Online Appendix

Appendix A: Proof of Lemma 1

1. Recall equation (2.1) and (2.4). Equation (2.1) says that the utility U_{ip} increases as the number of services offered increases. Taking the derivative of D_{isp} with respect to U_{ip}:

$$\frac{\partial D_{isp}}{\partial U_{ip}} = -\frac{N_{ip}(1-(\exp(-\lambda U_{ip})(\lambda U_{ip}+1))) \times (\sum_{j\in J} a_{sp}y_{ijs})\exp(\beta_{0s}-\beta_{dt}DT_s-\beta_{dc}q_s)}{U_{ip}^2} < 0 \tag{A.1}$$

as $\lambda > 0$, $U_{ip} > 0$, and $exp(-\lambda U_{ip}) \times (\lambda U_{ip}+1) > 1$. Hence, as the number of services offered increases, utility U_{ip} increases which results in decreasing D_{isp}. Therefore, maximum demand that may be captured by service $s \in S$, D_{isp}^{max} is achieved when only service $s \in S$ is available i.e., $y_{ijs} = 1$ and $y_{ijs'} = 0 \ \forall \ s' \neq s$.

2. Using equation (2.4), total demand captured TD_{ip}, by the e-retailer is expressed as:

$$TD_{ip} = \frac{N_{ip}(1-\exp(-\lambda U_{ip}))(U_{ip}-US_{ip})}{U_{ip}}, \tag{A.2}$$

where $US_{ip} = \exp(\beta_{0,n+1} - \beta_{tt}TT_i - \beta_{tc}TC_i)$ and $(U_{ip} - US_{ip}) \geq 0$, is the utility derived by customer zone $i \in I$ for package $p \in P$ given the services offered by the e-retailer. Taking the derivative of TD_{ip} with respect to total utility U_{ip}:

$$\frac{\partial TD_{ip}}{\partial U_{ip}} = \frac{N_{ip}e^{-\lambda U_{ip}}(US_{ip}(e^{\lambda U_{ip}}-1)+\lambda U_{ip}(U_{ip}-US_{ip}))}{U_{ip}^2} > 0 \tag{A.3}$$

as $\lambda > 0$, $U_{ip} > 0$, $(e^{\lambda U_{ip}} - 1) > 0$, and $\lambda U_{ip}(U_{ip} - US_{ip}) \geq 0$. Hence, as U_{ip} increases, TD_{ip} increases. Therefore, maximum total demand TD_{ip}^{max}, is achieved when the e-retailer offers all services in S to customer zone $i \in I$ for package $p \in P$. □

Appendix B: Linear formulation of model NP

Three sets of binary decision variables and one set of continuous nonnegative decision variables are defined as:

$$t_{ie} = \begin{cases} 1, & \text{if customer zone } i \in I \text{ is offered set of services } e \in \mathscr{P}(S) \\ 0, & \text{otherwise} \end{cases}$$

$$w_j = \begin{cases} 1, & \text{if candidate facility } j \in J \text{ is opened} \\ 0, & \text{otherwise} \end{cases}$$

$$x_{js} = \begin{cases} 1, & \text{if service } s \in S \text{ is offered at facility } j \in J \\ 0, & \text{otherwise} \end{cases}$$

$d_{ijspe} =$ demand captured by facility $j \in J$ using service $s \in S$ for package $p \in P$ in customer zone $i \in I$ when set of services offered is $e \in \mathscr{P}(S)$

The model NP is transformed into mixed integer program [IP] as:

$$
\begin{aligned}
\text{[IP]:} \quad \max \quad & \sum_{i\in I}\sum_{j\in J}\sum_{s\in S}\sum_{p\in P}\sum_{e\in\mathscr{P}(S)} (\alpha\pi_p + q_s - c_{ijs}) d_{ijspe} - \sum_{j\in J}\sum_{s\in S} F_s x_{js} - \sum_{j\in J} L_j w_j & & \text{(B.1)}\\
\text{s.t.} \quad & \sum_{e\in\mathscr{P}(S)} t_{ie} = 1 & i\in I, & \quad \text{(B.2)}\\
& x_{js} \le w_j & j\in J, s\in S & \quad \text{(B.3)}\\
& d_{ijspe} \le M t_{ie} & i\in I, j\in J, s\in S, p\in P, e\in\mathscr{P}(S) & \quad \text{(B.4)}\\
& d_{ijspe} \le M r_{ijs} x_{ijs} & i\in I, j\in J, s\in S, p\in P, e\in\mathscr{P}(S) & \quad \text{(B.5)}\\
& \sum_{j\in J} d_{ijspe} \le \overline{D}_{ispe} & i\in I, s\in S, p\in P, e\in\mathscr{P}(S) & \quad \text{(B.6)}\\
& t_{ie} \in \{0,1\} & i\in I, e\in\mathscr{P}(S) & \quad \text{(B.7)}\\
& x_{js} \in \{0,1\} & j\in J, s\in S & \quad \text{(B.8)}\\
& w_j \in \{0,1\} & j\in J & \quad \text{(B.9)}\\
& d_{ijspe} \ge 0 & i\in I, j\in J, s\in S, p\in P, e\in\mathscr{P}(S) & \quad \text{(B.10)}
\end{aligned}
$$

Appendix C: Data used

Borough	Minimum	Maximum
Manhattan	70	100
Staten Island	14	21
Brooklyn	65	75
Queens	14	25
Bronx	30	40

Table C1 Yearly Lease Rate ($) per sq. ft in Boroughs

ID	Borough Name	NTA code	Yearly Cost ($)
1	Brooklyn	BK82	5,000,000
2	Queens	QN49	2,450,000
3	Queens	QN01	3,000,000
4	Queens	QN18	2,700,000
5	Staten Island	SI11	2,750,000
6	Staten Island	SI24	2,600,000
7	Brooklyn	BK28	5,300,000
8	Bronx	BX13	3,600,000
9	Staten Island	SI45	2,650,000
10	Bronx	BX06	3,550,000
11	Staten Island	SI37	2,450,000
12	Manhattan	MN24	5,550,000
13	Queens	QN41	2,700,000
14	Brooklyn	BK31	5,000,000
15	Queens	QN53	3,000,000
16	Manhattan	MN11	6,100,000
17	Brooklyn	BK81	5,300,000
18	Brooklyn	BK42	5,250,000
19	Brooklyn	BK72	5,150,000
20	Queens	QN70	2,650,000
		Average	3,837,500

Table C2 Yearly facility Costs

Parameters	**Estimated Value**
Yearly demand of delivery by UAVs	YD
Avg hourly demand, H	$\frac{YD}{365\times 14}$
maximum hourly demand, $H^{max} = H \times 2.0$	$\frac{YD}{365\times 14} \times 2.0$
Nb. Of UAVs required, $NbUAVs = \frac{H^{max}}{2}$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2}$
Nb.of batteries required, $NbBatteries = NbUAVs$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2}$
Nb. Of UAVs per operator, ND	10
Nb.of operators required per hour $NbOperators = \frac{H^{max}}{2\times ND}$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times \frac{1}{10}$
Nb.of hours an operator works	8
Total Nb. of operators required, $TotalNbOperators = NbOperators \times \frac{14}{8}$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times \frac{1}{10} \times \frac{14}{8}$
Costs calculations	
Cost per UAV	3000
Cost per battery	200
Total battery cost, $BC = 200 \times NbBatteries$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times 200$
Total UAV cost, $DC = 3000 \times NbUAVs$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times 3000$
Total purchasing cost,$PC = BC + DC$	$(3000+200) \times \frac{YD}{365\times 14} \times 2 \times \frac{1}{2}$
Amortization rate, r	20%
Yearly amortized cost of UAVs & Batteries,$AC = r \times PC$	$(3000+200) \times \frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times 0.20$
Yearly operators salary	70,000
Total yearly operators salary cost,$OC = 70000 \times NbOperators$	$\frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times \frac{1}{10} \times \frac{14}{8} \times 70000$
Total yearly costs, $TC = AC + OC$	$(3000+200) \times \frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times 0.20 + \frac{YD}{365\times 14} \times 2 \times \frac{1}{2} \times \frac{1}{10} \times \frac{14}{8} \times 70000$
Battery charging cost per delivery(in dollars)	0.10
Cost per delivery, $\frac{TC}{YD}$	$\left(\frac{(3000+200)\times\frac{YD}{365\times 14}\times 2\times\frac{1}{2}\times 0.20+\frac{YD}{365\times 14}\times 2\times\frac{1}{2}\times\frac{1}{10}\times\frac{14}{8}\times 70000}{YD}\right)+0.10$
	$= 0.1252 + 2.397 + 0.10 \approx \mathbf{2.62}$

Table C3 Detailed calculations for UAV package delivery cost c_{ijn}