포항공과대학교
산업경영공학과

Ergonomic Design Technology Lab

# Workspace 설계를 위한 주변부 대표인체모델 생성 및 분석 시스템 개발

## Development of a **B**oundary **R**epresentative **H**uman **M**odel (**BRHM**) Generation and Analysis System for Workspace Design

2011. 05. 27

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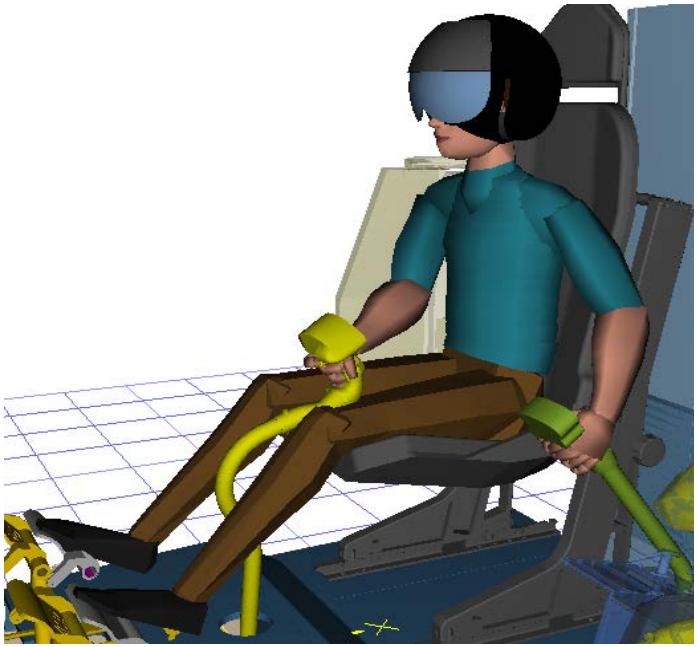
Global Contributor to Eco-Techno-Humanopia

# AGENDA

- Background
- Research Objectives
- Literature Survey
- System Development
- Discussion

# Digital Human Model (DHM) Simulation System

- 제품 및 작업공간 개발 초기부터 가상환경상에서 human model과 virtual mockup을 사용하여 인간공학적 평가 ⇒ 개발 기간 및 비용 ↓ (Chaffin, 2005; You, 2007)
- 평가, 진단, 개선 절차가 신속하고 경제적(Chaffin, 2001)



**한국형 헬리콥터 조종실 설계**
(Park et al., 2008)

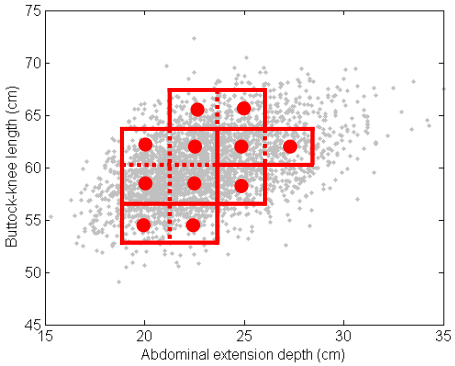
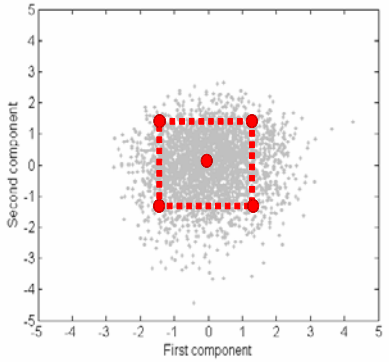

**방사성폐기물처리장 주제어실 평가**
(Lee et al., 2010)

⇒ **Workspace 설계에 유용하게 활용하기 위해 human model 생성이 중요하게 고려됨**

# Representative Human Model (RHM)

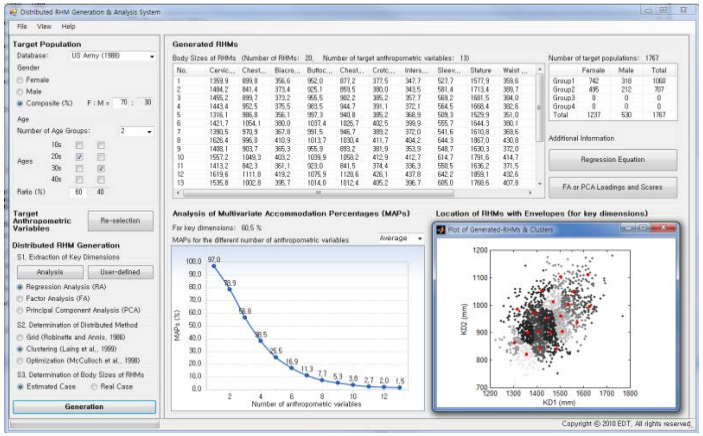
- 제품 설계대상인구(target population)의 인체크기를 통계적으로 적합하게 대표하는 소수의 인체모델(Jung and You, 2005)
- RHM은 제품 설계 적용 분야에 따라 2가지 방법으로 생성될 수 있음(Jung, 2009)

Focus

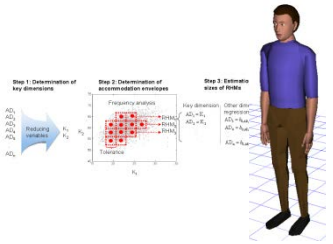
| | Distributed RHM (DRHM) | Boundary RHM (BRHM) |
|---|---|---|
| Illustration |  |  |
| Application area | • 다중치수제품(multiple-size product) 설계<br>• 예: 의복, 장갑 | • 단일치수제품(one-size product) 설계<br>• 예: 비행기 조종석, 자동차 운전석 |
| RHM generation methods | • *Grid* (Robinette and Annis, 1986)<br>• *Clustering* (Laing et al., 1999)<br>• *Optimization* (McCulloch et al., 1998) | • *Square* (Bittner, 2000)<br>• *Rectangular* (Kim and Whang et al., 1997)<br>• *Circular* (Meindl et al., 1993)<br>• *Boundary zone* (Jung, 2009) |

# DRHM Generation and Analysis System

**Distributed Representative Human Model (DRHM) Generation and Analysis System (Lee, 2011)**



**RHM Generation Procedural Interface**

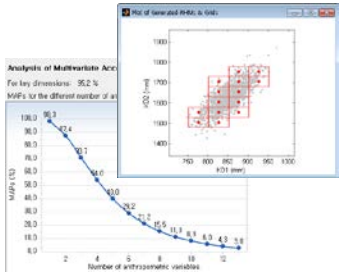


⇒ RHM 생성 절차가 적용되어
RHM 생성이 용이한 인터페이스 제공

**Customized Sizing Categorization**

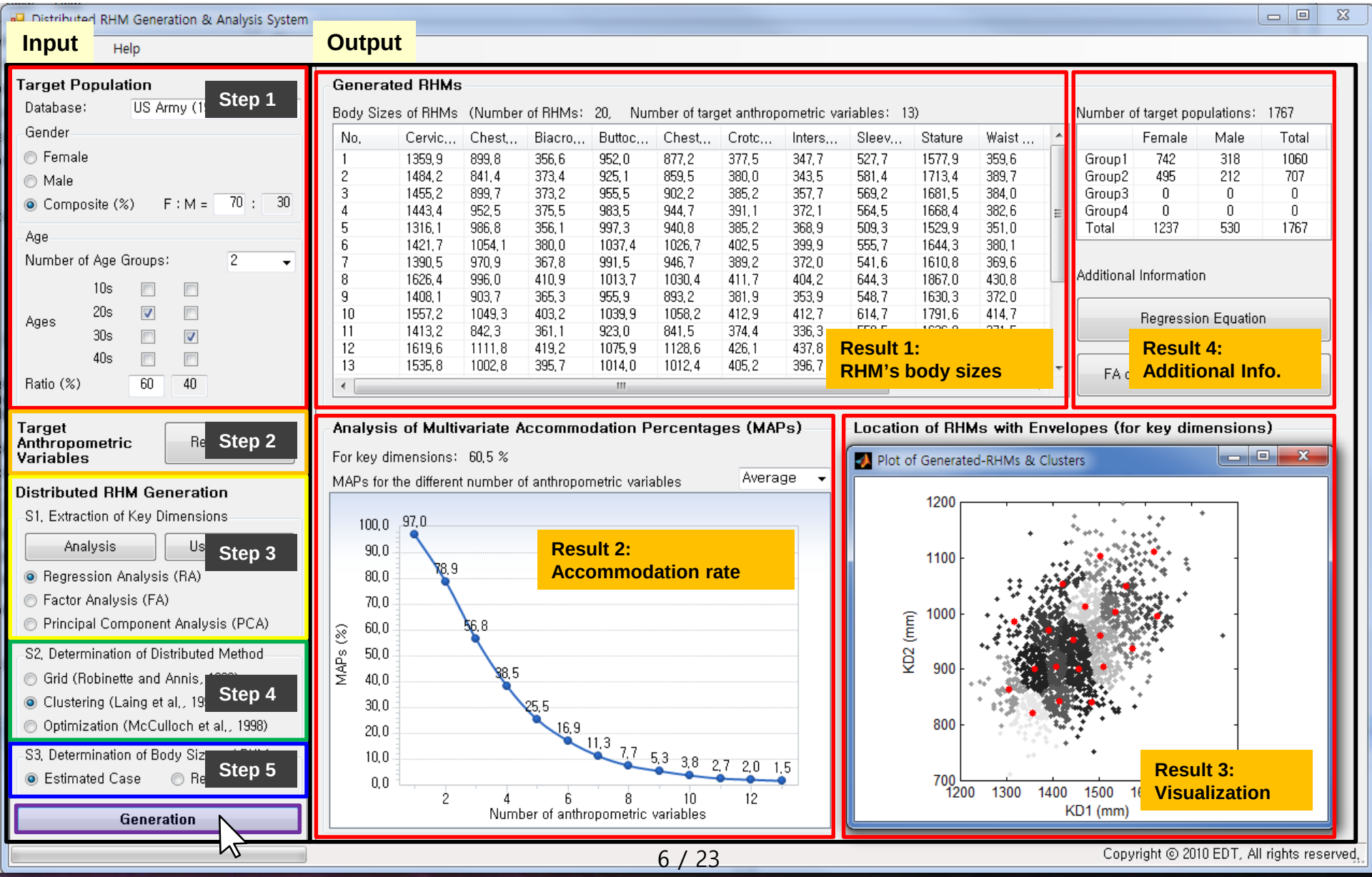
⇒ 맞춤형 치수체계 설계에 적합한 시스템

**Specialized RHM Analysis**



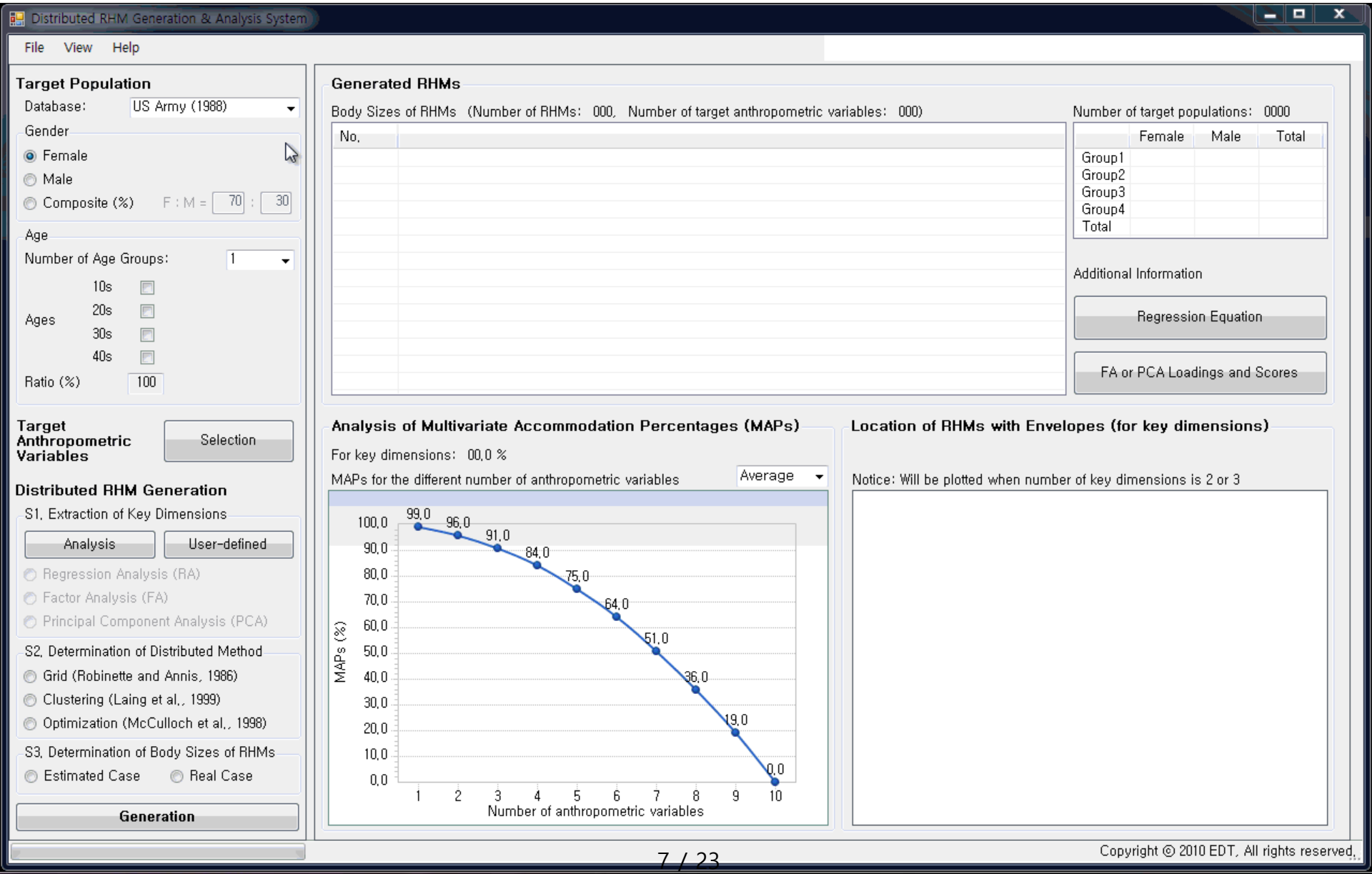
⇒ 생성된 RHM 분석에 특화된 시스템

# DRHM Generation and Analysis System



# DRHM System Demonstration

**Playing time: 2:20**



# Results: Performance Comparison

## 비행복 설계를 위한 DRHM 방법 별 비교분석(Lee, 2011)

- Target population: 485 males (US Army Pilot, 1988)
- Target anthropometric variables: 13 key variables for flight suit (Jeon et al., 2009)

| No. | DRHM generation methods | Accommodation rate for key dimensions (%) | Number of generated RHMs | *Real key dimensions (2) | Non-key dimensions (11) | | |
|---|---|---|---|---|---|---|---|
| | | | | Accommodation rate (%) | Coverage rate of ranges of dimensions (%) | | Number of outlier RHMs |
| | | | | | Average | SD | |
| 1 | RA-Grid-Estimated | **95.3** | 26 | **95.3** | 53.7 | 14.3 | 0 |
| 2 | RA-Grid-Real | 87.4 | | 87.4 | 55.2 | 14.8 | 0 |
| 3 | RA-Clustering-Estimated | **95.3** | 32 | **95.3** | 59.3 | 17.3 | 0 |
| 4 | RA-Clustering-Real | 90.9 | | 90.9 | 61.1 | 17.8 | 0 |
| 5 | RA-Optimization-Estimated | **95.1** | 33 | **95.1** | 56.9 | 16.4 | 0 |
| 6 | RA-Optimization-Real | 92.8 | | 92.8 | 58.3 | 16.8 | 0 |
| 7 | FA-Grid-Estimated | **95.1** | 26 | 51.1 | Non-key dimensions 비교 결과: 매우 유사함 | | |
| 8 | FA-Grid-Real | 86.8 | | 39.8 | | | |
| 9 | FA-Clustering-Estimated | **95.3** | 24 | 34.4 | 42.3 | 17.3 | 1 |
| 10 | FA-Clustering-Real | 92.8 | | 34.2 | 43.2 | 18.1 | 1 |
| 11 | FA-Optimization-Estimated | **95.3** | 26 | 35.9 | 44.4 | 14.8 | 1 |
| 12 | FA-Optimization-Real | 92.8 | | 36.1 | 41.5 | 16.0 | 1 |
| 13 | PCA-Grid-Estimated | **95.3** | 26 | 57.3 | 81.0 | 10.6 | 2 |
| 14 | PCA-Grid-Real | 92.4 | | 73.4 | 67.3 | 6.6 | 0 |
| 15 | PCA-Clustering-Estimated | **95.1** | 20 | 80.0 | 53.9 | 5.9 | 0 |
| 16 | PCA-Clustering-Real | 93.4 | | 80.0 | 55.6 | 5.0 | 0 |
| 17 | PCA-Optimization-Estimated | **95.9** | 23 | 76.7 | 56.1 | 7.3 | 0 |
| 18 | PCA-Optimization-Real | 92.6 | | 78.8 | 53.8 | 6.7 | 0 |

Optimal sizing system

*Real key dimensions: cervical height, chest circumference

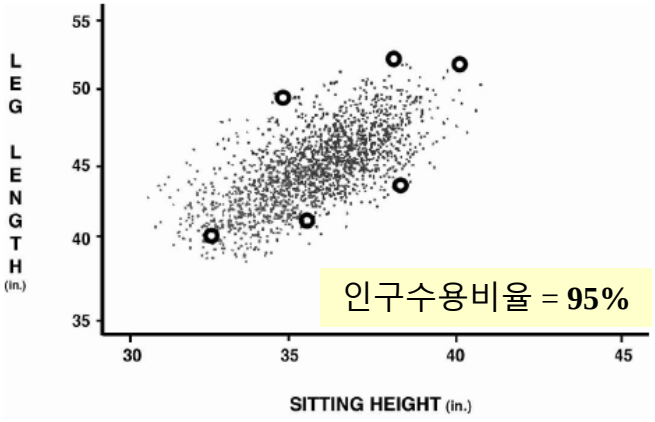
⇒ **DRHM 시스템을 통하여 효율적으로 최적 치수체계(optimal sizing system) 선정**

# Boundary RHM (BRHM)

- 중요변수(key dimension)에 대해 지정된 비율(designated accommodation percentage)의 설계 대상인구를 포함하는 주변부(boundary)에서 생성되는 인체모델

**효율적인 BRHM 생성**

- BRHM 수 ↓
- 인구수용비율 ↑




**Cockpit 설계를 위한 6개의 BRHM**
(Zehner, 1996)

| WORKSTATION RELATED VARIABLES | A-CADRE MANIKINS | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Stature | 99.0 | 91.0 | 82.7 | 95.4 | 75.6 | 52.0 | 24.4 | 38.3 | 61.7 | 75.6 | 48.0 | 9.0 | 17.3 | 4.6 | 24.4 | 1.0 | 50.0 |
| Illial Chest Ht. | 98.7 | 84.8 | 90.4 | 96.0 | 63.4 | 45.1 | 28.6 | 20.1 | 79.9 | 71.4 | 54.9 | 15.2 | 9.6 | 4.0 | 36.6 | 1.3 | 50.0 |
| Sitting Height | 96.6 | 89.7 | 31.5 | 91.0 | 93.6 | 85.0 | 21.6 | 83.2 | 16.8 | 78.4 | 15.0 | 10.3 | 68.5 | 9.0 | 6.4 | 3.4 | 50.0 |
| Eye-Height Sitting | 96.5 | 92.7 | 29.6 | 89.8 | 92.3 | 81.3 | 18.0 | 85.7 | 14.3 | 82.0 | 18.7 | 7.3 | 70.4 | 10.2 | 7.7 | 3.5 | 50.0 |
| Popliteal Height | 98.1 | 67.5 | 91.8 | 97.3 | 64.4 | 59.0 | 37.7 | 10.6 | 89.4 | 62.3 | 41.0 | 32.5 | 8.2 | 2.7 | 35.6 | 1.9 | 50.0 |
| Buttock-Knee Lth | 98.6 | 92.6 | 95.7 | 81.6 | 61.8 | 16.3 | 43.5 | 33.1 | 66.9 | 56.5 | 83.7 | 7.4 | 4.3 | 18.4 | 38.2 | 1.4 | 50.0 |
| Shoulder-Elbow Lth | 99.0 | 78.4 | 93.2 | 94.0 | 79.3 | 51.9 | 49.4 | 23.5 | 76.5 | 50.6 | 48.1 | 21.6 | 6.8 | 6.0 | 20.7 | 1.0 | 50.0 |
| Forearm-Hand Lth | 98.5 | 57.9 | 93.7 | 94.1 | 85.3 | 67.0 | 66.0 | 17.9 | 82.1 | 34.0 | 33.0 | 42.1 | 6.3 | 5.9 | 14.7 | 1.5 | 50.0 |
| Bideltoid Breadth | 93.6 | 87.4 | 89.6 | 18.9 | 93.6 | 18.9 | 89.6 | 87.4 | 12.6 | 10.4 | 81.1 | 12.6 | 10.4 | 81.1 | 6.4 | 6.4 | 50.0 |
| Hip Breadth | 96.9 | 96.1 | 89.6 | 34.4 | 86.4 | 12.3 | 69.2 | 84.1 | 15.9 | 30.8 | 87.7 | 3.9 | 10.4 | 65.6 | 13.6 | 3.1 | 50.0 |
| Foot Length | 98.9 | 65.7 | 92.5 | 92.9 | 89.3 | 66.9 | 65.7 | 26.4 | 73.6 | 34.3 | 33.1 | 34.3 | 7.5 | 7.1 | 10.7 | 1.1 | 50.0 |
| Hand Length | 98.0 | 45.9 | 90.6 | 92.5 | 92.9 | 80.1 | 76.6 | 24.3 | 75.7 | 23.4 | 19.9 | 54.1 | 9.4 | 7.5 | 7.1 | 2.0 | 50.0 |
| Functional Reach | 98.8 | 71.1 | 95.3 | 93.0 | 80.0 | 51.9 | 59.4 | 19.1 | 80.9 | 40.6 | 48.1 | 28.9 | 4.7 | 7.0 | 20.0 | 1.2 | 50.0 |
| Funct. Leg Throw | 99.0 | 82.4 | 93.3 | 94.6 | 72.3 | 45.5 | 41.1 | 21.5 | 78.5 | 58.9 | 54.5 | 17.6 | 6.7 | 5.4 | 27.7 | 1.0 | 50.0 |
| Acrom. Ht. Sit. | 97.1 | 93.4 | 35.8 | 88.9 | 92.2 | 77.3 | 20.1 | 84.9 | 15.1 | 79.9 | 22.7 | 6.6 | 64.2 | 11.1 | 7.8 | 2.9 | 50.0 |
| Cervicale Height | 99.0 | 90.0 | 84.9 | 95.4 | 75.2 | 51.0 | 26.4 | 35.3 | 64.7 | 73.6 | 49.0 | 10.0 | 15.1 | 4.6 | 24.8 | 1.0 | 50.0 |
| Tragon Height | 98.9 | 91.0 | 81.4 | 95.4 | 75.6 | 52.9 | 23.6 | 39.3 | 60.7 | 76.4 | 47.1 | 9.0 | 18.6 | 4.6 | 24.4 | 1.1 | 50.0 |
| Weight | 96.9 | 95.5 | 89.9 | 34.1 | 87.4 | 13.2 | 71.5 | 83.8 | 16.2 | 28.5 | 8 | | | | | | |
| Biacromial Breadth | 97.1 | 76.0 | 88.3 | 45.6 | 97.8 | 50.0 | 90.4 | 79.4 | 20.6 | 9.6 | 5 | | | | | | |

인구수용비율 = 75%

**Workstation 설계를 위한 17개의 BRHM**
(Bittner, 2000)

⇒ **BRHM을 효율적으로 생성할 수 있는 시스템은 부재**

# Research Objective

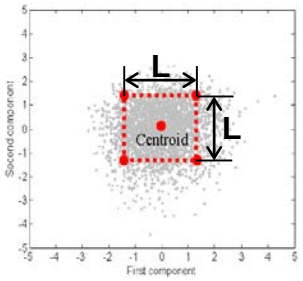
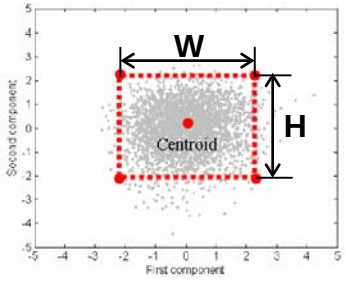
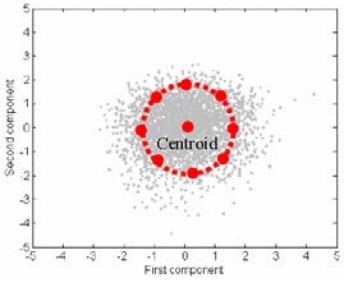
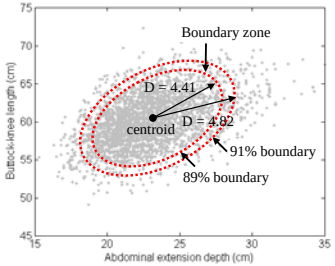
**Workspace 설계를 위한**

**주변부 대표인체모델(BRHM) 생성 및 분석 시스템 개발**

- **BRHM 생성 기법 조사 및 특성 파악**
  - ✓ BRHM 생성 방법 조사(예: square method)
  - ✓ BRHM 생성 절차 파악
- **기존 DRHM 시스템에 BRHM 생성 및 분석 기능 연계 방안 파악**
  - ✓ DRHM vs. BRHM: 공통점 및 차이점 파악
  - ✓ BRHM 생성 방법 별 algorithm 및 interface 개발

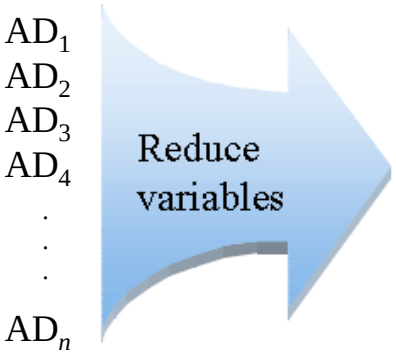
# Classification of BRHM Generation Methods

❑ 생성되는 boundary 형상에 근간하여 네 가지 방법으로 분류

| | ***Square*** **method (SM)** | ***Rectangular*** **method (RM)** | ***Circular*** **method (CM)** | ***Boundary Zone*** **method (BZM)** |
|---|---|---|---|---|
| Illustration |  |  |  |  |
| Studies (year) | • Bittner et al. (1987)<br>• Bittner (2000)<br>• Henry (1990) | • Kim and Whang (1997) | • Meindle et al. (1993)<br>• Zehner (1996, 1999)<br>• Reed and Flannagan (2000)<br>• Hsiao et al. (2005)<br>• Hudson et al. (1998, 2003, 2006) | • Jung (2009) |

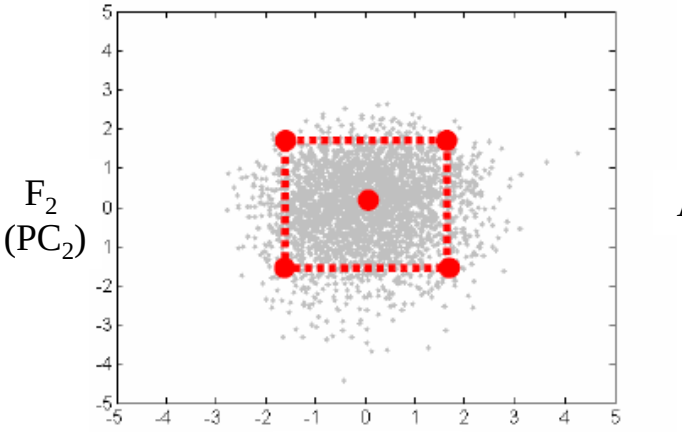
# Process of BRHM Generation: SM, RM, CM

**Step 1: Extract factors (components) by factor analysis (principal component analysis)**



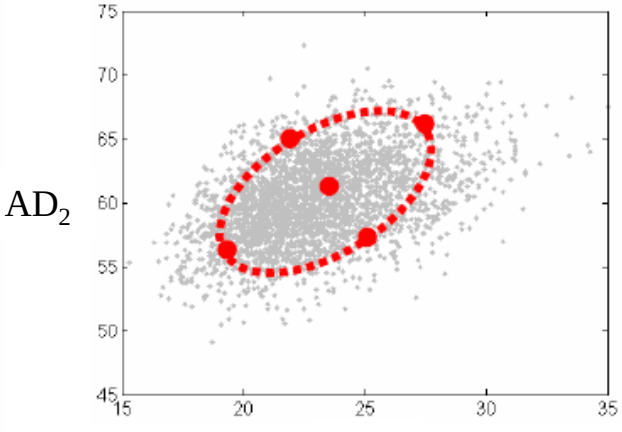

**Factor analysis (FA)**
**Principal component analysis (PCA)**

**Step 2: Determine factor (component) scores of RHMs**




**SM, RM, CM**

**Step 3: Convert the factor (component) scores to body sizes of RHMs**




**Z = FL x FS**

where: **Z** = *10* × *n* matrix of standard normal scores (n = number of RHMs generated)

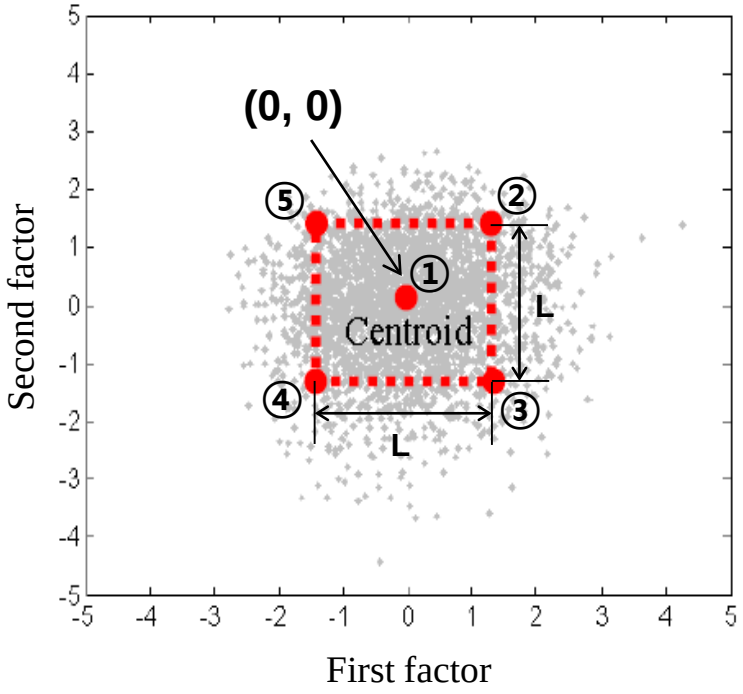
**FL** = *10* × *3* matrix of factor loading, and

**FS** = *3* × *n* matrix of the factor scores defined in the space of the factors

※ note: AD: anthropometric dimension, F: factor, *n*: number of anthropometric dimensions.

# Determination of Factor Scores of BRHM: SM

- Determined by Bittner constant (1.2208; Bittner, 2000)

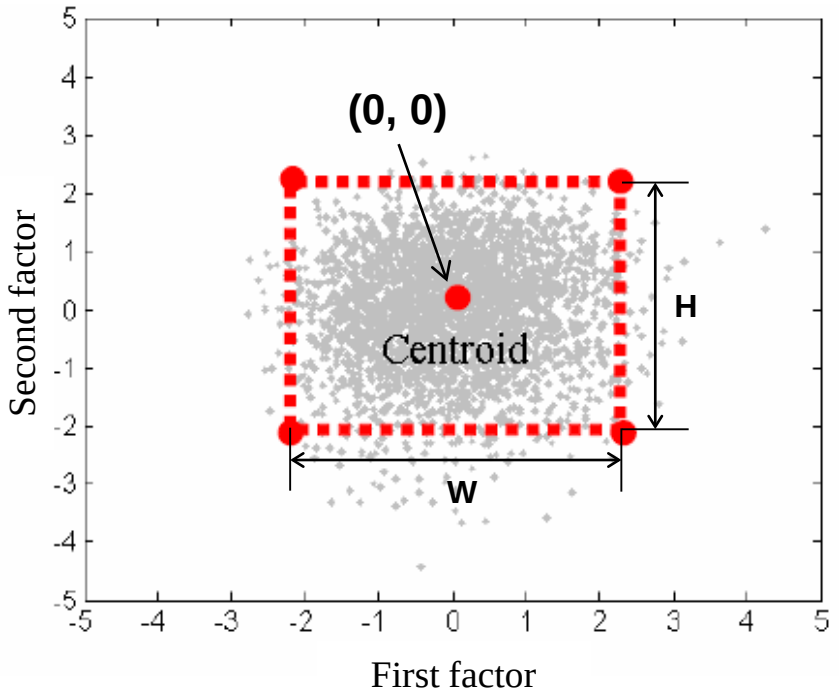



| | First factor | Second factor |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 1.2208 | 1.2208 |
| 3 | 1.2208 | -1.2208 |
| 4 | -1.2208 | -1.2208 |
| 5 | -1.2208 | 1.2208 |

※ L: length

# Determination of Factor Scores of BRHM: RM

- Determined by finding a boundary that statistically accommodate a designated percentage of the target population with weights of each factor (Kim and Whang, 1997)




※ W: width, H: height

$$(w_1+w_2)\kappa' - w_1 w_2 \kappa' = \tau$$

where: $w_i$ (weight of factor $i$) = $1/\sqrt{\lambda_i}$

$\lambda_i$ = eigen value of factor $i$

$\tau = 1 - \kappa$

$\kappa$ = designed accommodation percentage

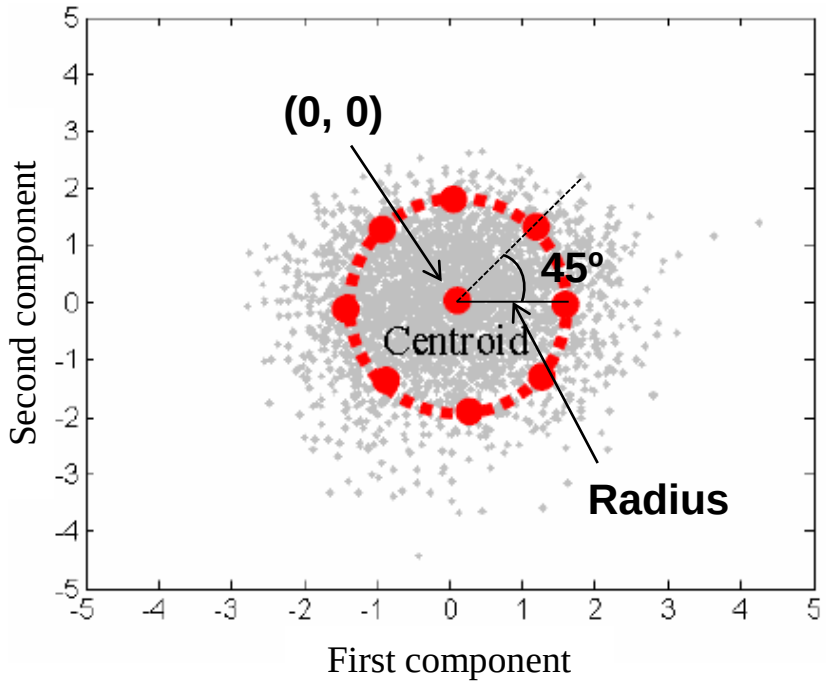
Obtain $\kappa'$

Rectangular boundary corners for factor $i$ = $\pm\left|\Phi^{-1}\left(\frac{w_i\kappa'}{2}\right)\right|$

where: $\Phi$ = cumulative density function

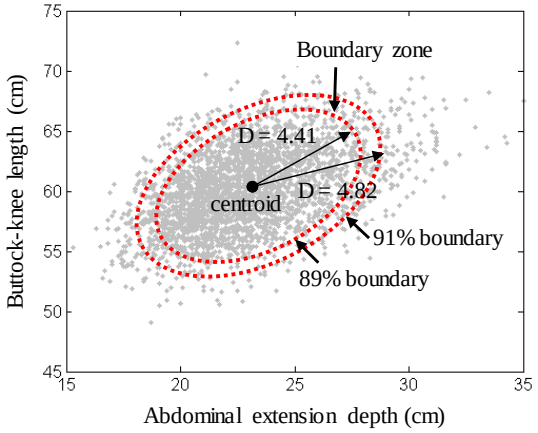
# Determination of Factor Scores of BRHM: CM

- Determined by the points with a predefined angular interval (usually 45º) on a circular boundary and the radius of the circle with the proportion of people within the circle met the designated percentage (Meindl et al., 1993)



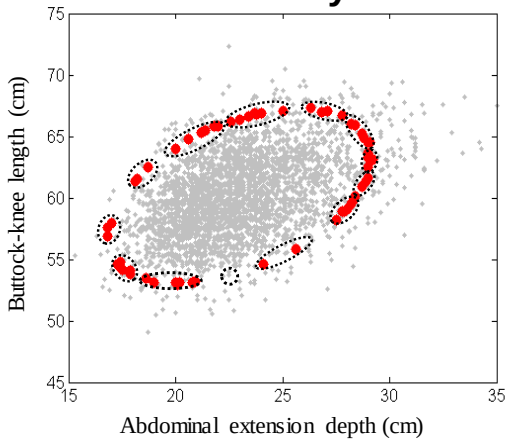
# Process of BRHM Generation: BZM

**Step 1. Formation of a boundary zone**



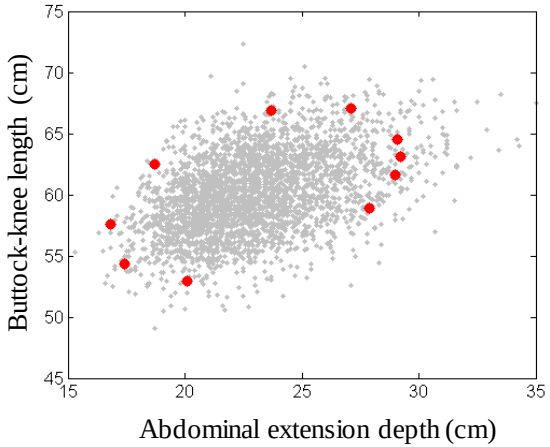

목표인구수용비율에 허용 비율을 가감(예: 90%±1%)하여 결정된 두 개의 경계선으로 형성

**Step 2. Clustering of anthropometric cases in the boundary zone**




군집분석(K-mean clustering analysis)을 통해 BRHM 수를 최적화

**Step 3. Selection of representative anthropometric cases**




군집의 중앙에서 한 개씩의 BRHM을 선정(군집의 centroid or real case)

$$D = (AD - \mu)^T \Sigma^{-1} (AD - \mu) \sim \chi_n^2$$

$\chi_2^2 (1 - 0.91) = 4.82$

$\chi_2^2 (1 - 0.89) = 4.41$

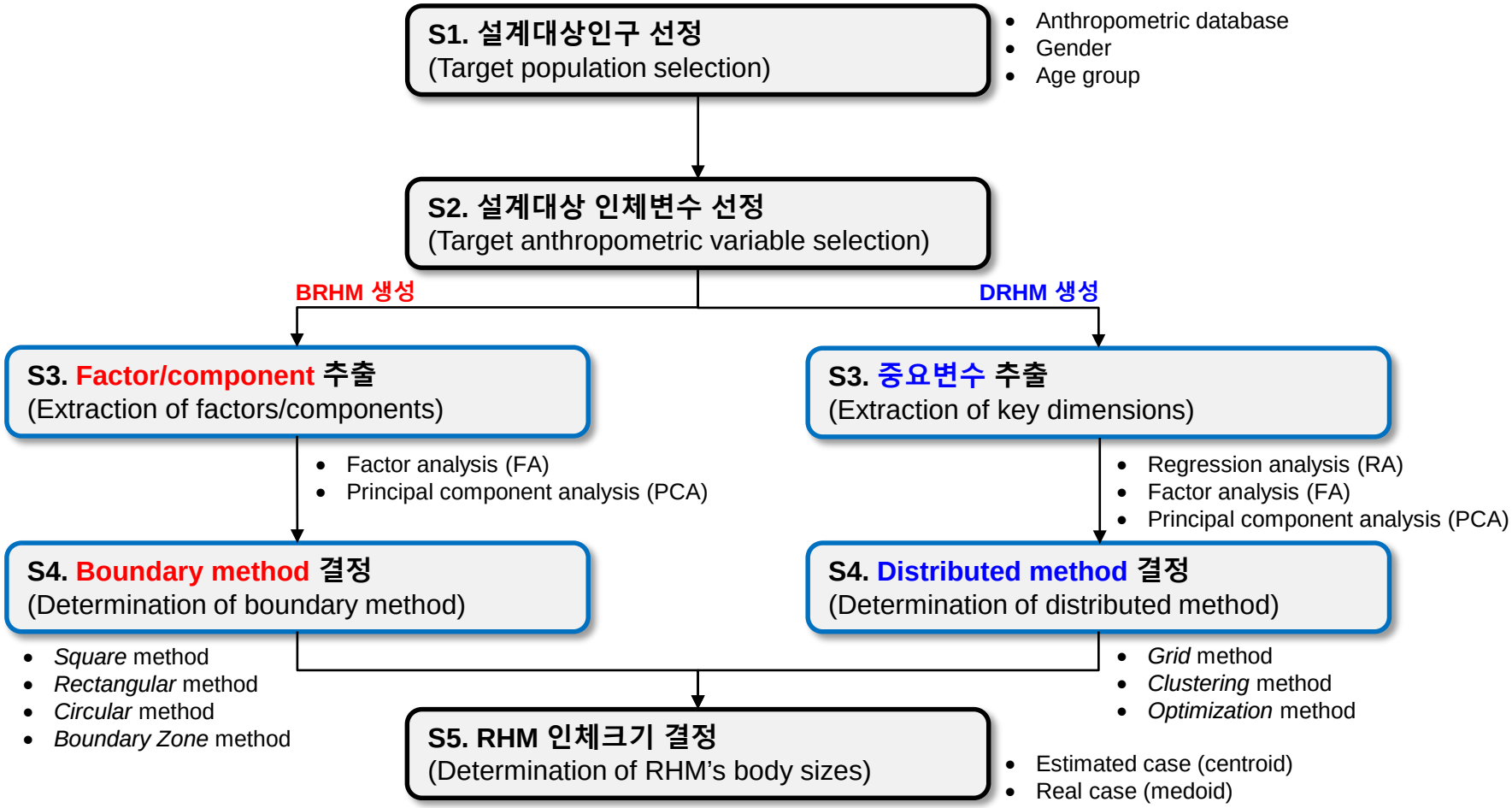
where: $D$ = normalized squared distance

$AD$ = $n \times 1$ anthropometric case matrix of $n$ anthropometric dimensions

$\mu$ = $n \times 1$ average matrix of $n$ anthropometric dimensions

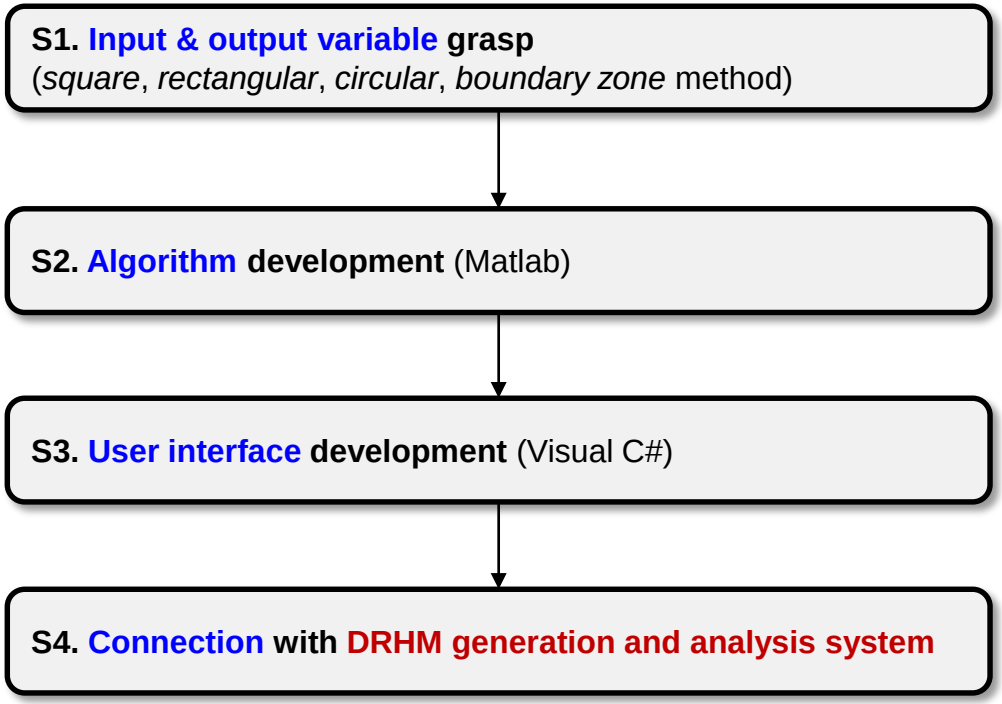
$\Sigma$ = $n \times n$ variance-covariance matrix of $n$ anthropometric dimensions

# BRHM vs. DRHM: Generation Process




⇒ 기존 DRHM 시스템(Lee et al, 2011)에 boundary method를 module화 하여 추가(add-on)하면 효율적으로 개발될 수 있음

# Development Protocol

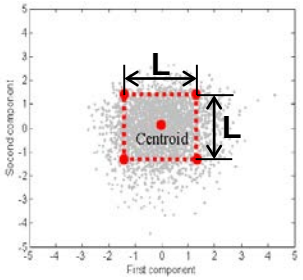
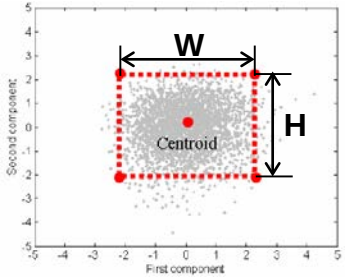
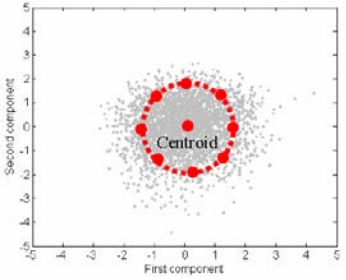
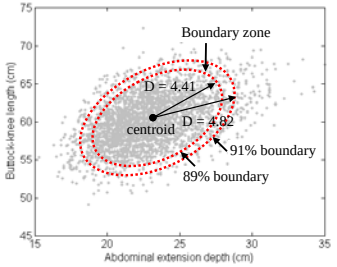



Complete

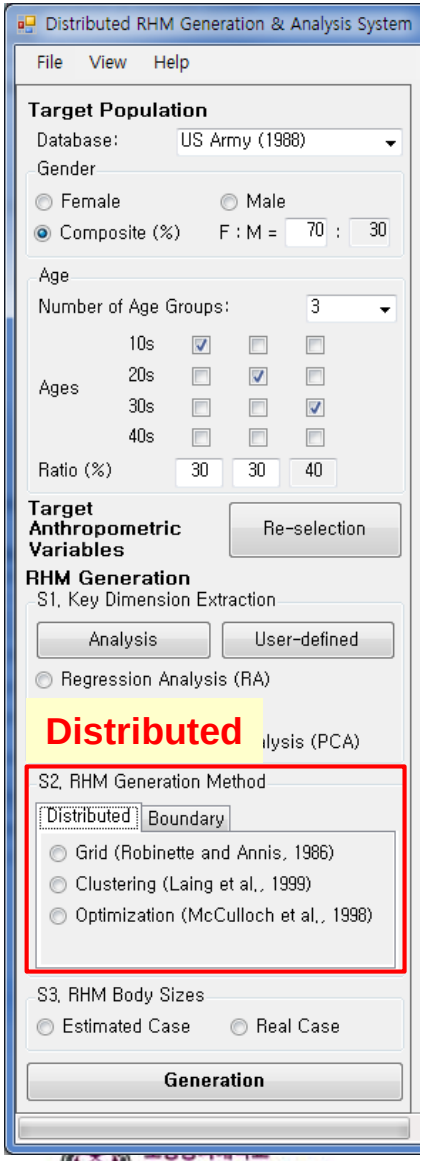
In progress (90%)

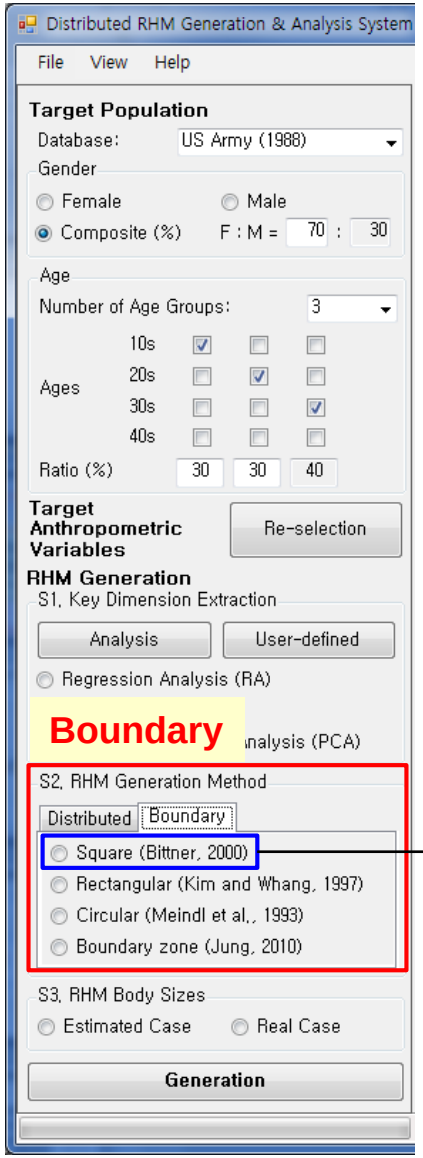
In progress (30%)

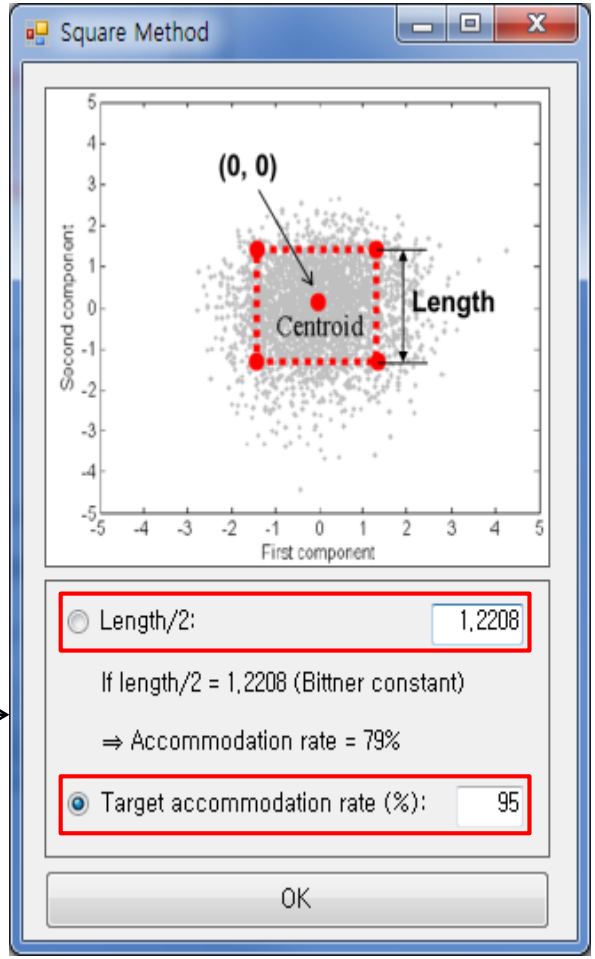
# Summary: Boundary Methods

| | *Square* method (SM) | *Rectangular* method (RM) | *Circular* method (CM) | *Boundary Zone* method (BZM) |
|---|---|---|---|---|
| **Illustration** |  |  |  |  |
| **Data reduction technique** | • Factor analysis | • Factor analysis | • Principal component analysis | - |
| **Input** | • Length/2<br>• Designated accommodation percentage (%) | • Width/2<br>• Height/2<br>• Designated accommodation percentage (%) | • Angular interval (º)<br>• Radius<br>• Designated accommodation percentage (%) | • Designated accommodation percentage (%)<br>• Tolerance (%) |
| **Process** | - | - | - | • Number of clusters |
| **Output** | • Body sizes of RHMs (unit: mm)<br>• Multivariate accommodation percentage (%)<br>• Outliers: magnitude / normalized magnitude (avg., SD, max) | | | |

# User Interface: SM



# Results: Performance Comparison

## 예: Workstation 설계를 위한 BRHM 방법 별 생성 결과

- Target population: 3,982 (US Army, 1988)
- Target anthropometric variables: abdominal extension depth, buttock-knee length, elbow rest height, foot length, forearm-to-forearm breadth, hip breadth, knee height, popliteal height, thigh clearance, buttock-popliteal length

| Boundary method | Trial | Number of factors/ principal components extracted | Percentage of variance explained | Number of Representative humanoids (RHs) | Multivariate accommodation percentage | Outlier percentage | | | Normalized outlier magnitude [ \|outlier - max or min\| / mean ] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Number of outlier RHs /total number of RHs | Number of vars. with Outliers /total number of vars. | Number of cells with Outliers /total number of cells | Average | SD | Max. |
| Square Method (SM) | 1 | 3 | 83% | 9 | 43% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 1 | 4 | 90% | 17 | 59% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 1 | 5 | 94% | 33 | 68% | 0% | 0% | 0% | 0% | 0% | 0% |
| Rectangular Method (RM) | 1 | 3 | 83% | 9 | 93% | 11% | 20% | 2% | 5% | 6% | 9% |
| | 1 | 4 | 90% | 17 | 98% | 35% | 70% | 8% | 3% | 3% | 11% |
| | 1 | 5 | 94% | 33 | 99% | 46% | 90% | 10% | 4% | 5% | 20% |
| Circular Method (CM) | 1 | 3 | 83% | 19 | 81% | 81% | 0% | 0% | 0% | 0% | 0% |
| | 1 | 4 | 90 | 33 | 84% | 12% | 20% | 1% | 3% | 4% | 8% |
| | 1 | 5 | % | 51 | 87% | 26% | 40% | 3% | 2% | 3% | 9% |
| Boundary Zone Method (BZM) | 1 | | | 47 | 91% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 2 | | | 47 | 90% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 3 | | | | 91% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 4 | | | | 90% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 5 | | | | 91% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 6 | | | | 90% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 7 | | | | 90% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 8 | | | | 91% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 9 | | | 45 | 90% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 10 | | | 46 | 91% | 0% | 0% | 0% | 0% | 0% | 0% |
| | Avg. | - | - | 44.3 | 91% | 0% | 0% | 0% | 0% | 0% | 0% |
| | SD | | | 2.3 | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| | Min | | | 41.0 | 90% | 0% | 0% | 0% | 0% | 0% | 0% |
| | Max | | | 47.0 | 91% | 0% | 0% | 0% | 0% | 0% | 0% |

**개발된 시스템을 사용하여 각 방법간 performance 비교를 통해 최적의 BRHM 선정 가능**

# Discussion

## ❑ 주변부 대표인체모델(BRHM) 생성 기법 및 생성 절차 파악

- ✓ 시스템 개발을 위한 네 가지 BRHM 생성 방법(square, rectangular, circular, boundary zone method)별 input, process, output 변수 파악
- ✓ BRHM과 DRHM의 비교분석을 통하여 기존 DRHM 시스템과의 효율적 연계 수행

## ❑ Workspace 설계를 위한 BRHM 생성 및 분석 시스템 개발

- ✓ 제품 개발자가 BRHM 생성 방법을 용이하게 적용할 수 있는 user-centered interface 제공
- ✓ BRHM 생성 절차 및 기법에 적용되는 통계적 기법의 총체적 제공: 개발 시간 ↓
- ✓ 생성된 BRHM의 고급 분석기능(예: multivariate accommodation rate 등) 제공

**⇒ 단일치수제품(one-size product)의 인간공학적 설계 및 평가 시 유용하게 활용될 수 있음**

# Q & A

# Thank You ☺