
Appendix A

Binary Search Algorithm

Initialization:

Let

$\epsilon = 10^{-3}$ // Small constant

$\delta = 10^{-3}$ // Target absolute difference between the calculated upper and lower bounds for Z

$L \leftarrow 0, U \leftarrow 1 + \delta + \epsilon$ // Initialization of lower and upper bounds for Z

$Z^0 \leftarrow 1$ // Initialization of the Z imbalance measure

$T = 10800$ // Time limit (in seconds) for searching for a feasible solution for a given Z^0

t // Time spent in attempting to find a feasible solution given bound Z^0 (if it exists)

while $(U - Z^0) > \delta$ **do**

 Solve model with Z fixed at the value Z^0 ,

if *feasible integer solution is found* **then**

$U \leftarrow Z^0$,

end

else if $t > T$ or *Infeasibility is proven* **then**

$L \leftarrow Z^0$,

end

$Z^0 \leftarrow \frac{U+L}{2} + L$

end

Appendix B

As defined in Section 5, d_{is} denotes the nominal number of doors required by destination i during sort s and is calculated as the median of the random variable \tilde{d}_{is} , representing the number of doors required by destination i during sort s .

FBP1-D

$$\text{minimize } Z \quad (\text{FBP1-D-1})$$

$$\text{s.t. } \sum_{j \in I} x_{ij} = 1, \quad \text{for all } i \in I, \quad (\text{FBP1-D-2})$$

$$\frac{\sum_{i \in I} \mu_{is} x_{ij}}{\sum_{i \in I} \mu_{is}} - P_{js} \leq Z, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-D-3})$$

$$P_{js} - \frac{\sum_{i \in I} \mu_{is} x_{ij}}{\sum_{i \in I} \mu_{is}} \leq Z, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-D-4})$$

$$\sum_{i \in I} d_{is} x_{ij} \leq D_j, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-D-5})$$

$$SC, \quad (\text{FBP1-D-6})$$

$$x_{ij} \in \{0, 1\}, \quad \text{for all } i \in I, j \in J. \quad (\text{FBP1-D-7})$$

FBP1-B

$$\text{minimize } Z \quad (\text{FBP1-B-1})$$

$$\text{s.t. } \sum_{j \in I} x_{ij} = 1, \quad \text{for all } i \in I, \quad (\text{FBP1-B-2})$$

$$F^{-1} \left(\frac{q+1}{2} \right)^2 (\boldsymbol{\tau}_{js}^\top \boldsymbol{\tau}_{js}) \leq \zeta_{js}^2, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-3})$$

$$F^{-1} \left(\frac{1-q}{2} \right)^2 (\boldsymbol{\tau}_{js}^\top \boldsymbol{\tau}_{js}) \leq \phi_{js}^2, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-4})$$

$$\boldsymbol{\tau}_{js} = \mathbf{L}_s^\top \mathbf{y}_{js}, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-5})$$

$$\zeta_{js} = (Z - \boldsymbol{\mu}_s^\top \mathbf{y}_{js}), \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-6})$$

$$\phi_{js} = (Z + \boldsymbol{\mu}_s^\top \mathbf{y}_{js}), \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-7})$$

$$\sum_{i \in I} d_{is} x_{ij} \leq D_j, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-8})$$

$$SC, \quad (\text{FBP1-B-9})$$

$$\zeta_{js}, \phi_{js} \geq 0, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-B-10})$$

$$x_{ij} \in \{0, 1\}, \quad \text{for all } i \in I, j \in J. \quad (\text{FBP1-B-11})$$

FBP1-R

$$\text{minimize } Z \quad (\text{FBP1-R-1})$$

$$\text{s.t. } \sum_{j \in I} x_{ij} = 1, \quad \text{for all } i \in I, \quad (\text{FBP1-R-2})$$

$$\frac{\sum_{i \in I} \mu_{is} x_{ij}}{\sum_{i \in I} \mu_{is}} - P_{js} \leq Z, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-3})$$

$$P_{js} - \frac{\sum_{i \in I} \mu_{is} x_{ij}}{\sum_{i \in I} \mu_{is}} \leq Z, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-4})$$

$$\sum_{i \in I} d_{is} x_{ij} + \sum_{i \in \hat{I}_s} \pi_{ijs} + V_{js} \leq D_j, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-5})$$

$$\eta_{js} \geq \rho \left(\sum_{i \in \hat{I}_s} x_{ij} \right), \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-6})$$

$$\lambda_{js} + \pi_{ijs} \geq \hat{d}_{is} x_{ij}, \quad \text{for all } i \in \hat{I}_s, j \in J, s \in S, \quad (\text{FBP1-R-7})$$

$$V_{js} \geq t \lambda_{js} + \left(\sum_{k=t}^{T_{js}} \kappa_{js}^k - 1 \right) M, \quad \text{for all } j \in J, s \in S, t = 0 \dots T_{js} \quad (\text{FBP1-R-8})$$

$$\eta_{js} = \sum_{t=0}^{T_{js}} t \kappa_{js}^t, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-9})$$

$$\sum_{t=0}^{T_{js}} \kappa_{js}^t = 1, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-10})$$

$$SC, \quad (\text{FBP1-R-11})$$

$$\eta_{js} \in \mathbb{Z}_+, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-12})$$

$$\pi_{ijs} \geq 0, \quad \text{for all } i \in \hat{I}_s, j \in J, s \in S, \quad (\text{FBP1-R-13})$$

$$\lambda_{js} \geq 0, \quad \text{for all } j \in J, s \in S, \quad (\text{FBP1-R-14})$$

$$x_{ij} \in \{0, 1\}, \quad \text{for all } i \in I, j \in J, \quad (\text{FBP1-R-15})$$

$$\kappa_{js}^t \in \{0, 1\}, \quad \text{for all } j \in J, s \in S, t = 0 \dots T_{js}. \quad (\text{FBP1-R-16})$$

Appendix C

Table 1: Hub 1 detailed results

	Workcenter 1 (#of Doors=12)				Workcenter 2 (#of Doors=12)				Workcenter 3 (#of Doors=12)				Workcenter 4 (#of Doors=12)			
	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}
Sort 1	6.12%	7	8	—	5.10%	10	10	—	4.86%	10	12	—	1.95%	10	12	—
Sort 2	4.30%	8	11	—	6.27%	10	10	—	4.82%	11	12	—	2.77%	10	12	—
Sort 3	4.34%	8	10	—	3.29%	9	12	—	3.90%	7	9	—	4.06%	10	12	—
Sort 4	3.44%	5	8	—	6.50%	8	10	—	6.42%	6	11	—	5.99%	7	11	—
Workcenter 5 (#of Doors=12)																
Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	
Sort 1	2.68%	9	11	—	4.20%	11	12	—	1.54%	10	11	—	3.25%	8	12	—
Sort 2	2.64%	9	12	—	3.00%	10	12	—	2.27%	10	12	—	3.35%	8	11	—
Sort 3	5.30%	7	10	—	2.35%	10	12	—	3.07%	10	11	—	4.89%	8	10	—
Sort 4	5.14%	6	7	—	5.69%	8	10	—	4.58%	7	8	—	5.03%	5	7	—

Table 2: Hub 2 detailed results

	Workcenter 1 (#of Doors=13)				Workcenter 2 (#of Doors=18)				Workcenter 3 (#of Doors=18)			
	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}
Sort 1	1.22%	11	13	—	2.69%	15	18	—	1.70%	17	18	—
Sort 2	1.72%	10	12	—	1.89%	16	17	—	1.45%	16	18	—
Sort 3	1.57%	10	11	—	2.44%	16	17	—	2.53%	15	18	—
Sort 4	2.86%	10	11	—	2.80%	14	16	—	2.85%	14	16	—
Workcenter 4 (#of Doors=17)												
Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	Imbalance	Nominal # Doors	Max. # Doors	P{Exceeding Capacity}	
Sort 1	2.77%	14	18	0.0004	1.26%	13	17	0.0075	2.50%	16	17	—
Sort 2	1.98%	13	16	—	2.69%	13	15	—	2.45%	15	17	—
Sort 3	2.00%	14	15	—	1.74%	14	15	—	2.14%	14	17	—
Sort 4	2.58%	13	13	—	2.75%	12	13	—	2.85%	12	13	—

Table 3: Hub 3 detailed results

		Workcenter 1 (#of Doors=22)				Workcenter 2 (#of Doors=22)			
		Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$	Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$
Sort 1		3.31%	20	24	0.0770	3.70%	20	24	0.0016
Sort 2		1.93%	21	22	—	3.65%	19	20	—
Sort 3		2.50%	21	22	—	2.08%	17	19	—
Sort 4		3.62%	21	22	—	3.75%	16	19	—
		Workcenter 3 (#of Doors=22)				Workcenter 4 (#of Doors=22)			
		Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$	Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$
Sort 1		3.55%	19	24	0.0009	3.68%	18	25	0.0043
Sort 2		2.73%	20	21	—	1.96%	20	22	—
Sort 3		3.22%	19	21	—	1.82%	20	22	—
Sort 4		3.68%	18	23	0.0000	3.58%	19	22	—

Table 4: Hub 5 detailed results

		Workcenter 1 (#of Doors=18)				Workcenter 2 (#of Doors=14)				Workcenter 3 (#of Doors=16)			
		Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$	Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$	Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$
Sort 1		7.91%	10	13	—	7.91%	8	9	—	4.01%	14	14	—
Sort 2		7.19%	15	18	—	4.79%	14	14	—	3.10%	16	16	—
Sort 3		7.86%	11	13	—	7.81%	9	11	—	8.53%	14	14	—
Sort 4		6.83%	5	6	—	10.67%	4	5	—	1.79%	4	4	—
		Workcenter 4 (#of Doors=14)				Workcenter 5 (#of Doors=16)				Workcenter 6 (#of Doors=16)			
		Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$	Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$	Imbalance	Nominal # Doors	Max. # Doors	$P\{\text{Exceeding Capacity}\}$
Sort 1		2.75%	9	10	—	11.86%	12	12	—	2.24%	9	12	—
Sort 2		2.28%	12	14	—	9.57%	15	16	—	1.98%	12	17	0.0098
Sort 3		4.65%	9	9	—	12.07%	15	16	—	6.58%	10	10	—
Sort 4		10.89%	5	7	—	11.76%	7	9	—	6.05%	6	7	—