① $U_{s1}=0,6$ $S_{s1}=0,1s$ $V_{s1}=0,5$ X_{s1}? (1.5) $R=5s$ N?

UTILIZATION LAW $U_{s1}=X_{s1}S_{s1} \Rightarrow X_{s1}=\frac{U_{s1}}{S_{s1}}=6$ JOBS/s

LITTLE'S LAW $N=XR=\frac{X_{s1}}{V_{s1}}\cdot R=60$ JOBS

② $U_{s1}=0,8$ $S_{s1}=0,2s$ $D_{s1}=0,1s$ X_{s1}? (2.5) $N=7$ R?

$U_{s1}=X_{s1}S_{s1} \Rightarrow X_{s1}=\frac{U_{s1}}{S_{s1}}=4$ JOBS/s

$N=XR$

FORCED FLOW LAW $\begin{cases} X_{s1}=V_{s1}X \\ D_{s1}=V_{s1}S_{s1} \end{cases} \Rightarrow X=\frac{X_{s1}}{D_{s1}/S_{s1}}$

$\Rightarrow R=\frac{N}{X}=\frac{N}{X_{s1}/(D_{s1}/S_{s1})}=0,875s$

③ $U_{s1}=0,8$ $S_{s1}=0,2s$ $D_{s1}=0,1s$ X_{s1}? (3.5) $R=2s$ N?

$U_{s1}=X_{s1}S_{s1} \Rightarrow X_{s1}=\frac{U_{s1}}{S_{s1}}=4$ JOBS/s

$N=XR=\frac{X_{s1}}{D_{s1}/S_{s1}}\cdot R=16$ JOBS

④ $N=20$ $Z=20s$ $D_{CPU}=0,1s$ $D_{DISK}=0,3s$ N_{DISK} | R_{MIN} L95s?

$D=D_{CPU}+\frac{D_{DISK}}{N_{DISK}} < 0,95 \Rightarrow N_{DISK} > \frac{D_{DISK}}{0,4}=0,75$ $N_{DISK}=1$

$ND_{max}-Z=-14s$

(4.5) $X=0,8/s$ R?

RESPONSE TIME LAW $R=\frac{N}{X}-Z=5s$

⑤ $T = 30\,min = 1800\,s \quad A = C = 1800 \quad V_{DBMS} = 10 \quad S_{DBMS} = 0{,}02\,s$

$U_{AS} = 60\% \quad C_{AS} = 3600 \quad F_{WS1} = \frac{V_{WS1}}{V_{WS1} + V_{WS2}} = 80\%$

$N_{WS} = N_{WS1} + N_{WS2} = 8 \quad R_{WS} = R_{WS1} \cdot F_{WS1} + R_{WS2} \cdot (1 - F_{WS1}) = 0{,}48$

$S_{WS2} = 0{,}1\,s \quad X_{WS1} + X_{WS2}\,? \quad X_{AS}\,? \quad X_{DBMS}\,?$

5.1 $U_{WS1}\,? \quad U_{WS2}\,?$ 5.2 $X_{MAX}\,?$

$X_{AS} = \frac{C_{AS}}{T} = 2 \text{ JOBS/s} \quad X_{DBMS} = V_{DBMS} \cdot X = V_{DBMS} \cdot \frac{C}{T} = 10 \text{ JOBS/s}$

LITTLE'S LAW $N_{WS} = X_{WS} \cdot R_{WS} \rightarrow X_{WS} = \frac{N_{WS}}{R_{WS}} = 20 \text{ JOBS/s}$

UTILIZATION LAW $U_{WS2} = X_{WS2} \cdot S_{WS2} = (1 - F_{WS1}) \cdot X_{WS} \cdot S_{WS2} = 40\%$

"LOAD-BALANCED TO ACHIEVE THE SAME UTILIZATION" $\Rightarrow U_{WS1} =$

$= U_{WS2} = 40\%$

$U_{WS2} = X D_{WS2} = \frac{C}{T} D_{WS2} \rightarrow D_{WS2} = 0{,}4\,s$

$U_{WS1} = X D_{WS1} = \frac{C}{T} D_{WS1} \rightarrow D_{WS1} = 0{,}4\,s$

$D_{DBMS} = V_{DBMS} \cdot S_{DBMS} = 0{,}2\,s$

$U_{AS} = X \cdot D_{AS} \rightarrow D_{AS} = \frac{U_{AS}}{C/T} = 0{,}6\,s$

$X_{MAX} = \frac{1}{D_{MAX}} = \frac{1}{D_{AS}} = 1{,}67 \text{ JOBS/s}$

⑥ $T = 60\,min = 3600\,s$ $X = 1{,}2\,1/s$ $B_{S1} = 450\,s$ $X_{S1} = 0{,}6\,1/s$ $B_{S2} = 900\,s$

$X_{S2} = 2{,}4\,1/s$ D_{S1}? D_{S2}? (6.1) V_{S1}? V_{C2}? (6.3) $Z = 6\,s$ N^*?

$$U_{S1} = \frac{B_{S1}}{T} = 12{,}5\% \qquad U_{S2} = \frac{B_{S2}}{T} = 2{,}5\%$$

$U_{S1} = X D_{S1} \rightarrow D_{S1} = 0{,}104\,s$ $U_{S2} = X D_{S2} \rightarrow D_{S2} = 0{,}208\,s$

FORCED FLOW LAW $X_{S1} = V_{S1} X \rightarrow V_{S1} = 0{,}5$ SIMILARLY, $V_{S2} = 2$

$$N^* = \frac{D+Z}{D_{MAX}} = \frac{D_{S1} + D_{S2} + Z}{D_{S2}} = 30{,}3$$

⑦ $N = 8$ $T = 7200\,s$ $C = 5400$ $R = 4\,s$ $B_{FS} = 1350\,s$ $U_{S1} = 13{,}5\%$

$S_{S1} = 0{,}015\,s$ $S_{S2} = 0{,}005\,s$ $V_{SL} = 32$ $N_{SL} = 4$ Z? R_{SL}?

(7.1) D_{FS}? D_{S1}? D_{S2}? (7.2) BOTTLENECK? X_{MAX}?

RESPONSE TIME LAW $R = \frac{N}{X} - Z = \frac{N}{C/T} - Z \Rightarrow Z = \frac{N}{C/T} - R = 6{,}66\,s$

LITTLE'S LAW $N_{SL} = R_{SL} \cdot X_{SL}$ $R_{SL} = \frac{N_{SL}}{X_{SL}} = \frac{N_{SL}}{V_{SL} \cdot X} = \frac{N_{SL}}{V_{SL} \cdot C/T} = 0{,}166\,s$

$D_{FS} = \frac{B_{FS}}{C} = 0{,}25\,s$ $U_{S1} = X \cdot D_{S1} \Rightarrow D_{S1} = 0{,}18\,s$

$D_{S1} = V_{S1} \cdot S_{S1} \Rightarrow V_{S1} = 12$ $V_{SL} = V_{S1} + V_{S2} \rightarrow V_{S2} = 20$

$D_{S2} = V_{S2} \cdot S_{S2} = 0{,}1\,s$

$D_{FS} > D_{MAX} \Rightarrow$ BOTTLENECK = FS

$$X_{MAX} = \min\left(\frac{N}{D+Z}; \frac{1}{D_{MAX}}\right) = \min\left(\frac{N}{D_{FS} + D_{S1} + D_{S2} + Z}; \frac{1}{D_{MAX}}\right) =$$

$$= \min(1{,}11;\ 4) = 1{,}11\,1/s$$

(8) $T=60s$ $C=300$ $C_{SV1}=600$ $C_{SV2}=400$ $U_{SV1}=0,3333$

$U_{SV2}=0,250$ B_{SV1}? B_{SV2}? (8.1) D_{SV1}? D_{SV2}?

(8.2) $Z=10s$ $N=40$ X_{MAX}? R_{MIN}? (8.3) 8.2 BUT USE 2 SV_1

$U=\frac{B}{T} \Rightarrow$ $B_{SV1}=U_{SV1}\cdot T=200s$ $B_{SV2}=U_{SV2}\cdot T=150s$

$D_{SV1}=\frac{B_{SV1}}{C}=0,666s$ $D_{SV2}=\frac{B_{SV2}}{C}=0,5s$ $D=1,166s$ $D_{MAX}=0,666s$

$X_{MAX}=\min\left(\frac{N}{D+Z};\frac{1}{D_{MAX}}\right)=\min(3,582;1,5)=1,5/s$

$R_{MIN}=\max(D;ND_{MAX}-Z)=(1,166;16,66)=16,66s$

USING 2 ISTANCES OF SV_1 $\Rightarrow$ $U'_{SV1}=\frac{U_{SV1}}{2}\rightarrow B'_{SV1}=100s$

$D'_{SV1}=0,333s \Rightarrow$ $D'=0,833s$ $D'_{MAX}=0,5s$

$X_{MAX}=\min(3,692;2)=2/s$ $R_{MIN}=\max(0,833,10)=10s$

(9) $N_{CPU}=1$ $N=30$ $Z=20s$ $D_{CPU}=0,1s$ $D_{DISK}=0,3s$ $R_{MIN}\leq 0,5s$ N_{DISK}?

$R_{MIN}=\max(D,ND_{MAX}-Z)=(D_{CPU}+N_{DISK}D_{DISK},-14)=$

$=D_{CPU}+N_{DISK}D_{DISK}\leq 0,5s \Rightarrow N_{DISK}\leq 1,33$ $N_{DISK}=1$

(9.5) $R=30s$ X?

RESPONCE TIME LAW $R=\frac{N}{X}-Z \Rightarrow X=\frac{N}{R+Z}=0,650BS/s$

10 $T=1200/h \quad C=400 \quad C_{S1}=800 \quad C_{S2}=200 \quad B_{S1}=300/h$

$B_{S2}=900/h \quad D_{S1}? \; D_{S2}? \; U_{S1}? \; U_{S2}?$

$$D_{S1}=\frac{B_{S1}}{C}=0,75/h \qquad D_{S2}=\frac{B_{S2}}{C}=2,25/h$$

$$U_{S1}=XD_{S1}=\frac{C}{T}D_{S1}=25\% \qquad U_{S2}=\frac{C}{T}D_{S2}=75\%$$

10.5 $\lambda=3/h \quad N_{S1}, N_{S2} \mid U_{S1}, U_{S2} \leq 0,7?$

$$U_{S1}=\frac{D_{S1}\lambda}{N_{S1}} \leq 0,7 \rightarrow N_{S1} \geq 3,21 \quad N_{S1}=4 \quad \text{SIMILARLY, } N_{S2}=10$$

11 $T=600/h \quad C=12000 \quad B=540/h \quad R=0,1/h \quad S? \; N?$

$$S=\frac{B}{C}=0,45/h \qquad R=\frac{N}{X}=\frac{N}{C/T} \rightarrow N=\frac{C}{T}R=2$$

11.5 $D_{CPU}=0,03/s \quad D_{DISK1}=0,01/s \quad D_{DISK2}=0,035/h \quad N=10 \quad Z=0,1/h \quad X_{max}?$

$$D=D_{CPU}+D_{DISK1}+D_{DISK2}=0,075/h \qquad D_{MAX}=D_{DISK2}$$

$$X_{MAX}=\min\left(\frac{N}{D+Z}; \frac{1}{D_{MAX}}\right)=\min(57,14; 28,57)=28,57/h$$

12 $V_{CPU}=3 \quad S_{CPU}=0,01/h \quad X_{DSK}=12/h \quad D_{DISK}=0,35/h \quad D_{NET}=0,004/h$

$X_{NET}=20/h \quad N=25 \quad X=1,85/h \quad R=0,8/h \quad D_{CPU}? \; V_{NET}?$

12.1 $Z?$ **12.2** $N=50$ 3 DISKS $R_{MIN}?$

$$D_{CPU}=V_{CPU}\cdot S_{CPU}=0,03/h \qquad D_{NET}=V_{NET}S_{NET}$$

UTILIZATION LAW $X_{NET}S_{NET}=XD_{NET} \Rightarrow S_{NET}=3,7\cdot 10^{-4}/h \Rightarrow V_{NET}=10,81$

RESPONCE TIME LAW $R=\frac{N}{X}Z \Rightarrow Z=12,7135/h$

$$R_{MIN} = D = D_{DISK} + D_{CPU} + D_{NET} = 9384\,s$$

(13) $T = 1200\,s$ $C = 300$ $C_{S1} = 600$ $C_{S2} = 100$ $B_{S1} = 350\,s$

$B_{S2} = 200\,s$ D_{S1}? D_{S2}? U_{S1}? U_{S2}?

$$D_{S1} = \frac{B_{S1}}{C} = 1{,}166\,s \qquad D_{S2} = \frac{B_{S2}}{C} = 0{,}666\,s$$

$$U_{S1} = X D_{S1} = \frac{C}{T} D_{S1} = 29{,}17\% \qquad U_{S2} = \frac{C}{T} D_{S2} = 16{,}66\%$$

(13.1) $Z = 18\,s$ $N = 30$ X_{MAX}? (13.2) ANOTHER S_1 X_{MAX}?

$$X_{MAX} = \min\left(\frac{N}{D+Z}; \frac{1}{D_{MAX}}\right) \qquad D_{MAX} = D_{S1} \qquad D = D_{S1} + D_{S2} = 1{,}83\,s$$

$$X_{MAX} = \min\left(\frac{30}{1{,}83 + 18}; \frac{1}{1{,}86}\right) = (1{,}5;\ 0{,}857) = 0{,}857\,1/s$$

$$D = \frac{D_{S1}}{2} + \frac{D_{S1}}{2} + D_{S2} = 1{,}83\,s \qquad D_{MAX} = D_{S2}$$

$$X_{MAX} = \min(1{,}5;\ 1{,}5) = 1{,}5\,1/s$$

(14) $R_1 = 10\,s$ $R_2 = 4\,s$ $X_1 = 3/s$ $X_2 = 5/s$ $X = 4/s$ R?

LITTLE'S LAW $N = RX \rightarrow R = \frac{N}{X}$

$$N = N_1 + N_2 = X_1 R_1 + X_2 R_2 = 50 \Rightarrow R = 12{,}5\,s$$

(14.1) $N_{CPU} = 8$ $N_{GPU} = 1$ $N_{SSD} = 1$ $N = 10$ $Z = 60\,min$ $D_{CPU} = 2\,min$ $S_{CPU} = 2\,min$

$D_{GPU} = 5\,min$ $D_{DISK} = 1\,min$ X_{MAX}? R_{MIN}?

$$X_{MAX} = \min\left(\frac{N}{D+Z}; \frac{1}{D_{MAX}}\right) \qquad D = 8D_{CPU} + D_{GPU} + D_{DISK} = 22\,min \qquad D_{MAX} = 5\,min$$

$$X_{MAX} = 0{,}122\,min = 7{,}317\,30\,BS/h \qquad R_{MIN} = \max(D; N D_{MAX} - Z) = 22\,min$$

(14) $N_{CPU}=2$ X_{MAX}? R_{MIN}?

$$X_{MAX}=\min\left(\frac{N}{D+Z};\frac{1}{D_{max}}\right) \quad D=8D_{CPU}+\frac{D_{GPU}}{2}+\frac{D_{GPU}}{2}+D_{DISK}=22min$$

$D_{MAX}=5min$ $X_{MAX}=0,1\overline{22}min=7,31\overline{730}BS/h$

$R_{MIN}=max(D;ND_{MAX}-Z)=22min$

(15) $\lambda=2/s$ $D_{RPI}=0,4s$ $D_{VM}=0,6s$ $U_{RPI}=0,3$ $U_{VM}=0,5$ N_{RPI}? N_{VM}?

$$U_{RPI}=\frac{\lambda D_{RPI}}{N_{RPI}}\leq 0,3 \Rightarrow N_{RPI}\geq\frac{2\cdot 0,4}{0,3}=2,67 \quad N_{RPI\,MIN}=3$$

$$U_{VM}=\frac{\lambda D_{VM}}{N_{VM}} \quad \text{SIMILARLY, } N_{VM}\geq 2,4 \quad N_{VM\,MIN}=3$$

(15.5) $N=50$ $Z=0$ 4 RPI AND 4 VM R_{MIN}?

$R_{MIN}=max(D,ND_{MAX})$ $D_{MAX}=\frac{D_{VM}}{4}=0,15s$ $D=1s$

$R_{MIN}=max(1;50\cdot 0,15)=7,5s$