**Table 1. Common mathematical formulations for the DPHHC**

|  |  |  |
| --- | --- | --- |
| **Location-Allocation (*LA*)**Hess et al. (1965) | **Facility-Location (*FL*)**Hojati (1996) | **Set-Partitioning (*SP*)**Bennet (2010) |
| **Notation:**$m:$ defined set of district centers$n:$ set of basic units$c\_{ij}:$ cost of assigning subunit $i$ to district center $j$ $x\_{ij}:$ binary variable indicating whether subunit $i$ is assigned to district center $j$$d\_{i}:$ demand of basic unit $i$, $\overbar{a}=\sum\_{i}^{}d\_{i}/m:$ average demand | **Notation:**(additional to Hess et al., 1965)$m:$ set of potential district centers$n:$ set of basic units$x\_{ij}:$ variable indicating the fraction of subunit $i$ to be assigned to district center $j$$y\_{j}:$ binary variable indicating whether subunit $j$ is selected as a district center | **Notation:**$D:$ set of all feasible districts $γ\_{ij}:$ binary parameter indicating 1 if district $j$ includes subunit $i$ and 0 otherwise$C\_{j}$: cost of district $j$$y\_{j}:$ binary variable indicating whether district $j$ is selected |
| **Formulation:**

|  |  |
| --- | --- |
| $$Min\sum\_{j=1}^{m}\sum\_{i=1}^{n}c\_{ij}x\_{ij}$$ | (1) |
| Subject to: |  |
| $$\sum\_{i=1}^{n}d\_{i}x\_{ij}=\overbar{a}, ∀j$$ | (2) |
| $$\sum\_{j=1}^{m}x\_{ij}=1, ∀i$$ | (3) |
| $$x\_{ij} \in \{0,1\}$$ | (4) |

 | **Formulation:**

|  |  |
| --- | --- |
| $$Min\sum\_{j=1}^{m}\sum\_{i=1}^{n}c\_{ij}x\_{ij}$$ | (5) |
| Subject to: |  |
| $$\sum\_{j=1}^{m}x\_{ij}=1, ∀i$$ | (6) |
| $$ \sum\_{i=1}^{n}d\_{i}x\_{ij}=\overbar{a}y\_{j}, ∀j$$ | (7) |
| $$ \sum\_{j=1}^{n}y\_{j}=m$$ | (8) |
| $$x\_{ij}\leq y\_{j}, ∀i,j$$ | (9) |
| $$0\leq x\_{ij}\leq 1, ∀ i,j$$ | (10) |
| $$y\_{j} \in \{0,1\}$$ | (11) |

 | **Formulation:**

|  |  |
| --- | --- |
| $$Min\sum\_{j \in D}^{}C\_{j}y\_{j}$$ | (12) |
| Subject to: |  |
| $$\sum\_{j \in D}^{}γ\_{ij} y\_{j}=1, ∀i$$ | (13) |
| $$ \sum\_{j \in D}^{}y\_{j}=m$$ | (14) |
| $$y\_{i} \in \{0,1\}$$ | (15) |

 |
| **Objective**(1) Minimizes the total cost of assigning subunits to district centers | **Objective**(5) Minimizes the total cost of assigning subunits to district centers | **Objective**(12) Minimizes the total cost of all selected districts |
| **Constraints**(2) Ensure that demand assigned to each district is equal to the average demand(3) Ensure each subunit is assigned exactly to one district | **Constraints**(6) Same as (3)(7) Same as (2) if a district is open(8) Ensure $m$ districts are selected(9) Ensure subunits can only be assigned to selected districts  | **Constraints**(13) Ensure that each subunit $i$ is included in exactly one district(14) Ensure that $m$ districts are selected |

**Source: Presented by the authors based on each referred paper**

**Table 2. HHC Services offered in Cali, Colombia**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Type of Medical Activity**$$a\in A$$ | **Type of Medical Staff**$$k\in K$$ | **Group** | **Standard****Service Time** $\overbar{st\_{a}}$**, [min]** | **Annual****Demand** $\overbar{d\_{a}}$**[annual visits]** |
| Medicines Supply (MSP) | Auxiliary Nurse (AN) | G1 | 30 | 45.950 |
| Auxiliary Nurse Care (ANC-6) | 360 | 5.240 |
| Auxiliary Nurse Care (ANC-12) | 720 | 15.040 |
| Auxiliary Nurse Care (ANC-24) | 1.440 | 38.360 |
| Nursing Care (NCR) | Nurse (NU) | 30 | 12.530 |
| General Practitioner Visit (GPV) | Gn. Practitioner (GP) | G2 | 30 | 6.590 |
| Specialist Home Visit (SHV) | Specialist (SP) | 30 | 2.180 |
| Therapies Home Visit (THV) | Therapist (TE) | 60 | 176.360 |

**Source: Presented by the authors**

**Table 3. Results minimizing *Travel Workload* (**$f\_{1}$**)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***m*** | $f\_{1}^{\*}$: **Travel Workload [hr/year]** | **Total Workload [hr/year]** | **Average Workload [hr/year]** | $f\_{2}$**:Workload Deviations [hr/year]** | **Ratio** $T\_{T}/V\_{T}$ |
| 1 | 1.132.067 | 2.230.377 | 2.230.377 | 0 | 103,07% |
| 2 | 435.002 | 1.533.310 | 766.655 | 210.800 | 39,61% |
| 3 | 242.188 | 1.340.498 | 446.833 | 277.036 | 22,05% |
| 4 | 179.018 | 1.277.328 | 319.332 | **79.658** | 16,30% |
| 5 | 129.777 | 1.228.087 | 245.617 | 346.956 | 11,82% |
| 6 | 94.087 | 1.192.397 | 198.733 | 340.506 | 8,57% |
| 7 | 72.868 | 1.171.178 | 167.311 | 231.159 | 6,63% |
| 8 | 55.736 | 1.154.045 | 144.256 | 172.255 | 5,07% |
| 9 | 43.844 | 1.142.154 | 126.906 | 263.710 | 3,99% |
| 10 | 34.324 | 1.132.633 | 113.263 | 199.284 | 3,13% |
| 11 | 27.805 | 1.126.115 | 102.374 | 226.629 | 2,53% |
| 12 | **22.307** | **1.120.617** | **93.385** | 244.243 | **2,03%** |

**Source: Presented by the authors**

**Table 4. Results minimizing *Workload Deviations* (**$f\_{2}$**)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***m*** | $f\_{2}^{\*}$**:Workload Deviations [hr/year]** | **Total Workload [hr/year]** | **Average Workload [hr/year]** | $f\_{1}: $**Travel Workload [hr/year]** | **Ratio** $T\_{T}/V\_{T}$ |
| 1 | 0 | 2.230.383 | 2.230.383 | 1.132.073 | 103,07% |
| 2 | **11.492** | 1.579.638 | 789.819 | 481.328 | 43,82% |
| 3 | 18.046 | 1.448.363 | 559.545 | 350.053 | 31,87% |
| 4 | 24.600 | 1.317.087 | 329.272 | 218.777 | 19,92% |
| 5 | 30.408 | 1.226.503 | 174.402 | 128.193 | 11,67% |
| 6 | 36.217 | 1.225.637 | 204.273 | 127.327 | 11,59% |
| 7 | 37.083 | 1.226.503 | 175.413 | 128.193 | 11,67% |
| 8 | 37.949 | 1.172.423 | 146.553 | 74.113 | 6,75% |
| 9 | 47.158 | 1.163.543 | 131.010 | 65.233 | 5,94% |
| 10 | 56.367 | 1.154.663 | 115.466 | 56.353 | 5,13% |
| 11 | 80.945 | 1.149.851 | 105.443 | 51.541 | 4,69% |
| 12 | 105.523 | **1.145.040** | **95.420** | **46.730** | **4,25%** |

**Source: Presented by the authors**

**Table 5. Trade-offs Analysis: *Travel Workload* (**$f\_{1}$**) and *Workload* *Deviations* (**$f\_{2}$**)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| $$∝$$**[%]** | $f\_{1}: $**Travel Workload [hr/year]** | $f\_{2}$**:Workload Deviations [hr/year]** | **Total Workload [hr/year]** | **Average Workload [hr/year]** | **Deterioration of** $f\_{1}^{\*}$ | **Improvement of** $f\_{2}$ |
| 1 | 55.735 | 172.255 | 1.154.045 | 144.256 | 0,00% | 0,00% |
| 5 | 56.478 | 155.369 | 1.154.788 | 144.348 | 1,33% | 10,87% |
| 10 | 57.400 | 146.450 | 1.155.710 | 144.464 | 2,99% | 17,62% |
| 15 | 57.969 | 99.811 | 1.156.279 | 144.535 | 4,01% | 72,58% |
| 20 | 58.779 | 92.211 | 1.157.089 | 144.636 | 5,46% | 86,80% |
| 25 | 62.303 | 93.706 | 1.160.613 | 145.077 | 11,78% | 83,83% |
| 30 | 63.094 | 74.474 | 1.161.404 | 145.176 | 13,20% | 131,30% |

**Source: Presented by the authors**

**Figure 1. Cali, Colombia: Population Distribution**



**Source: Presented by the authors based on (DAP, 2012)**

**Figure 2. Optimized values when minimizing *Travel Workload* (**$f\_{1}$**)**



**Source: Presented by the authors**

**Figure 3. Efficient Frontier: *Travel Workload* (**$f\_{1}$**) and *Workload* *Deviations* (**$f\_{2}$**)**

****

**Source: Presented by the authors**

**Figure 4. Districting Configurations Obtained**

|  |  |
| --- | --- |
| **a. Minimizing: *Total Travel Workload* individually** | **b. Thresholds: *Total Travel Workload* vs. *Workload Deviations* (**$∝ =20\%$**)** |

**Source: Presented by the authors**

**Figure 5. Trade-offs Analysis: Improvements of *Workload* *Deviations*** $(f\_{2})$ **due to Deterioration of *Travel Workload*** $(f\_{1}^{\*})$



**Source: Presented by the authors**