3.11.

(a) For OR,

$$A_2(t) = (6500 \times 15\%/hr)\, t$$

$$D_2(t) = \begin{cases} (500 \times 50\%)/hr \; t & t < 20 \text{ mins} \\ \left(\frac{6500}{3} \times 50\%\right) & 20 \text{ mins} < t < T_0 \\ \quad \text{slope} & \\ (6500 \times 15\%/hr)\, t & t > T_0 \\ \quad \text{slope} & \end{cases}$$

where T_0 is the time it takes to clear the OR Bottleneck.

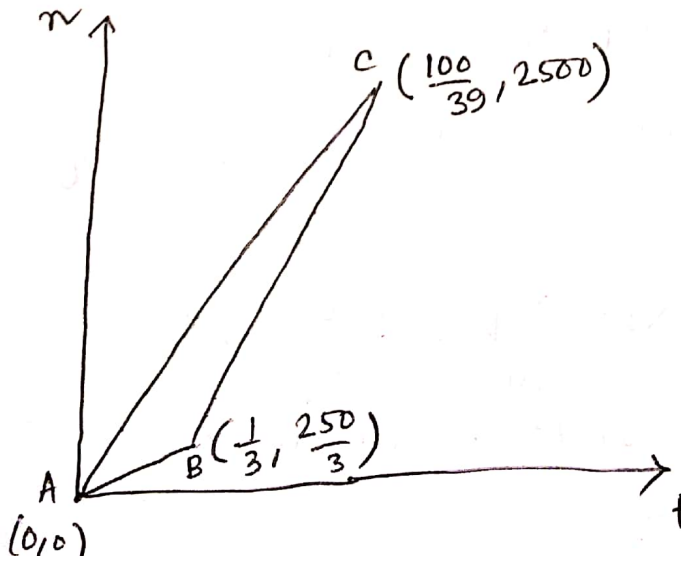
Queue formed in OR in the 20 mins

$$= (6500 \times 15\% \text{ \&} - 500 \times 50\%) \times \frac{20}{60} = \frac{725}{3} = Q_0 \text{ (say)}$$

Queue clearing rate

$$= \left(\frac{6500}{3} \times 50\% - 6500 \times .15\right)/hr = \frac{325}{3\,hr} = r \text{ (say)}$$

$$T_0 = 20 \text{ mins} + Q_0/r = \frac{100}{39} hr$$



For exiting vehicles

Total delay = area (Δ ABC)

$$= \boxed{309.829 \text{ hr}}$$

Avg. delay $= \frac{309.829}{2500 - 0} \times 60$ mins

$$= \boxed{7.44 \text{ mins}}$$

For Freeway, initially it stays unaffected as the 200 m of OR gets filled up first at timestamp 'τ' (say). Then one lane gets blocked reducing the capacity of the Freeway to $\frac{2}{3}^{rd}$. So, 2 lanes carry the load of non-existing vehicles till the time it takes for the off-ramp queue to be limited only to the 200m of OR, which is denoted by timestamp 'T_1' (say). As the third lane gets cleared, all the queues and new non-existing vehicles get cleared as the freeway is served at full capacity. The timestamp for that clearance is denoted by 'T_2' (say).

$$A_1(t) = (6500 \times 85\% /hr) \times t$$

$$D_1(t) = \begin{cases} (6500 \times 85\% /hr)\, t & t < \tau \\ (6500 \times \frac{2}{3}) /hr \text{ slope} & \tau \le t \le T_1 \\ 6500 /hr \text{ slope} & T_1 \le t < T_2 \\ (6500 \times 85\% /hr)\, t & t \ge T_2 \end{cases}$$

Assumption: A car and allowable space behind it a queue altogether be assumed to 6m (say). So, the OR holds $\frac{200}{6} = \frac{100}{3}$ vehicles before affecting freeway lane at $t = \tau$

$$(6500 \times 15\% - 500 \times 50\%)/hr \; \tau = \frac{100}{3} \Rightarrow \tau = 165.52 s$$

Queue formed in Freeway lane due to OR

$$Q_1 = Q_0 - \frac{100}{3} = \frac{625}{3}$$

Time stamp at which that gets cleared

$$T_1 = 20 \text{ mins} + \frac{Q_1}{r} = \frac{88}{39} \text{ hr.}$$

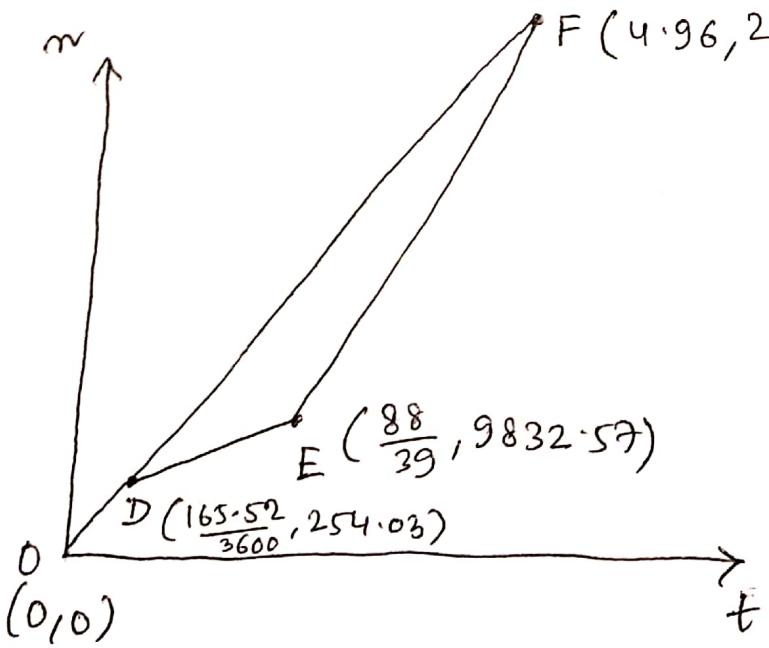
Total queue formed on the other 2-lanes from $t = T$ to $t = T_1$ is given by

$$Q_2 = (T_1 - T) \times \left[\frac{6500 \times 85\% - 6500 \times \frac{2}{3}}{\text{hr}} \right] \approx 2634.1$$

Rate of queue clearance at the freeway after $t = T_1$ is given by

$$r_2 = [6500 - 6500 \times 85\%]/\text{hr}$$

$$\therefore T_2 = T_1 + \frac{Q_2}{r_2} \approx 4.96 \text{ hr.}$$



Total delay for non-exiting vehicles

= area (ΔDEF)

= 6472.02 hr

avg. delay

$$= \frac{6472.02 \text{ hr}}{27404 - 254.03}$$

$$\approx 14.3 \text{ mins}$$