

- Grid method
- Clustering method
- Optimization method

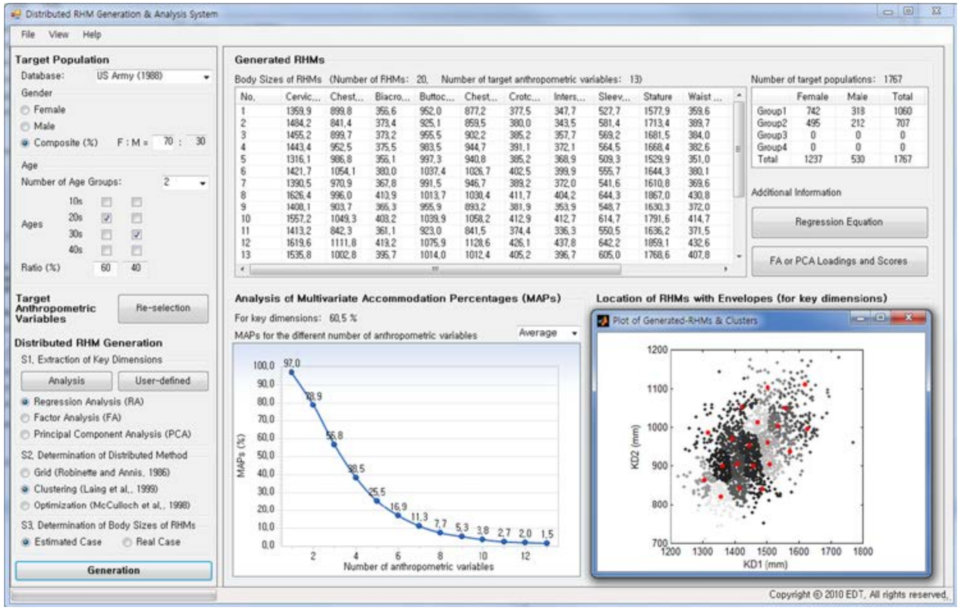
- Estimated case
- Real case

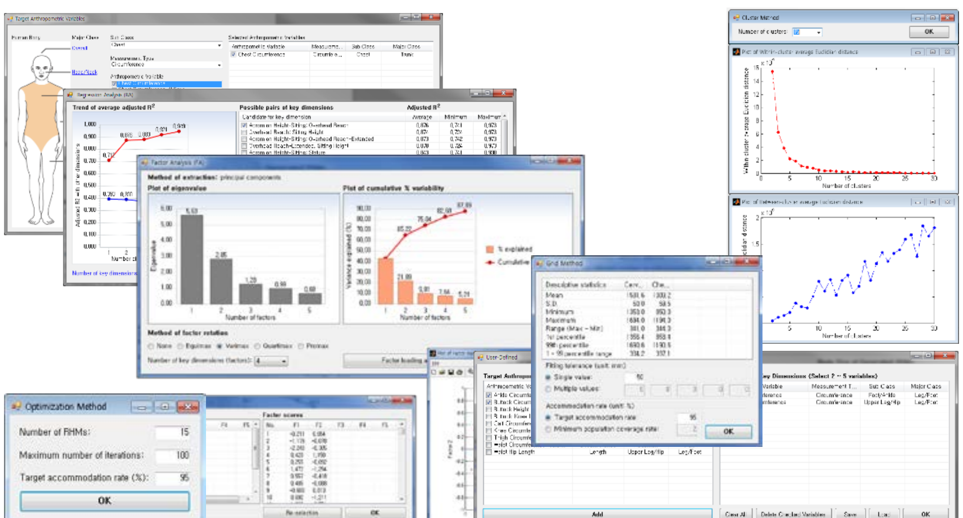
DRHM Generation: Methods

Method	Grid	Clustering	Optimization
Illustration			
Studies	• Robinette and Annis (1986) • Rosenblad-Wallin (1987) • Moon (2002) • Kwon et al. (2004) • Zheng et al. (2007)	• Laing et al. (1999)	• McCulloch et al. (1998)
Formation method of grids/clusters	• Generate grids which accommodate a designate percentage of the target population	• Generate clusters using *K*-means cluster analysis	• Generate grids applying the Nelder-Mead optimization algorithm
Parameters	• Design fitting tolerance • Accommodation percentage	• Number of clusters (*K*) referring to within- and between-cluster average distances	• Loss score • Accommodation percentage

System Development

System Features



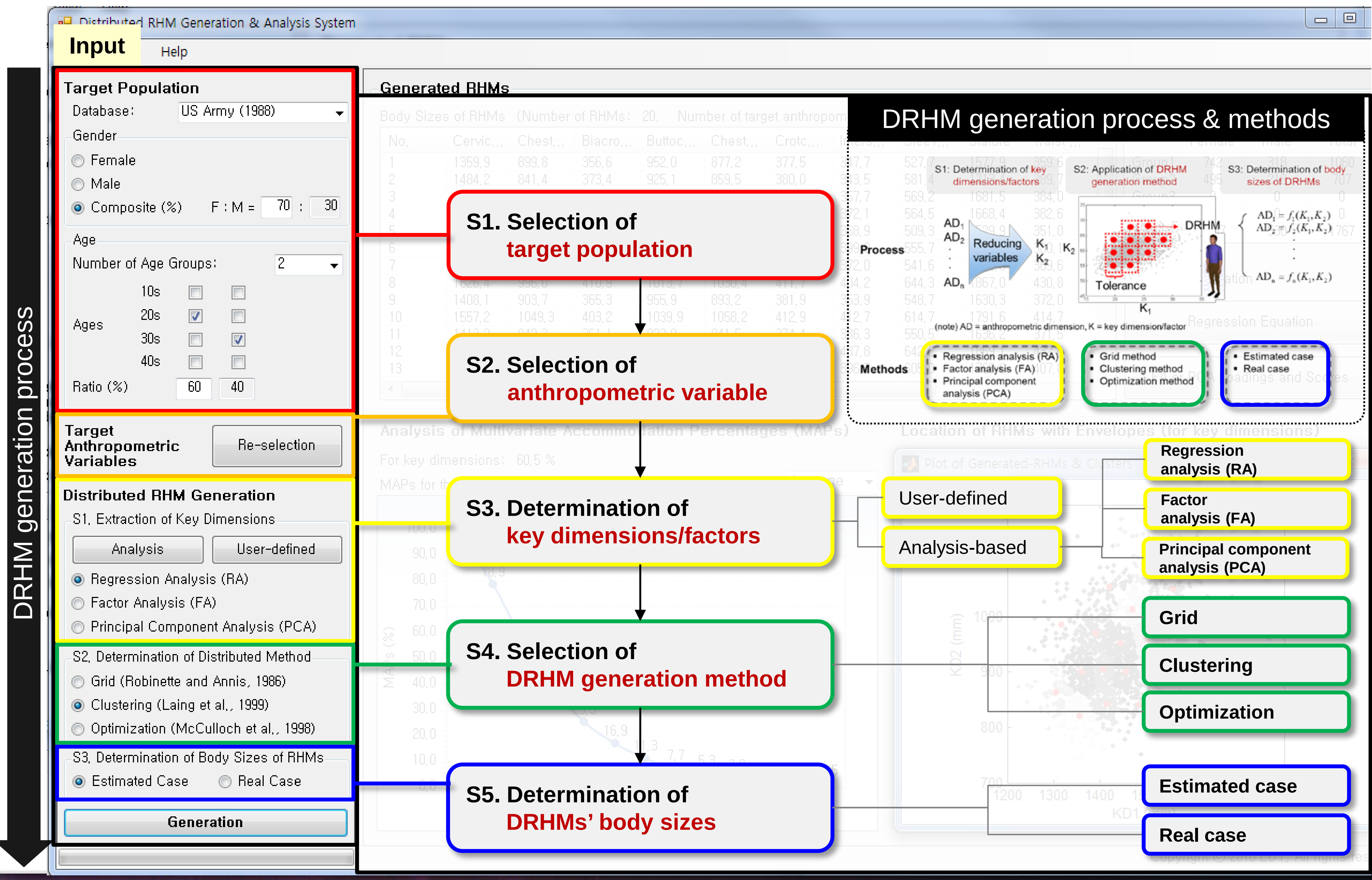


F1. Procedural interface of DRHM generation

F2. Sophisticated input and output interfaces in one panel

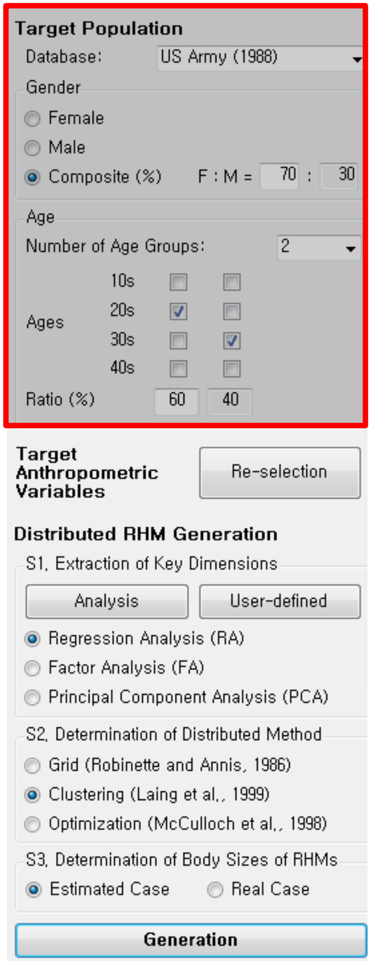
F3. Interoperation with anthropometric databases

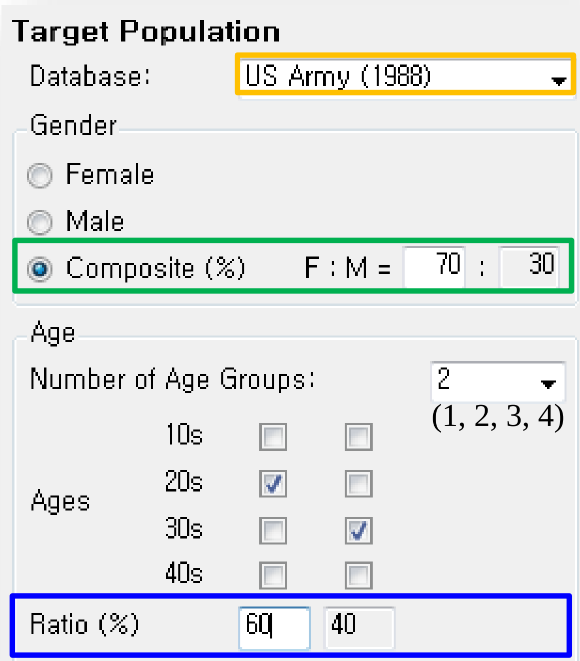
Procedural Interface for DRHM Generation



S1. Selection of Target Population

- Select an anthropometric database and form a target population



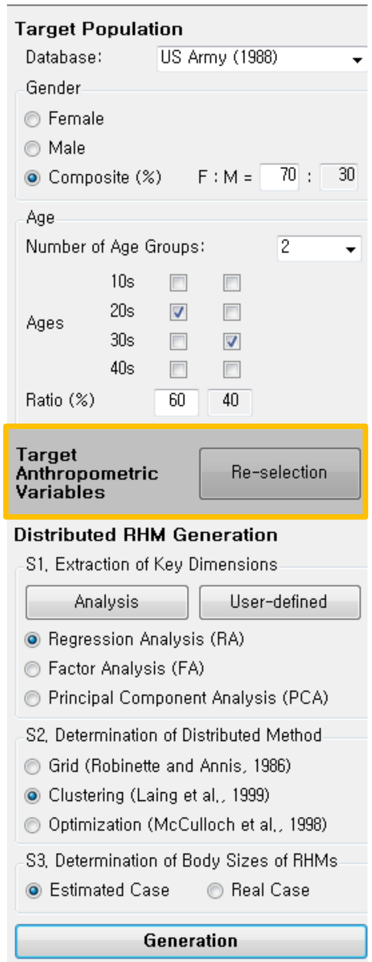


Anthropometric databases		US Army	US Army Pilot	Korean Pilot
Year disseminated		1988	1988	2007
Sample size (*n*)	Female	2,208	334	-
	Male	1,774	487	1,237
	Total	3,982	821	1,237
Range of age		10s ~ 40s	20s ~ 40s	20s ~ 40s

	Female (70%)	Male (30%)	Total	
Group1	742	318	1060	60%
Group2	495	212	707	40%
Group3	0	0	0	
Group4	0	0	0	
Total	1237	530	1767	

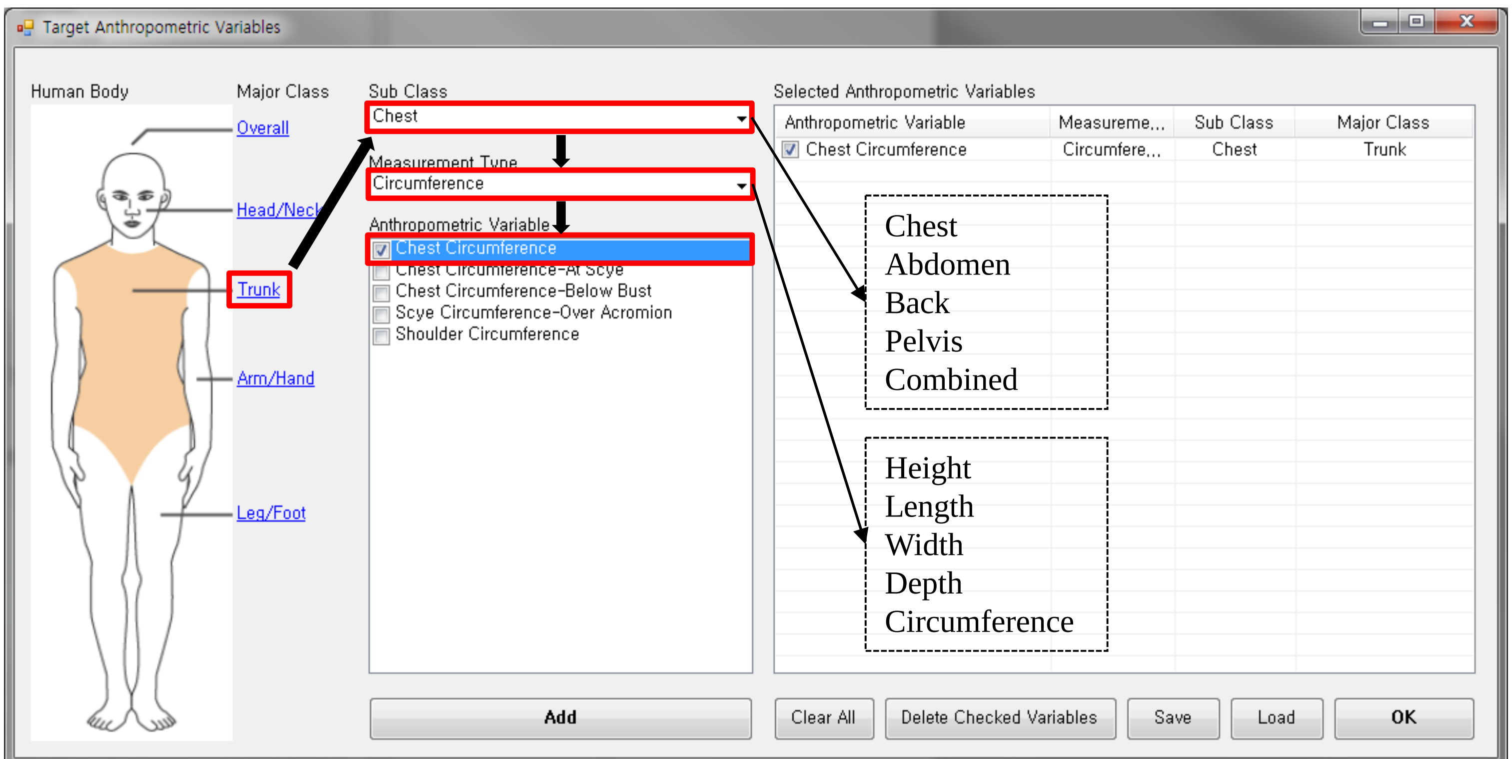
S2. Selection of Anthropometric Variable

- Provide a hierarchical interface for systematic and efficient search of anthropometric variables (You et al., 2004)



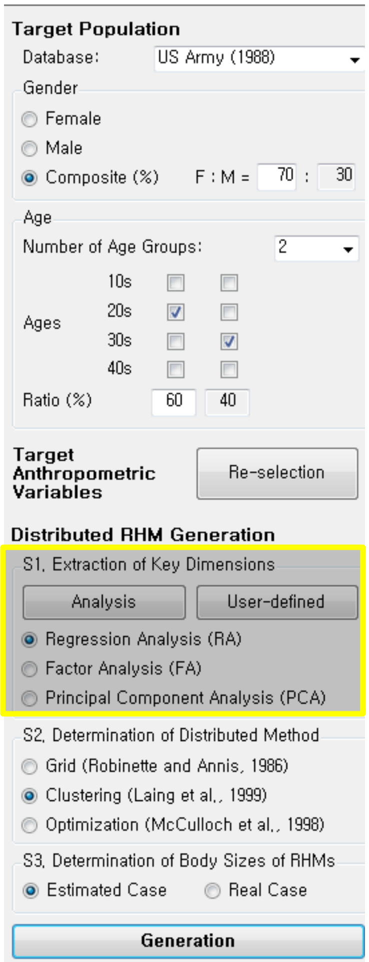
Anthropometric databases	US Army	US Army Pilot	Korean Pilot
Number of AVs	132	132	16

e.g., selection of chest circumference

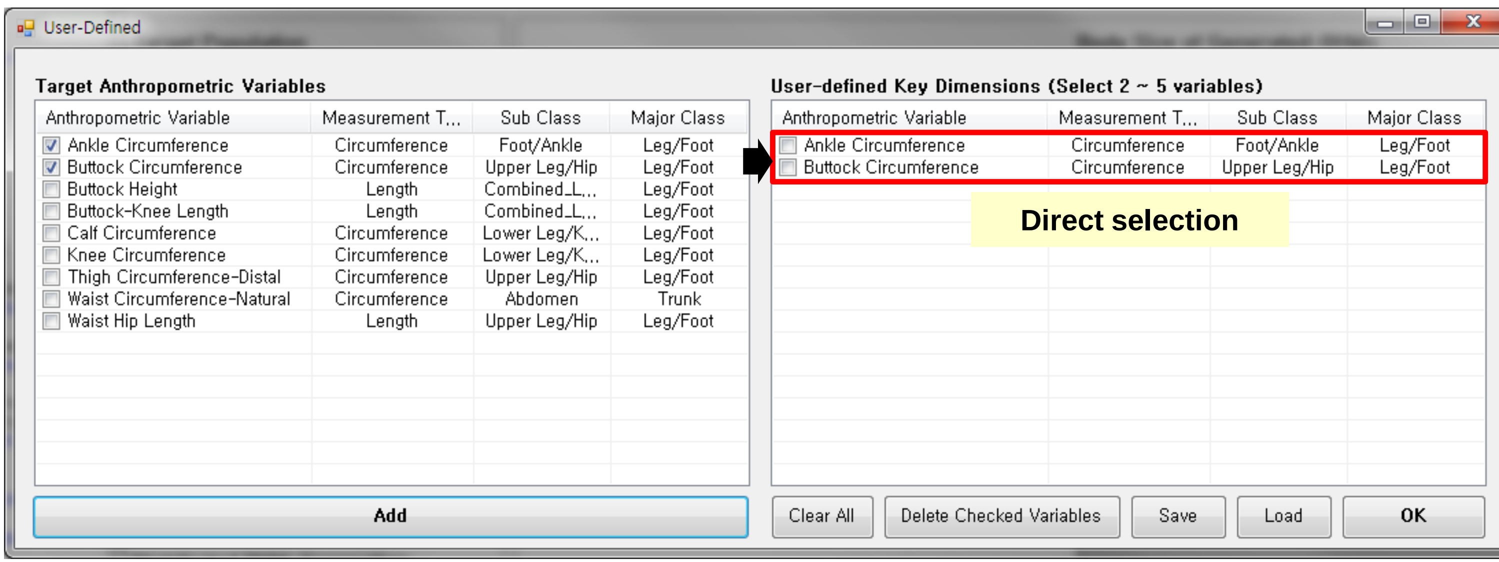


S3. Selection of Key Dimension: User-Defined

❑ Determine key dimensions directly by a user's preliminary knowledge

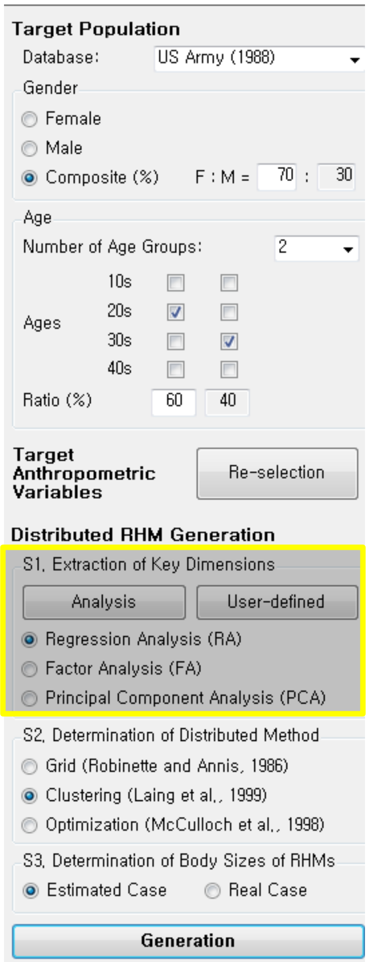


e.g., # anthropometric variables = 9

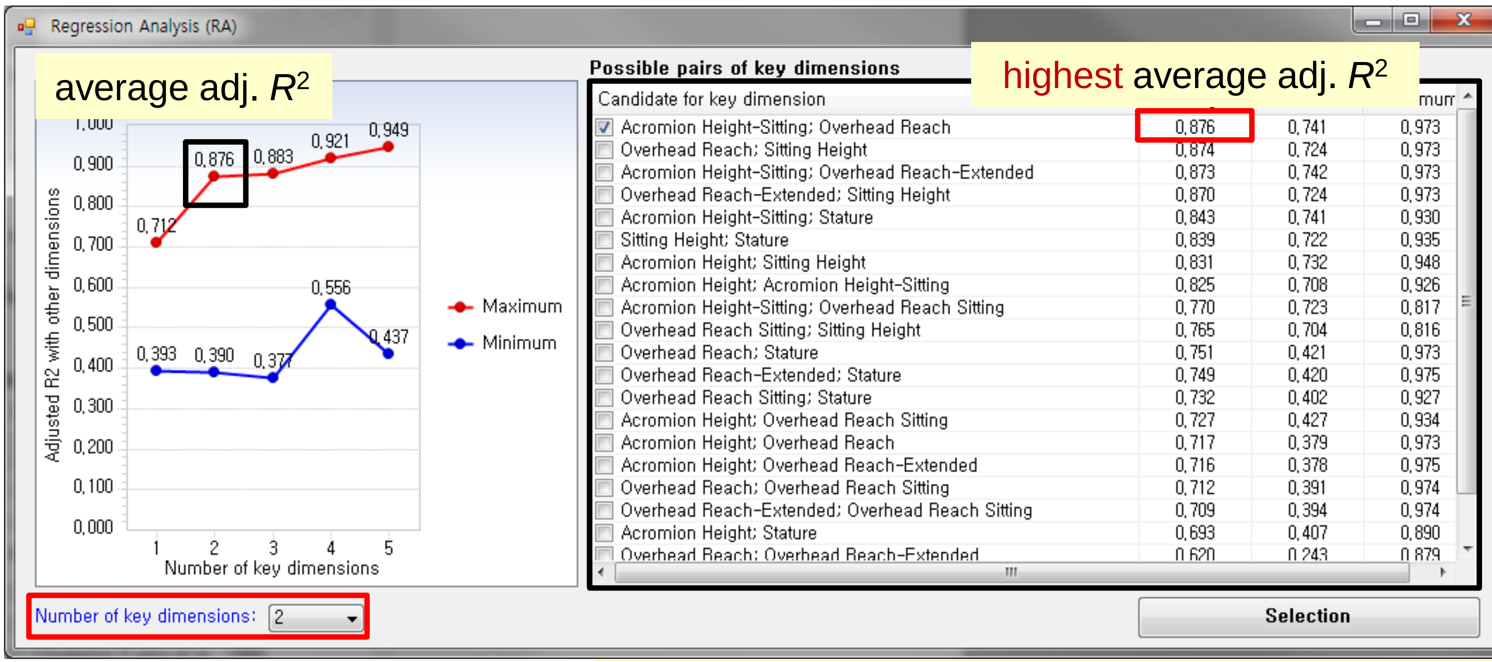


S3. Selection of Key Dimension: Regression Analysis

- Determine key dimensions by referring to increase in average adjusted R^2 by # key dimensions



e.g., # anthropometric variables = 7



Select # key dimensions referring to increase in average adj. R^2

Provide adj. R^2 between key dimension candidates and other dimensions in descending order for quick search of key dimensions with high performance

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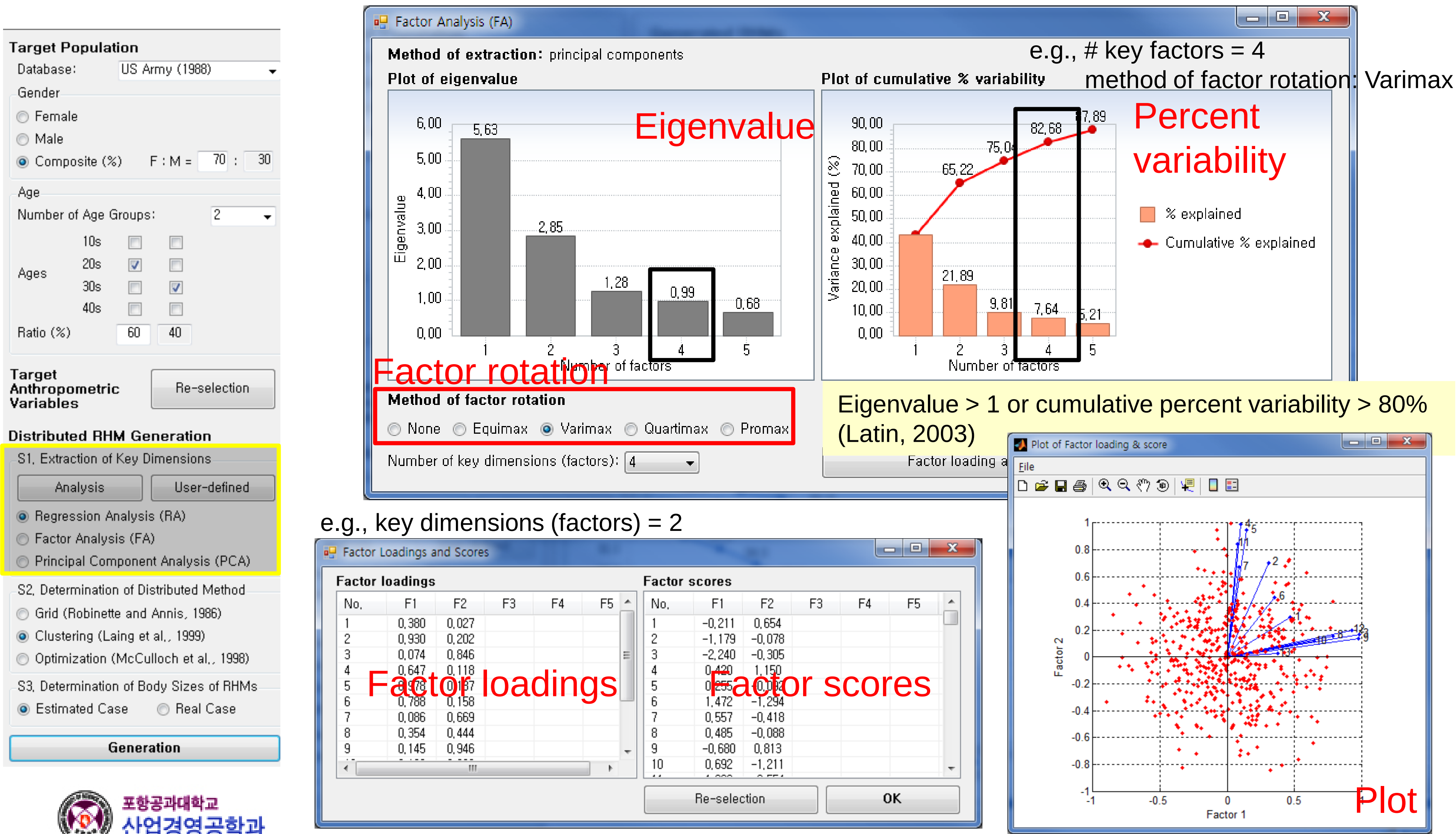
S3. Selection of Key Factor: Factor Analysis

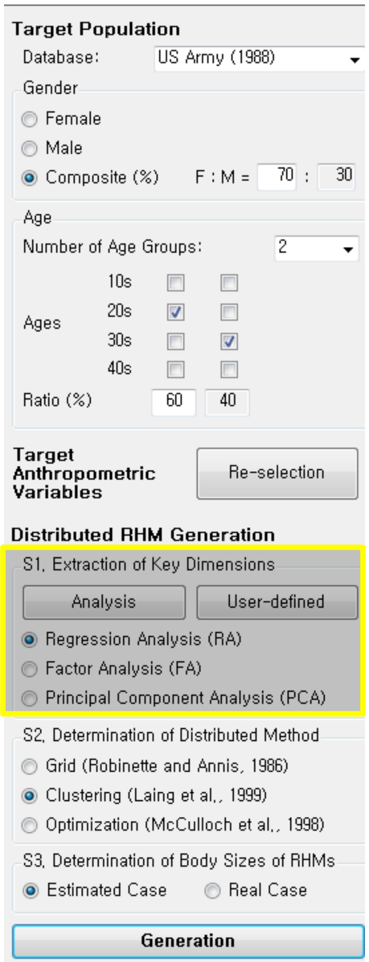
- Determine key factors by referring to eigenvalue and cumulative percent variability

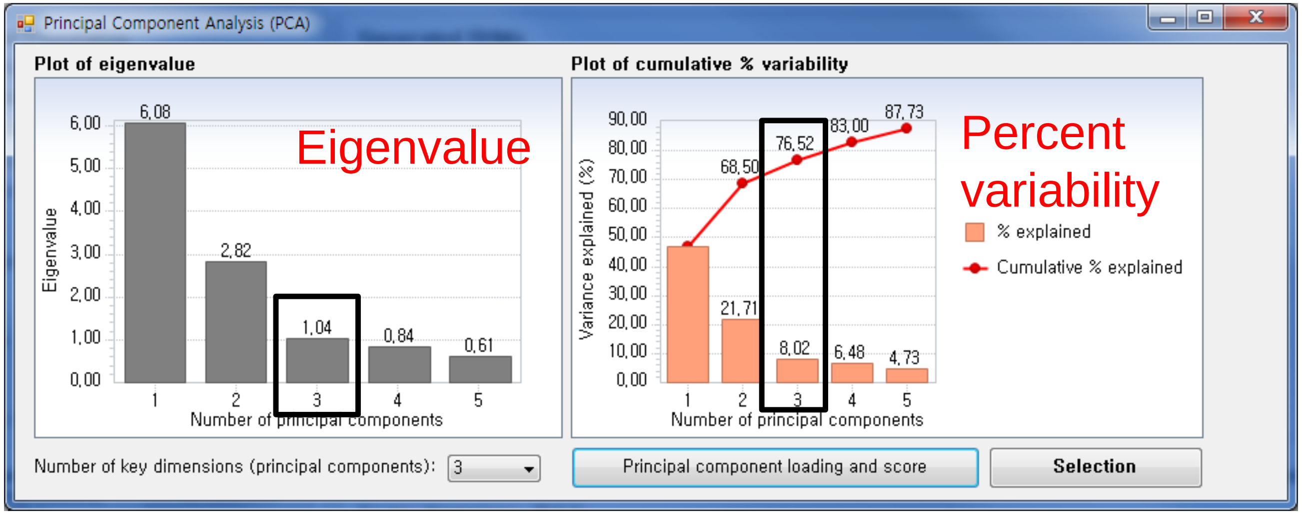


S3. Selection of Key Factor: Principal Component Analysis

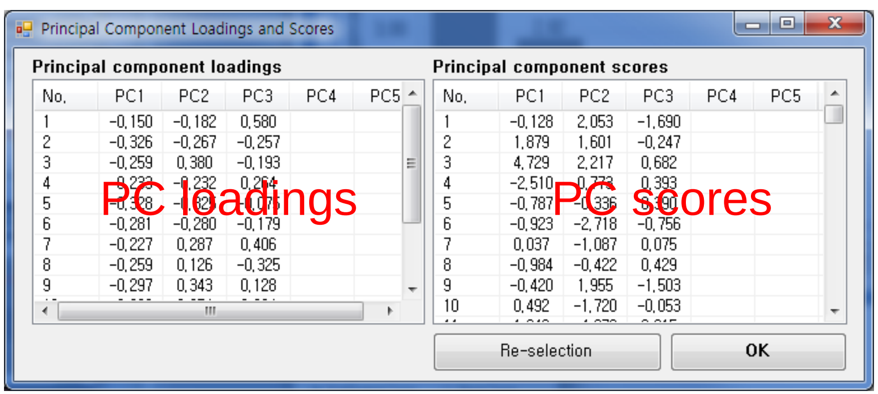
- Refer to eigenvalue and cumulative percent variability

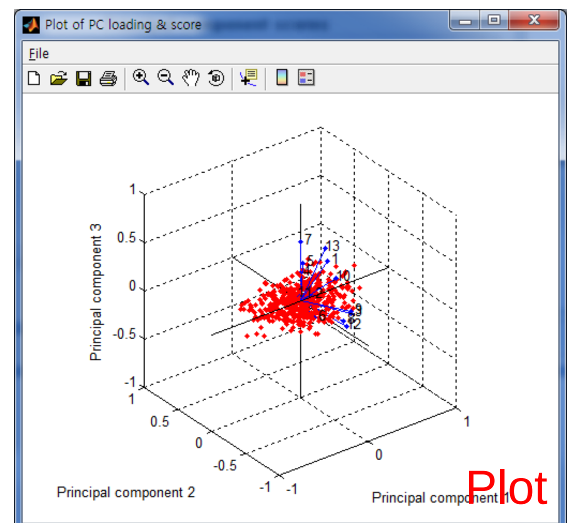
e.g., # key dimensions = 3





Eigenvalue > 1 or cumulative percent variability > 80% (Latin, 2003)





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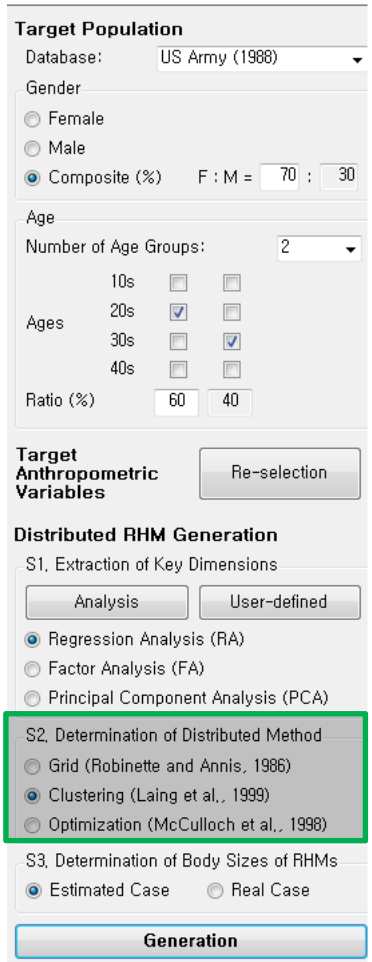
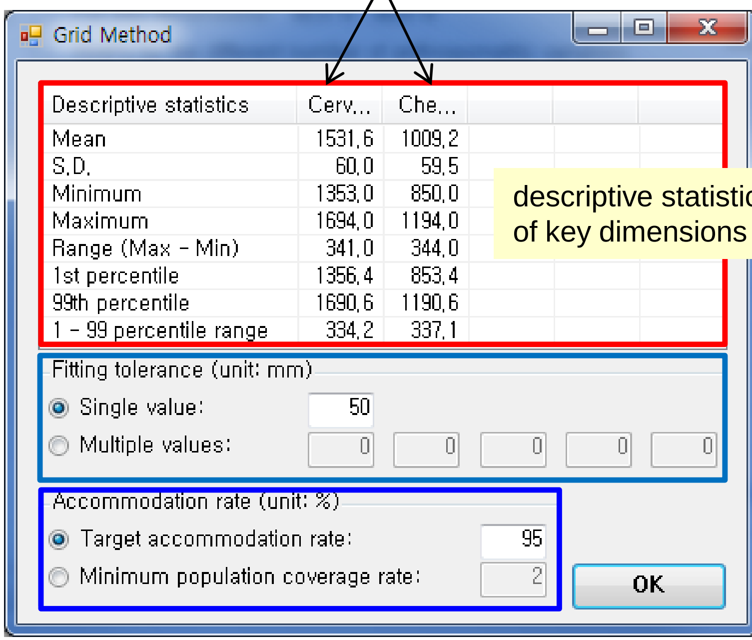
S4. Selection of DRHM Generation Method: Grid

- Set fitting tolerance (size of a grid) and accommodation percentage



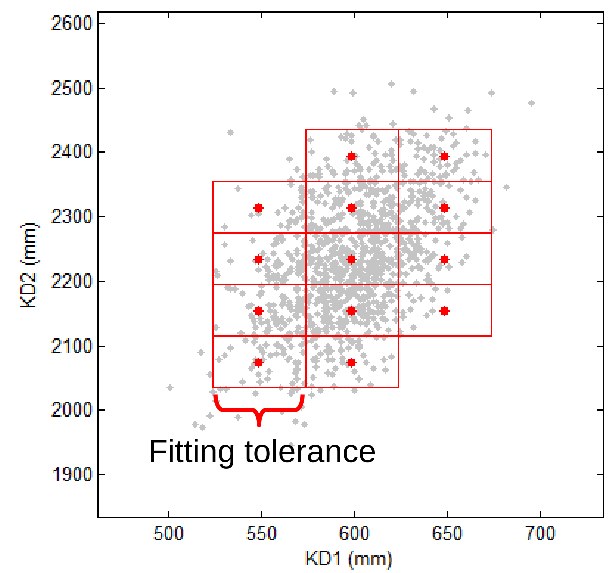
e.g., # key dimensions = 2

Key dimensions



Descriptive statistics	Cerv...	Che...
Mean	1531.6	1009.2
S.D.	60.0	59.5
Minimum	1353.0	850.0
Maximum	1694.0	1194.0
Range (Max - Min)	341.0	344.0
1st percentile	1356.4	853.4
99th percentile	1690.6	1190.6
1 - 99 percentile range	334.2	337.1

descriptive statistics of key dimensions



1) Target accommodation rate
: accommodation rate of all grids > 95%
2) Minimum presence rate
: accommodation rate of each grid > 2%

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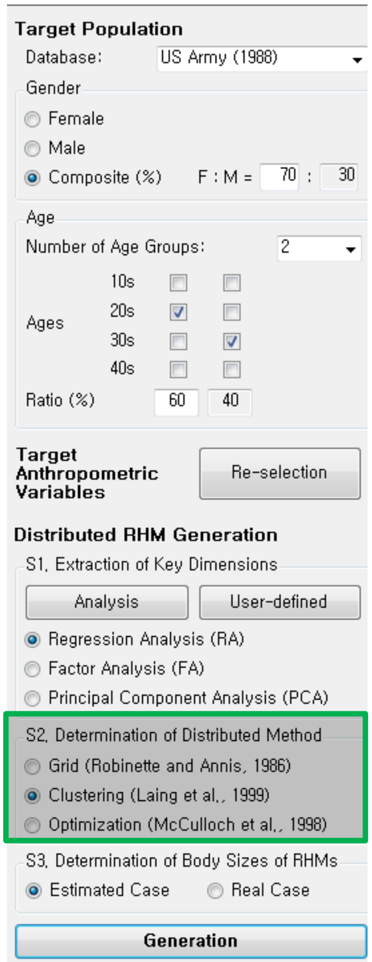
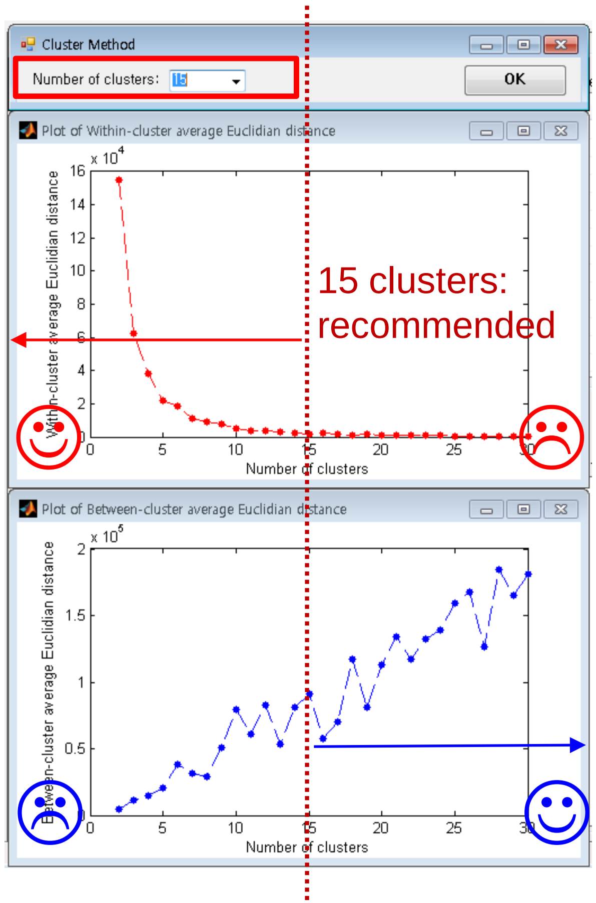
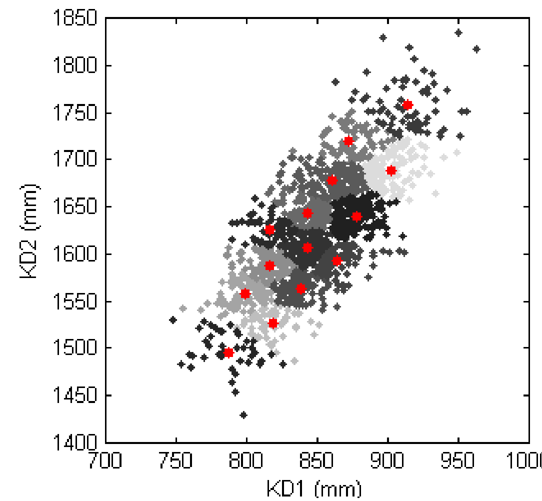
S4. Selection of DRHM Generation Method: Clustering

❑ Determine the number of DRHMs referring to within- & between-cluster distance plots



Within-cluster homogeneity ↑

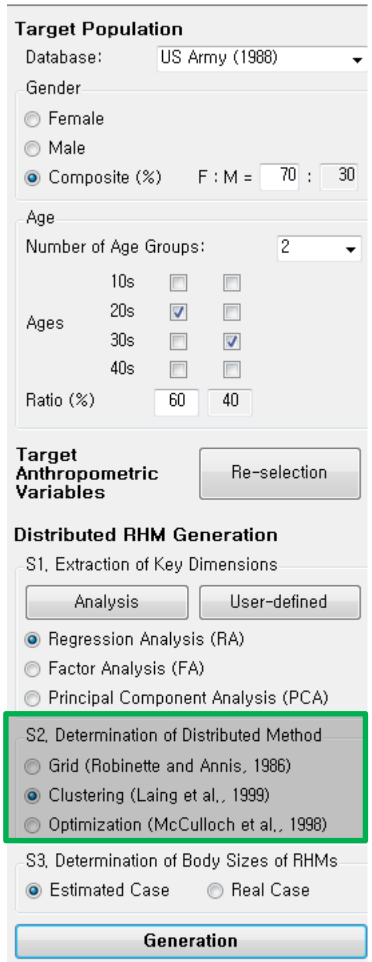


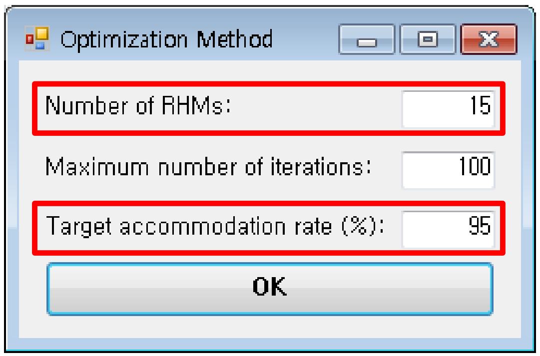


Between-clusters heterogeneity ↑

S4. Selection of DRHM Generation Method: Optimization

- Set the number of DRHMs with the target accommodation percentage





$$\min \sum_{i=1}^{n} l(p_i)k_i + l(c_\alpha)(1-k_i)$$

$$k_i = \begin{cases} 1 & \text{if } l(p_i) < l(c_\alpha) \text{ where } l(p_i) \\ 0 & o/w \end{cases}$$

$$d(\mathbf{x}_i, \mathbf{y}_s) = \sum_{j=1}^{k} [d(x_{ij}, y_{sj})]^2$$

$$d(x_{ij}, y_{sj}) = \begin{cases} y_{sj} - x_{ij}, & \text{if } x_{ij} \le y_{sj} \\ x_{ij} - y_{sj}, & \text{if } x_{ij} > y_{sj} \end{cases}$$

where: n = number of the target population,

$l(p_i)$ = loss score of person i,

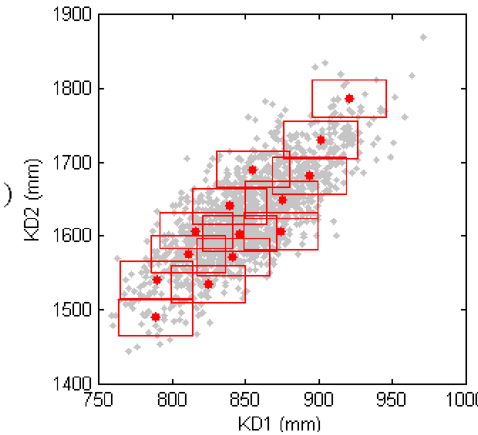
$l(c_\alpha)$ = loss cutoff to determine whether a person is accommodated or not,

$d(\mathbf{x}_i, \mathbf{y}_s)$ = distance between person i and its nearest grid,

k = number of key dimensions,

x_{ij} = body size of key dimension j of person i, and

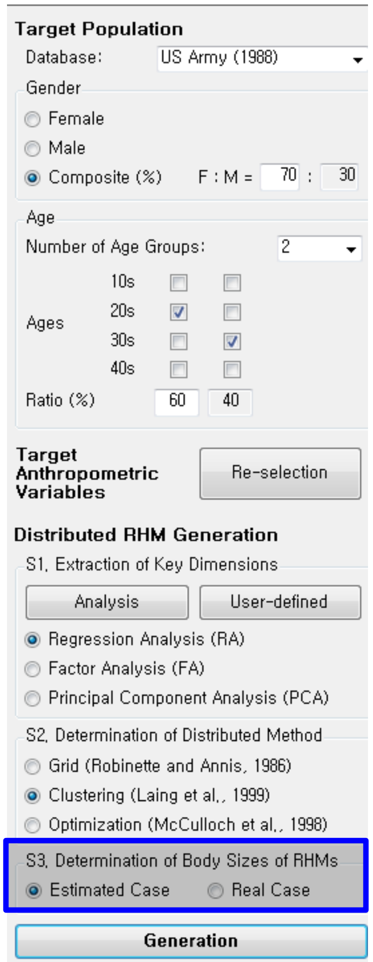
y_{sj} = centroid of the nearest grid s in key dimension j.

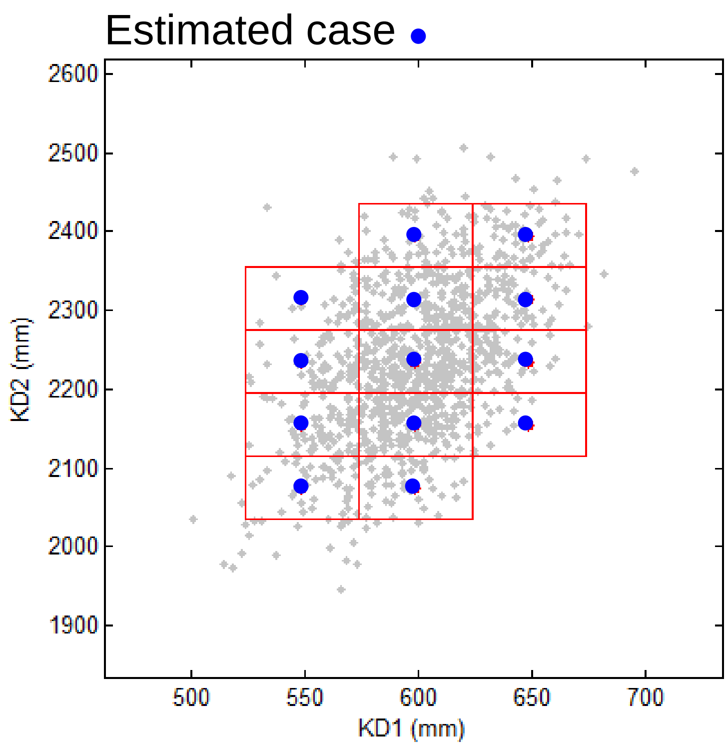


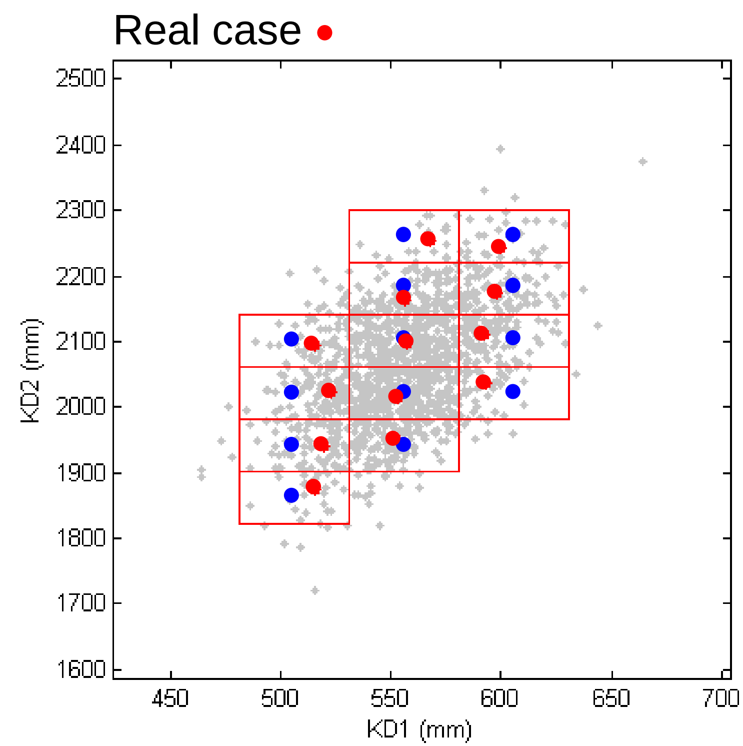
$$l(p(x_k)) \leqslant l(c_\alpha) \leqslant l(p(x_m)).$$

S5. Determination of Body Sizes of DRHMs

- Select a body sized determination method



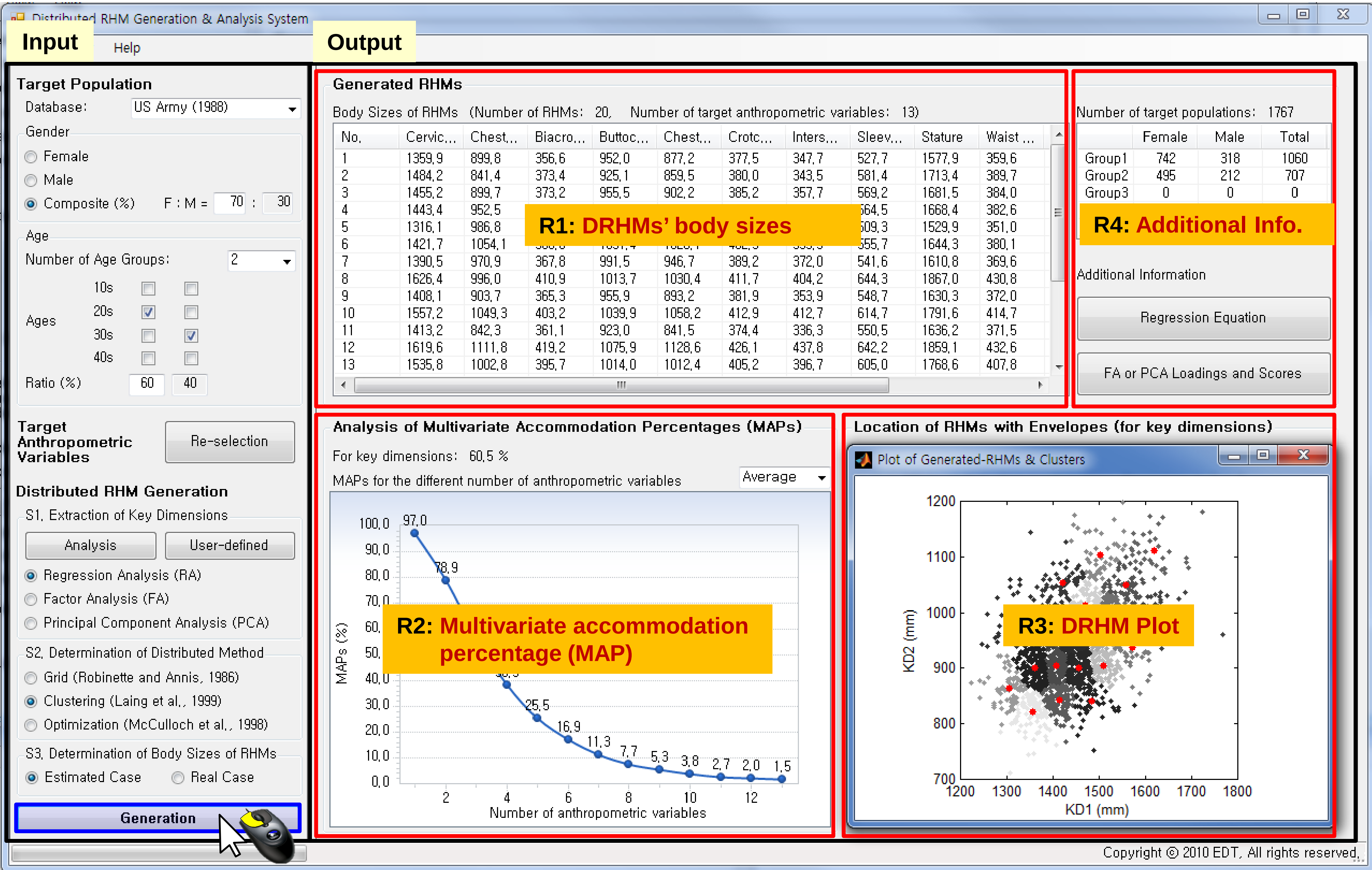




Centroid: Finding an object *i* located geometric center in a grid

Medoid: Finding an object *i* whose average distance is the closest in a grid

Specialized DRHM Analysis



R1. Body Sizes of DRHMs

- Provide generated DRHMs' body sizes by anthropometric variable

e.g., # DRHMs = 20, # anthropometric variables = 13

Generated RHMs

Body Sizes of RHMs (Number of RHMs: 20, Number of target anthropometric variables: 13)

No.	Cervic...	Chest...	Biacro...	Buttoc...	Chest...	Crotc...	Inters...	Sleev...	Stature	Waist ...
1	1359.9	899.8	356.6	952.0	877.2	377.5	347.7	527.7	1577.9	359.6
2	1484.2	841.4	373.4	925.1	859.5	380.0	343.5	581.4	1713.4	389.7
3	1455.2	899.7	373.2	955.5	902.2	385.2	357.7	569.2	1681.5	384.0
4	1443.4	952.5	375.5	983.5	944.7	391.1	372.1	564.5	1668.4	382.6
5	1316.1	986.8	356.1	997.3	940.8	385.2	368.9	509.3	1529.9	351.0
6	1421.7	1054.1	380.0	1037.4	1026.7	402.5	399.9	555.7	1644.3	380.1
7	1390.5	970.9	367.8	991.5	946.7	389.2	372.0	541.6	1610.8	369.6
8	1626.4	996.0	410.9	1013.7	1030.4	411.7	404.2	644.3	1867.0	430.8
9	1408.1	903.7	365.3	955.9	893.2	381.9	353.9	548.7	1630.3	372.0
10	1557.2	1049.3	403.2	1039.9	1058.2	412.9	412.7	614.7	1791.6	414.7
11	1413.2	842.3	361.1	923.0	841.5	374.4	336.3	550.5	1636.2	371.5
12	1619.6	1111.8	419.2	1075.9	1128.6	426.1	437.8	642.2	1859.1	432.6
13	1535.8	1002.8	395.7	1014.0	1012.4	405.2	396.7	605.0	1768.6	407.8

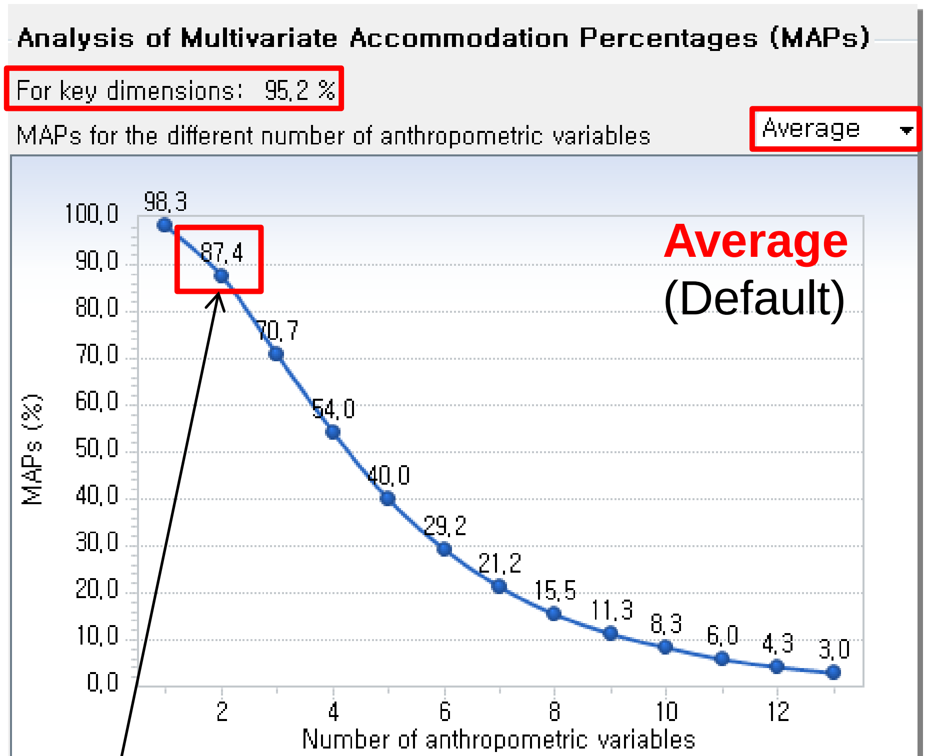
Generated DRHMs

DRHMs' body size by anthropometric variable

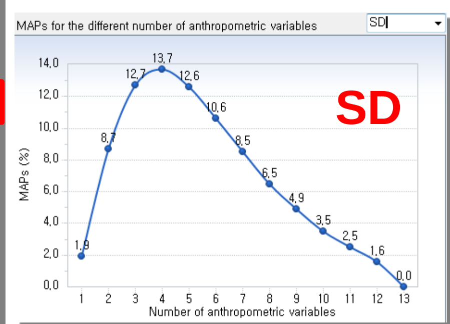
R2. Multivariate Accommodation Percentage

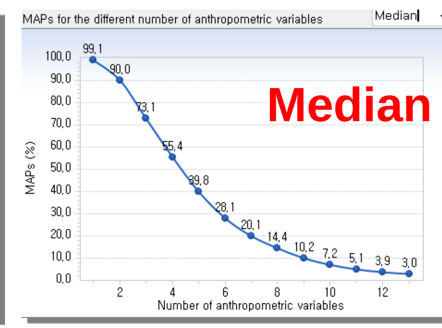
- Provide multivariate accommodation percentages (average, SD, median, minimum, and maximum) by the number of anthropometric variables

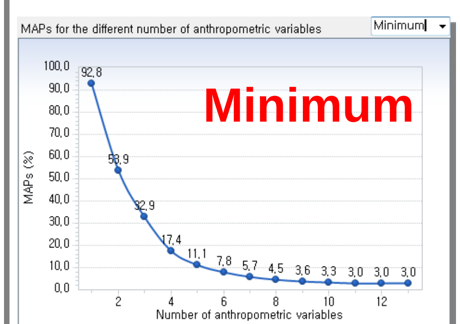
e.g., # anthropometric variables = 13

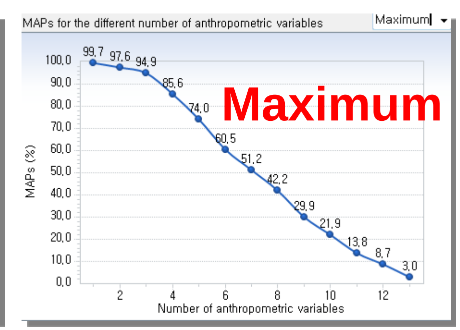


Average of accommodation percentages of 78 cases ($_{13}C_2$)









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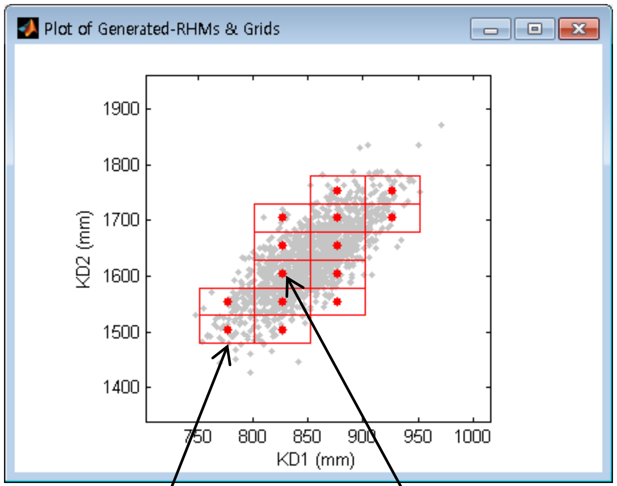
R3. DRHM Plot

- Provide plot of DRHMs on the grid in the distribution of key dimensions/factors by the DRHM generation method

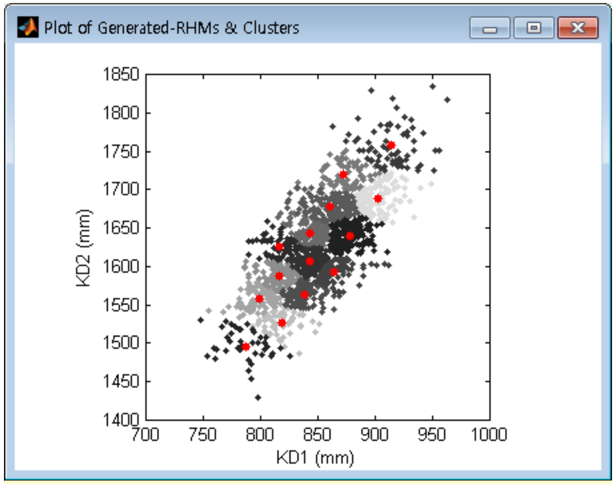
Grid method



Generated grid

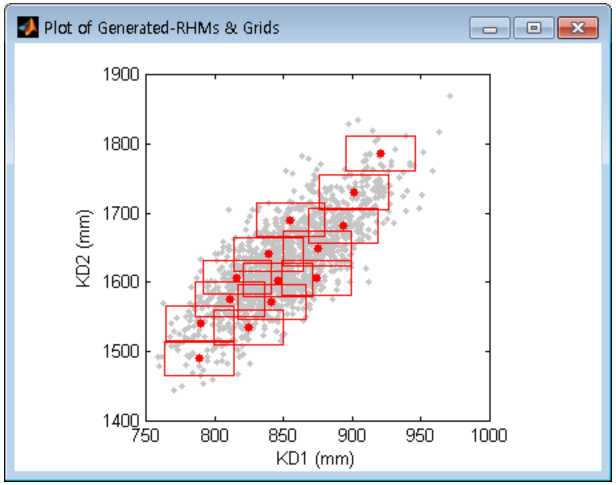
DRHM

Clustering method



Automatic color coding for different clusters

Optimization method



R4. Additional Information

- Provide population information, regression equations for RA, and factor/principal component loadings and scores for FA/PCA

Number of target populations: 1767

	Female	Male	Total
Group1	742	318	1060
Group2	495	212	707
Group3	0	0	0
Group4	0	0	0
Total	1237	530	1767

Additional Information

Regression Equation

FA or PCA Loadings and Scores

Regression Equations

Regression equations using key dimensions

Anthropometric Variable	β0	β1	β2	β3	β4	β5	Adjusted R^2
Overhead Reach	10.848	-0.889	1.723				0.912
Overhead Reach Sitting	48.499	0.038	0.765				0.765
Overhead Reach-Extended	30.468	-0.877	1.761				0.907

e.g., Overhead Reach = 10.848 – 0.889 × Sitting Height + 1.723 × Stature
⇒ Overhead reach estimation equation by key dimensions

Independent variables (Key dimensions)

Variable	Key dimension
X1	Sitting Height
X2	Stature

OK

Factor Loadings and Scores

Factor loadings

No.	F1	F2	F3	F4	F5
1	0.820	0.527			
2	0.306	0.950			
3	0.827	0.431			
4	0.954	0.277			
5	0.959	0.262			

Factor scores of generated RHMs

No.	F1	F2	F3	F4	F5
1	-2.093	-1.329			
2	0.709	-2.208			
3	0.254	-2.182			
4	1.966	1.171			
5	1.957	-1.357			
6	-1.744	-0.535			
7	1.664	0.478			
8	1.866	-0.490			
9	-1.779	0.522			
10	-0.875	-1.298			

OK

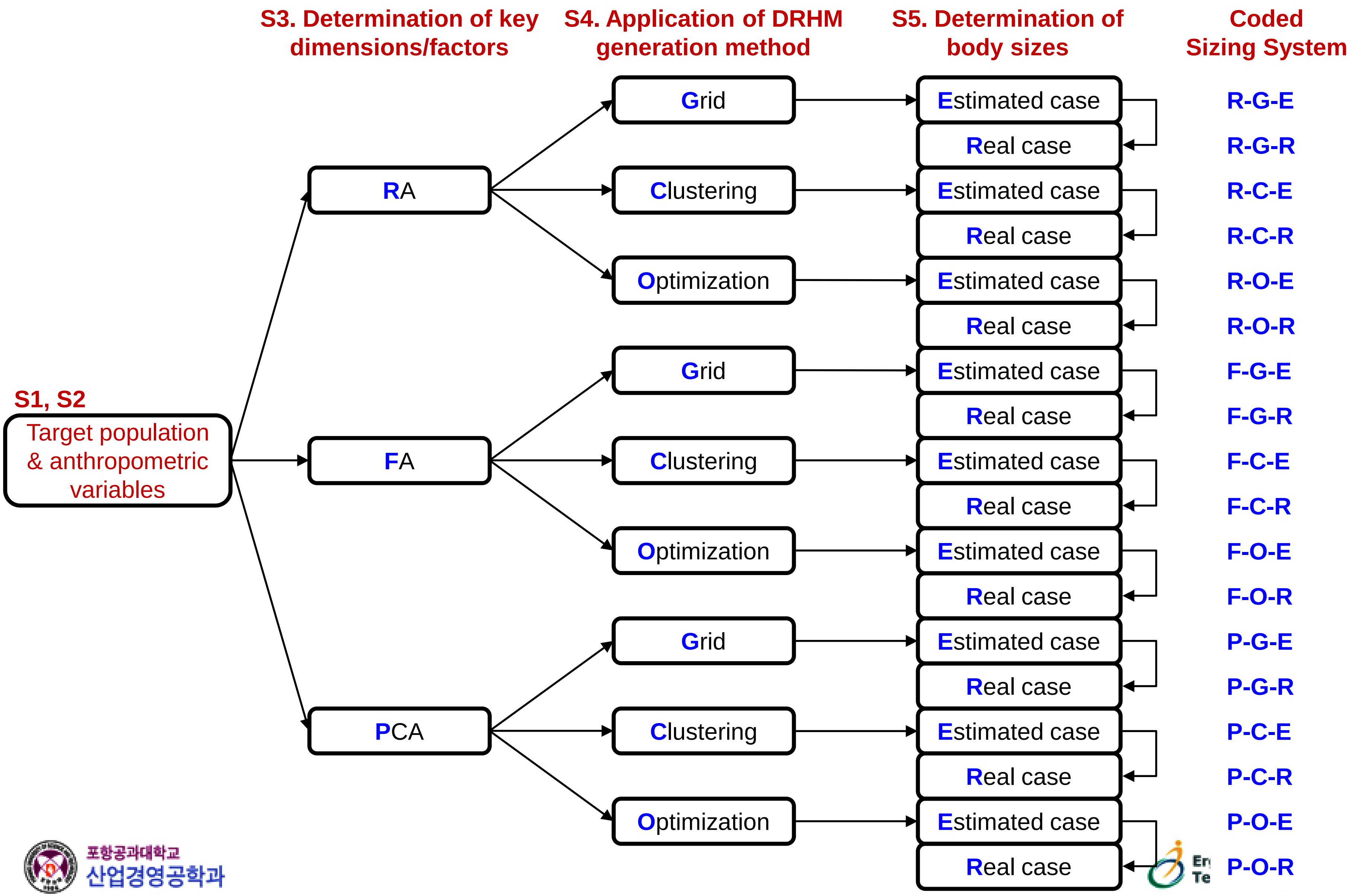
Design Application

Design Application Context

- Establish an optimal men's sizing system for flight suit design
- Target population & anthropometric variables
  - ✓ US Army male pilots (*n* = 485; Gordon et al., 1998)
  - ✓ 13 anthropometric variables for flight suit design (Jeon et al., 2009)

Major class	Sub class	Measurement type	Anthropometric variable (AV)	Code	Descriptive statistics (unit: mm)		
					Mean	SD	Range
Trunk	Chest	Width	Biacromial breadth	AV1	400.6	17.5	105.0
Leg/Foot	Upper Leg/Hip	Circumference	Buttock circumference	AV2	991.5	55.0	351.0
Head/Neck	Neck	Height	Cervical height	AV3	1531.8	60.0	341.0
Trunk	Chest	Circumference	Chest circumference	AV4	1009.2	59.6	344.0
Trunk	Chest	Circumference	Chest circumference – at scye	AV5	1035.8	55.3	309.0
Trunk	Combined	Length	Crotch length	AV6	772.0	47.3	339.0
Trunk	Back	Length	Interscye distance	AV7	408.7	28.2	164.0
Arm/Hand	Combined	Length	Sleeve outseam	AV8	601.4	29.9	154.0
Overall	-	Height	Stature	AV9	1771.0	64.8	362.0
Trunk	Back	Length	Waist back length	AV10	421.6	21.2	130.0
Trunk	Abdomen	Circumference	Waist circumference	AV11	856.4	65.7	375.0
Trunk	Abdomen	Height	Waist height	AV12	1131.4	48.1	274.0
Leg/Foot	Upper Leg/Hip	Length	Waist hip length	AV13	184.0	19.6	118.0

Decision Tree: 18 Sizing System Alternatives



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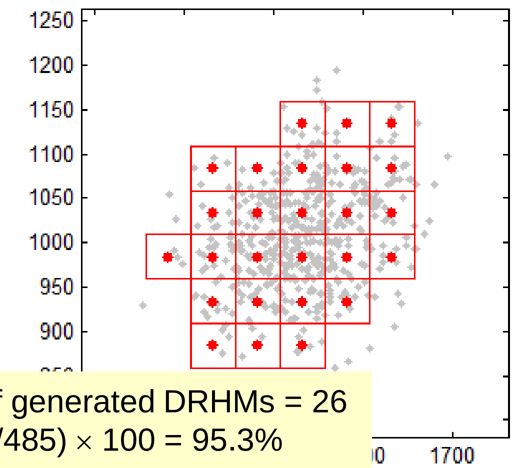
Analysis Method: Measure

- ❑ Number of generated DRHMs
- ❑ Key dimensions: accommodation percentage (AP; %)
- ❑ Non-key dimensions
  - ✓ Cover ratio (%)
  - ✓ Number of outlier DRHMs

e.g., R-G-E



※ Number of generated DRHMs = 26
※ AP = (462/485) × 100 = 95.3%

e.g., P-G-E

No.	Anthropometric variable	Original dimensions			Generate DRHM's dimensions			Generated DRHM's dimensions		Outlier dimensions	
		Min	Max	Range	Min	Max	Covered Range	DRHM 16	DRHM 23	DRHM 16	DRHM 23
1	Biacromial breadth	347.0	452.0	105.0	367.2	435.7	68.5	378.0	367.2	×	×
2	Buttock circumference	849.0	1200.0	351.0	879.9	1132.5	252.6	999.1	895.1	×	×
3	Chest circumference – at syce	894.0	1203.0	309.0	937.0	1183.0	246.0	1077.6	954.6	×	×
4	Crotch length	314.0	467.0	153.0	321.8	461.1	139.3	380.1	347.2	×	×
5	Interscye distance	388.0	502.0	164.0	354.5	485.0	130.5	428.7	378.1	×	×
6	Sleeve outseam	530.0	684.0	154.0	528.3	676.1	146.1	528.5	528.3	O	O
7	Stature	1596.0	2056.0	460.0	1586.2	1955.6	359.6	1586.9	1586.2	O	O
8	Waist back length	363.0	493.0	130.0	378.6	464.4	85.8	378.7	378.6	×	×
9	Waist circumference	689.0	1064.0	375.0	709.6	1017.7	308.1	927.1	781.3	×	×
10	Waist height	993.0	1267.0	274.0	999.8	1262.9	263.1	1009.7	999.8	×	×
11	Waist hip length	122.0	240.0	118.0	127.1	229.4	102.3	155.2	157.4	×	×
Total		-	-	2593.0	-	-	2101.9	-	-	2	2

e.g., DRHM 16 and 23

※ Cover ratio = (2101.9/2593.0) × 100 = 81.0%
※ Number of outlier DRHMs = 2

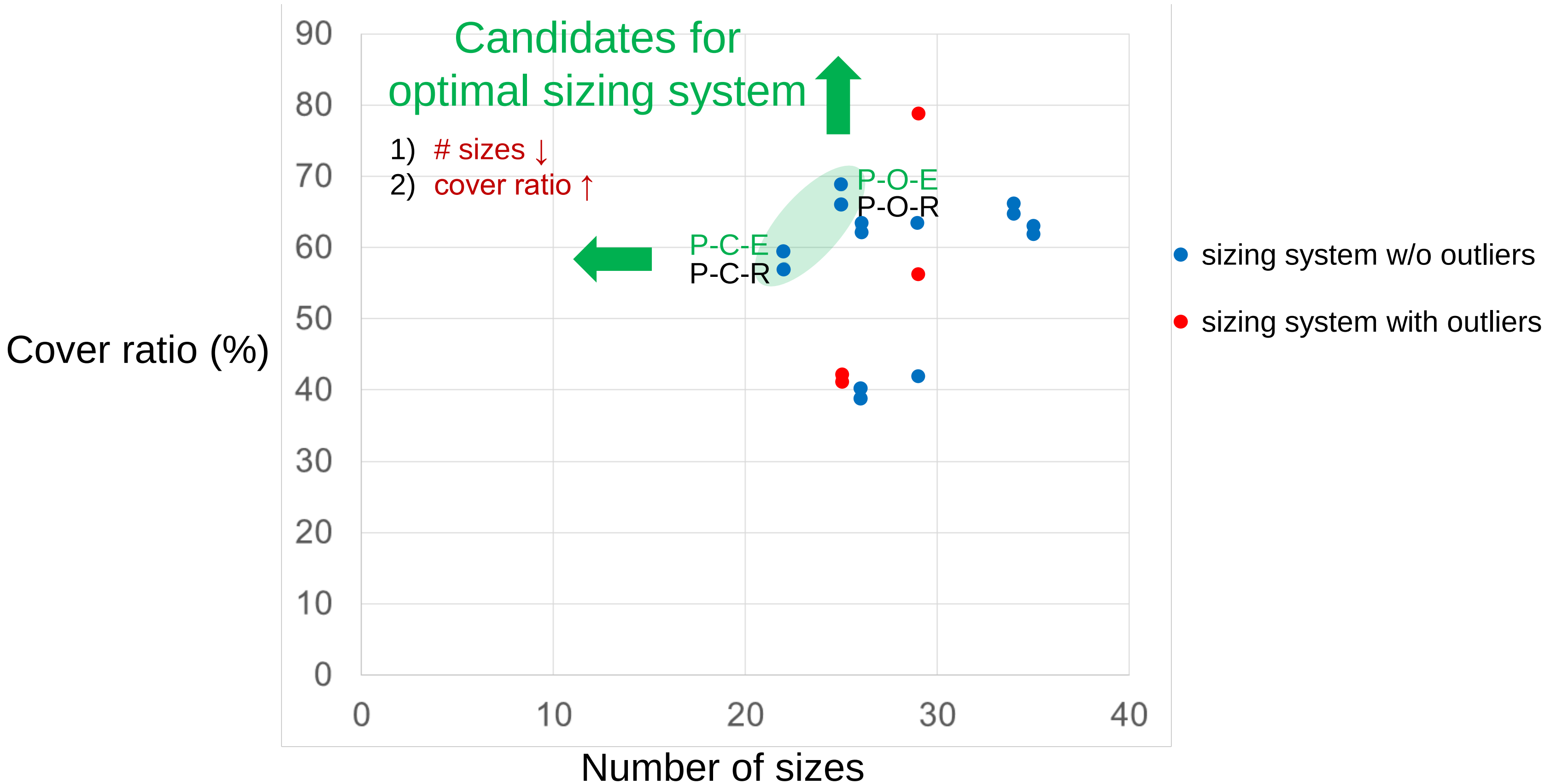
Comparison of Sizing Systems

- Total calculation time of generating 18 sizing systems ≈ 2 hrs

No.	Sizing System	Accommodation percentage for key dimensions (%)	Number of generated DRHMs	Non-key dimensions	
				Cover ratio (%)	Number of outlier DRHMs
1	R-G-E	95.3	26	62.2	-
2	R-G-R	83.3	26	63.0	-
3	R-C-E	95.3	34	65.9	-
4	R-C-R	92.4	34	65.0	-
5	R-O-E	95.1	35	61.9	-
6	R-O-R	91.8	35	62.8	-
7	F-G-E	95.1	29	56.2	2
8	F-G-R	91.1	29	41.8	-
9	F-C-E	95.5	25	41.5	1
10	F-C-R	91.1	25	41.6	1
11	F-O-E	96.1	26	38.8	-
12	F-O-R	91.8	26	39.9	-
13	P-G-E	95.3	29	78.7	3
14	P-G-R	91.1	29	63.4	-
15	P-C-E	95.1	22	59.4	-
16	P-C-R	91.5	22	57.3	-
17	P-O-E	95.1	25	68.7	-
18	P-O-R	92.4	25	66.1	-

: controlled value

Optimal Sizing System

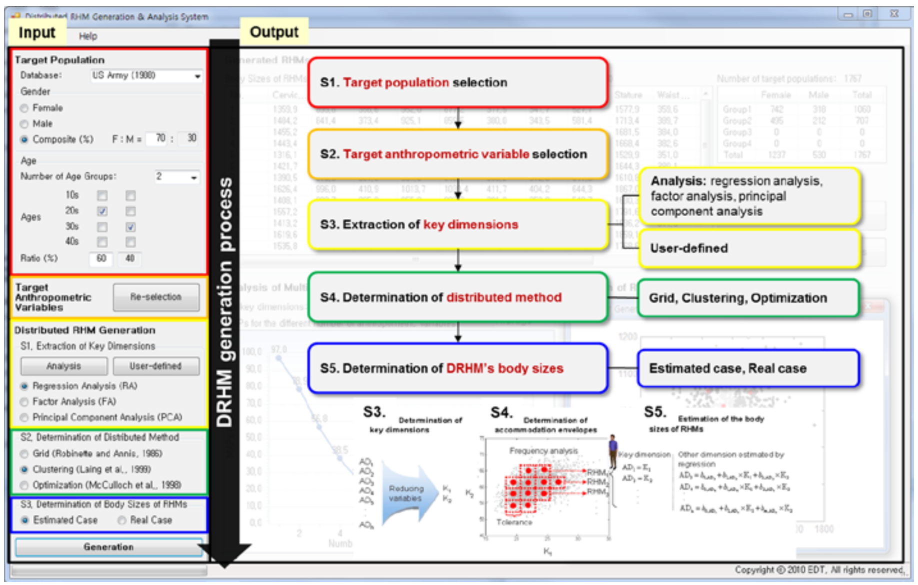


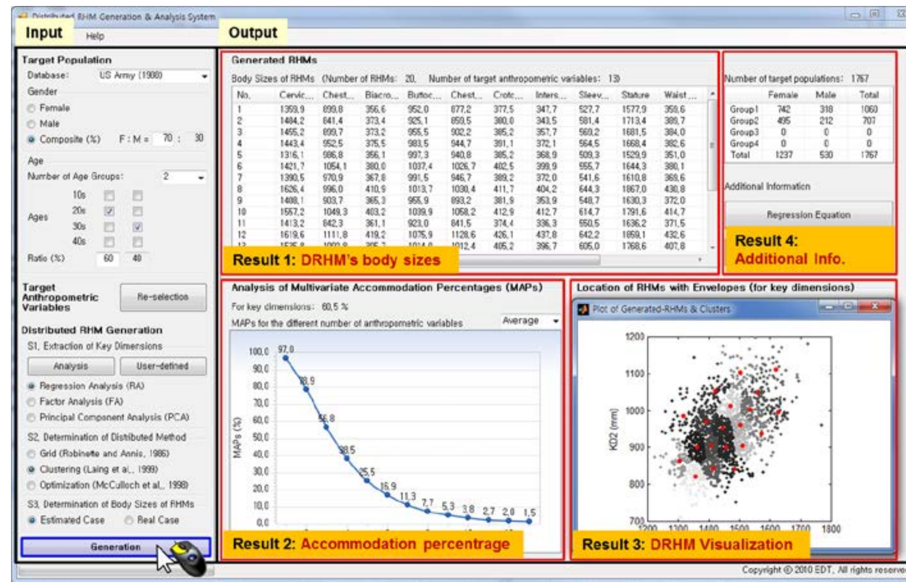
⇒ Candidates: P-C-E (22 sizes; 59%) vs. P-O-E (25 sizes; 69%)

⇒ Economical sizing system: P-C-E (less than # sizes of P-O-E)

Discussion (1/2)

- Developed a computerized system for DRHM generation and analysis by incorporating the DRHM generation process and methods

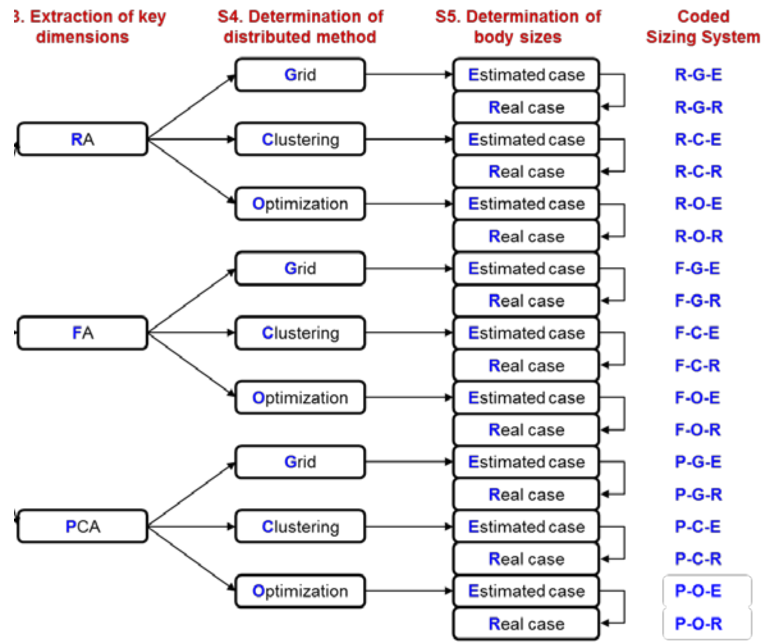




⇒ Can save time and effort in establishing a desirable sizing system

Discussion (2/2)

❑ Developed sophisticated interfaces incorporating complex and various algorithms for DRHM generation



⇒ Helpful for identifying an optimal sizing system out of sizing system alternatives easily and efficiently

Q & A

Distributed RHM Generation & Analysis System
File
View
Help
Target Population
Database: US Army (1988)
Gender
Female
Male
Composite (%) F : M = 70 : 30
Age
Number of Age Groups: 2
Ages
10s
20s
30s
40s
Ratio (%) 60 40
Target Anthropometric Variables
Re-selection
Distributed RHM Generation
S1. Extraction of Key Dimensions
Analysis
User-defined
Regression Analysis (RA)
Factor Analysis (FA)
Principal Component Analysis (PCA)
S2. Determination of Distributed Method
Grid (Robinette and Annis, 1986)
Clustering (Laing et al., 1999)
Optimization (McCulloch et al., 1998)
S3. Determination of Body Sizes of RHMs
Estimated Case
Real Case
Generation
Generated RHMs
Body Sizes of RHMs (Number of RHMs: 20, Number of target anthropometric variables: 13)
No. Cervic... Chest... Biacro... Buttoc... Chest... Crotc... Inters... Sleev... Stature Waist ...
1 1359.9 899.8 356.6 952.0 877.2 377.5 347.7 527.7 1577.9 359.6
2 1484.2 841.4 373.4 925.1 859.5 380.0 343.5 581.4 1713.4 389.7
3 1455.2 899.7 373.2 955.5 902.2 385.2 357.7 569.2 1681.5 384.0
4 1443.4 952.5 375.5 983.5 944.7 391.1 372.1 564.5 1668.4 382.6
5 1316.1 986.8 356.1 997.3 940.8 385.2 368.9 509.3 1529.9 351.0
6 1421.7 1054.1 380.0 1037.4 1026.7 402.5 399.9 555.7 1644.3 380.1
7 1390.5 970.9 367.8 991.5 946.7 389.2 372.0 541.6 1610.8 369.6
8 1626.4 996.0 410.9 1013.7 1030.4 411.7 404.2 644.3 1867.0 430.8
9 1408.1 903.7 365.3 955.9 893.2 381.9 353.9 548.7 1630.3 372.0
10 1557.2 1049.3 403.2 1039.9 1058.2 412.9 412.7 614.7 1791.6 414.7
11 1413.2 842.3 361.1 923.0 841.5 374.4 336.3 550.5 1636.2 371.5
12 1619.6 1111.8 419.2 1075.9 1128.6 426.1 437.8 642.2 1859.1 432.6
13 395.7 1012.4 396.7 605.0 407.8
Number of target populations: 1767
Female Male Total
Group1 742 318 1060
Group2 495 212 707
Group3 0 0 0
Group4 0 0 0
Total 1237 530 1767
Additional Information
Regression Equation
FA or PCA Loadings and Scores
Analysis of Multivariate Accommodation Percentages (MAPs)
For key dimensions: 60.5 %
MAPs for the different number of anthropometric variables
Average
MAPs (%)
97.0
78.9
56.8
38.5
25.5
16.9
11.3
7.7
5.3
3.8
2.7
2.0
1.5
Number of anthropometric variables
Location of RHMs with Envelopes (for key dimensions)
Plot of Generated-RHMs & Clusters
KD2 (mm)
KD1 (mm)
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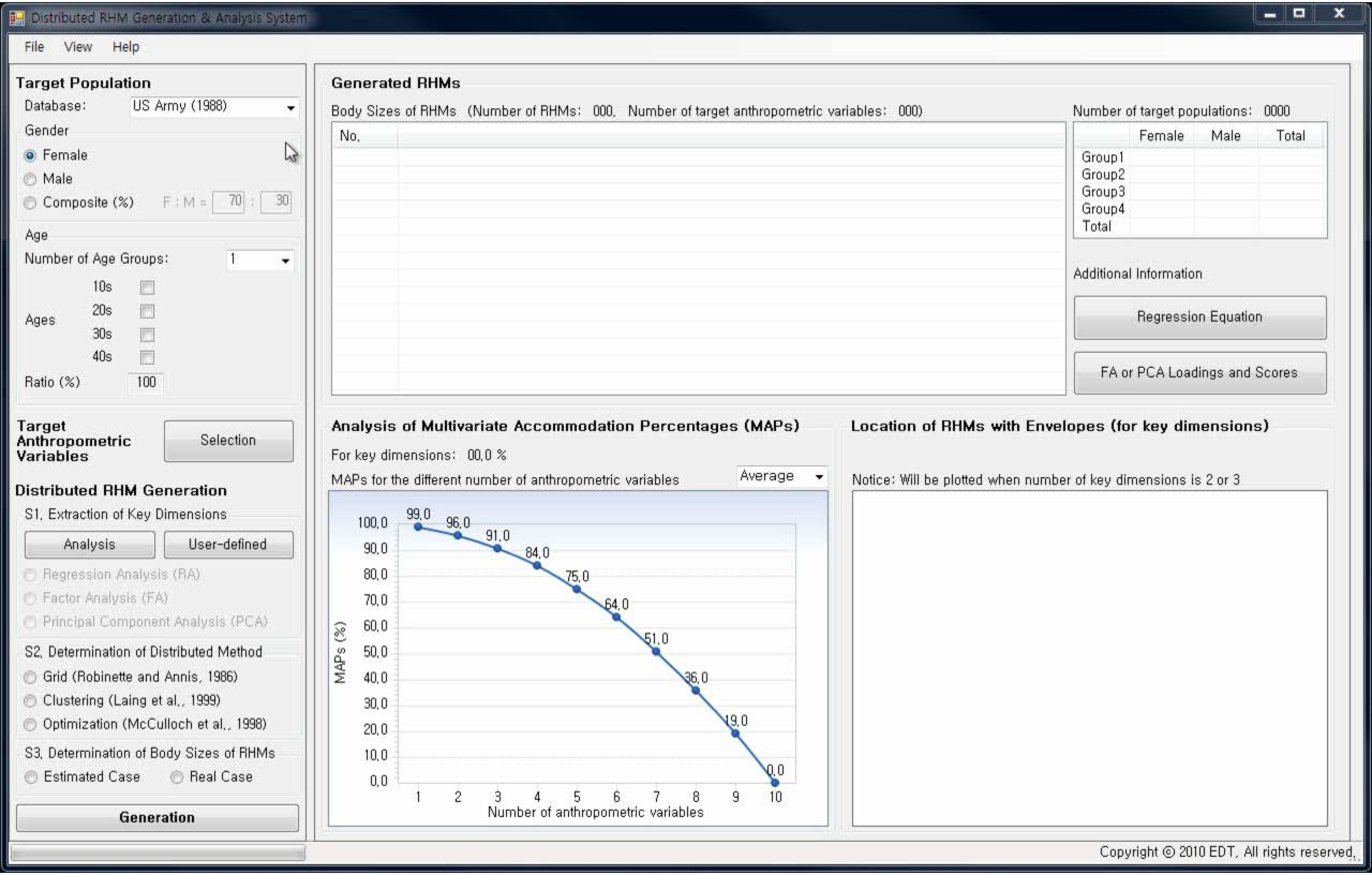
Thank You ☺

APPENDIX

Demonstration: RA – Grid – Estimated Case



Generation Method

S3. Extraction of key dimensions

S4. Determination of distributed method

Accommodation rate = 95%

- **RA**
  - **Grid** — Fitting tolerance = 50 mm
  - **Clustering**
  - **Optimization** — Number of iterations = 1,000
- **FA** (Method of factor rotation: Varimax)
  - **Grid** — Fitting tolerance = 2.35*
  - **Clustering**
  - **Optimization** — Number of iterations = 1,000
- **PCA**
  - **Grid** — Fitting tolerance = 3.32*
  - **Clustering**
  - **Optimization** — Number of iterations = 1,000

Random initial solution — **Clustering** / **Optimization**

10 trials

Find the minimum number of DRHMs

Factor scores

No.	F1	F2	F3	F4
1	0.509	-0.229	0.728	1.184
2	1.115	-0.689	-1.155	-0.834
3	-0.583	1.975	1.278	0.164
4	0.257	-0.331	-1.414	-0.664
5	0.022	1.740	0.463	-0.405
6	-1.661	-0.320	2.617	-0.906
7	0.840	-0.071	-0.827	-1.313
8	0.368	-0.520	-0.663	0.857
9	-0.697	1.719	-0.028	0.908
10	0.527	-0.165	-1.025	2.028

Descriptive statistics	F1	F2	F3	F4
Mean	0.0	0.0	0.0	0.0
S.D.	1.0	1.0	1.0	1.1
Minimum	-2.7	-2.6	-3.5	-3.7
Maximum	2.5	3.2	2.9	3.7
Range (Max - Min)	5.2	5.9	6.4	7.4
1st percentile	-2.7	-2.6	-3.5	-3.6
99th percentile	2.5	3.2	2.8	3.7
1 - 99 percentile range	5.1	5.8	6.3	7.3

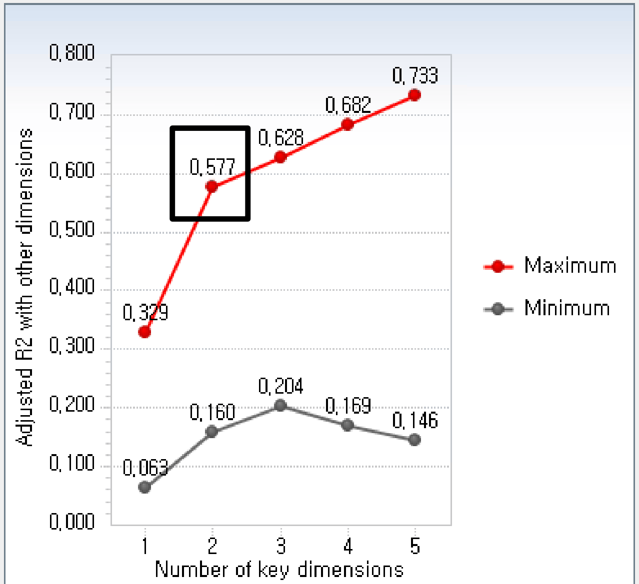
*equivalent to 50 mm of R-G's fitting tolerance

Key Dimensions for Flight Suit Design

- Chest circumference and Stature considering both performance (average adjusted R^2 with other dimensions = 0.574; current key dimensions) and usability

Regression Analysis (RA)

Trend of average adjusted R^2



Possible pairs of key dimensions

Candidate for key dimension	Adjusted R^2 Average	Minimum	Maximum
☑ Cervicale Height; Chest Circumference	0,577	0,140	0,971
Chest Circumference; Stature	0,574	0,158	0,972
Cervicale Height; Chest Circumference-At Scye	0,568	0,140	0,970
Chest Circumference-At Scye; Stature	0,563	0,158	0,971
Cervicale Height; Waist Circumference-Natural	0,549	0,156	0,972
Stature; Waist Circumference-Natural	0,548	0,170	0,973
Chest Circumference; Waist Height-Natural	0,538	0,081	0,907
Chest Circumference-At Scye; Waist Height-Natural	0,529	0,081	0,905
Buttock Circumference; Cervicale Height	0,515	0,140	0,971
Buttock Circumference; Stature	0,512	0,158	0,971
Waist Circumference-Natural; Waist Height-Natural	0,507	0,095	0,904
Chest Circumference; Sleeve-Outseam Length	0,480	0,052	0,907
Cervicale Height; Interscye Distance	0,479	0,148	0,970
Buttock Circumference; Waist Height-Natural	0,476	0,081	0,904
Chest Circumference-At Scye; Sleeve-Outseam Length	0,471	0,052	0,905
Interscye Distance; Stature	0,471	0,165	0,970
Sleeve-Outseam Length; Waist Circumference-Natural	0,450	0,059	0,724
Interscye Distance; Waist Height-Natural	0,447	0,093	0,904
Buttock Circumference; Sleeve-Outseam Length	0,435	0,065	0,689
Cervicale Height; Crotch Length-Posterior-Natural	0,425	0,086	0,970

Number of key dimensions: 2

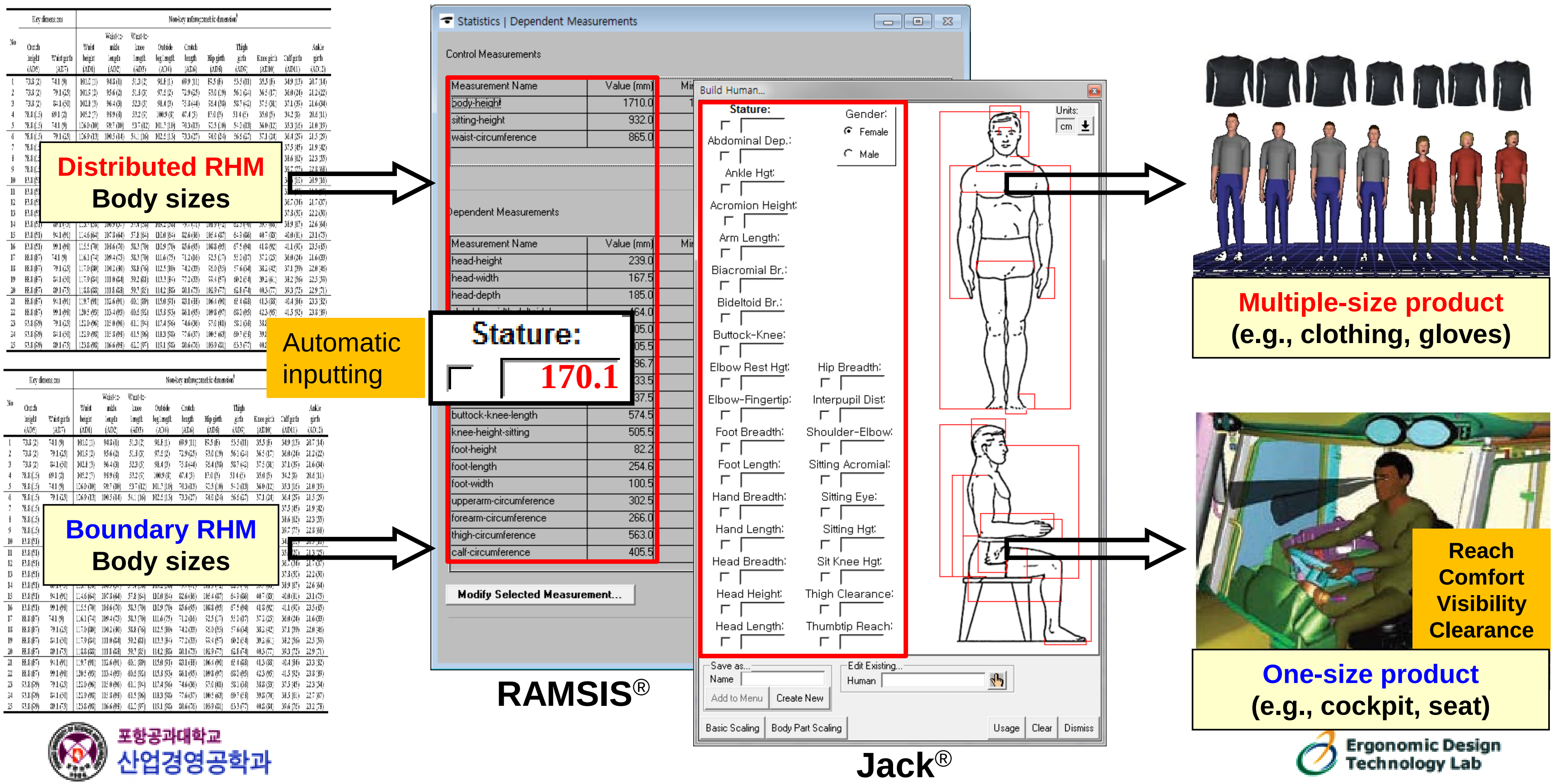
Selection

Comparison of Sizing Systems: Average of MAPs

No.	Sizing System	Generated number of DRHMs	Number of anthropometric variables												
			1	2	3	4	5	6	7	8	9	10	11	12	13
1	R-G-E	29	98.7	90.7	76.8	61.7	48.3	37.5	29.2	23.0	18.4	15.1	12.6	10.7	9.3
2	R-G-R		98.9	91.3	77.6	62.3	48.5	37.2	28.6	22.1	17.4	13.9	11.4	9.5	8.0
3	R-C-E	34	99.1	92.4	80.4	66.7	53.8	42.8	33.9	26.9	21.4	17.3	14.0	11.5	9.5
4	R-C-R		98.9	92.1	80.2	66.7	54.0	43.1	34.2	27.2	21.7	17.5	14.2	11.6	9.5
5	R-O-E	35	98.8	92.3	80.3	66.6	53.7	42.8	34.0	27.0	21.6	17.3	14.0	11.4	9.3
6	R-O-R		98.7	91.9	80.0	66.5	53.8	43.1	34.3	27.3	21.8	17.5	14.0	11.3	9.1
7	F-G-E	29	93.0	78.0	59.9	43.9	31.6	22.8	16.6	12.4	9.5	7.4	5.9	4.7	3.9
8	F-G-R		88.5	71.5	54.7	40.7	29.9	21.9	16.1	11.8	8.8	6.5	4.9	3.6	2.7
9	F-C-E	25	87.3	69.2	52.5	39.1	29.1	21.8	16.7	13.1	10.5	8.6	7.2	6.2	5.4
10	F-C-R		87.1	68.3	51.6	38.4	28.7	21.6	16.5	12.9	10.2	8.3	6.8	5.7	4.7
11	F-O-E	26	87.1	69.8	53.4	40.1	30.0	22.6	17.2	13.3	10.4	8.3	6.7	5.5	4.5
12	F-O-R		86.7	69.5	53.5	40.4	30.3	22.8	17.3	13.1	10.0	7.5	5.7	4.2	3.1
13	P-G-E	29	99.6	92.4	70.5	45.4	27.3	16.5	10.4	6.9	4.9	3.6	2.8	2.3	1.9
14	P-G-R		98.3	91.7	78.3	61.2	45.1	32.4	23.3	17.1	12.8	9.8	7.7	6.1	4.9
15	P-C-E	22	98.2	90.4	76.8	61.2	47.0	35.6	27.1	20.9	16.3	13.0	10.5	8.7	7.2
16	P-C-R		98.4	89.7	75.3	59.4	45.3	34.0	25.6	19.4	14.8	11.4	8.7	6.7	4.9
17	P-O-E	25	98.6	91.5	77.9	61.9	47.2	35.3	26.5	20.1	15.5	12.2	9.7	7.9	6.4
18	P-O-R		99.1	91.6	77.1	60.3	45.3	33.5	24.8	18.7	14.3	11.0	8.6	6.7	5.2

Follow-Up Studies

- Development of (1) a boundary representative human model (BRHM) generation and analysis system for one-size product design and (2) a linkage with the custom-built interface of digital human model simulation systems



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