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LAMPIRAN

LAMPIRAN1. Titik Kesetimbangan Adanya Perokok

> restart :

> with(linalg) : with(DEtools) : with(LinearAlgebra) : with(VectorCalculus) :

#misalkan:#ρ +μ = Ω1

#τ2u2 = Ω2

#η +ω+μ = Ω3

#τ1 u1 = Ω4

#γ+μ = Ω5

#γ (1 + u2) δ = Ω6

#α (1 − u1) = Ω7

#γ (1 + u2) (1 − δ) = Ω8

> Pdot := Lambda − beta1·P·S − mu·P

$$-P S \beta 1 - P \mu + \Lambda$$

> Sdot := beta1·P·S − beta2·S·X − (Omega1)·S + Omega2·Y

$$P S \beta 1 - S X \beta 2 - \Omega 1\, S + \Omega 2\, Y$$

> Xdot := beta2·S·X − (Omega3)·X − Omega4·X

$$S X \beta 2 - \Omega 3\, X - \Omega 4\, X$$

> Ydot := omega·X − (Omega5)·Y + Omega7·Qt − Omega2·Y

$$-\Omega 2\, Y - \Omega 5\, Y + \Omega 7\, Qt + X \omega$$

> Qtdot := Omega6·Y − mu·Qt − (Omega7)·Qt

$$\Omega 6\, Y - \Omega 7\, Qt - Qt\, \mu$$

> Qpdot := Omega8·Y − mu·Qp

$$\Omega 8\, Y - Qp\, \mu$$

#dari per3

> Sbintang := solve(Xdot, S)

$$\frac{\Omega 3 + \Omega 4}{\beta 2}$$

#dari pers.1

> p := solve(Pdot, P)

$$\frac{\Lambda}{S \beta 1 + \mu}$$

> Pbintang := $\frac{\text{Lambda}}{Sbintang \cdot beta1 + \text{mu}}$

$$\frac{\Lambda}{\frac{(\Omega 3 + \Omega 4)\, \beta 1}{\beta 2} + \mu}$$

#dari pers2

> $y := solve(Sdot, Y)$

$$\frac{S\left(-P\,\beta 1+X\,\beta 2+\Omega 1\right)}{\Omega 2}$$

> $Ybintang := \frac{Sbintang\left(-Pbintang\,\beta 1+X\,\beta 2+\Omega 1\right)}{\Omega 2}$

$$\frac{\left(\Omega 3+\Omega 4\right)\left(-\frac{\Lambda\,\beta 1}{\frac{\left(\Omega 3+\Omega 4\right)\beta 1}{\beta 2}+\mu}+X\,\beta 2+\Omega 1\right)}{\beta 2\,\Omega 2}$$

#dari pers5

> $qt := solve(Qtdot, Qt)$

$$\frac{\Omega 6\,Y}{\Omega 7+\mu}$$

> $Qtbintang := \frac{\Omega 6\,Ybintang}{\Omega 7+\mathrm{mu}}$

$$\frac{\Omega 6\left(\Omega 3+\Omega 4\right)\left(-\frac{\Lambda\,\beta 1}{\frac{\left(\Omega 3+\Omega 4\right)\beta 1}{\beta 2}+\mu}+X\,\beta 2+\Omega 1\right)}{\beta 2\,\Omega 2\left(\Omega 7+\mu\right)}$$

#dari pers6

> $qp := solve(Qpdot, Qp)$

$$\frac{\Omega 8\,Y}{\mu}$$

> $Qpbintang := \frac{\Omega 8\,Ybintang}{\mu}$

$$\frac{\Omega 8\left(\Omega 3+\Omega 4\right)\left(-\frac{\Lambda\,\beta 1}{\frac{\left(\Omega 3+\Omega 4\right)\beta 1}{\beta 2}+\mu}+X\,\beta 2+\Omega 1\right)}{\beta 2\,\Omega 2\,\mu}$$

#subtitusi semua nilai yang diperoleh pada persamaan 4

#Ydot:=omega·X−(Omega5)·Y + Omega7·Qt − Omega2·Y

> $subs\_semuanilai := \mathrm{omega}\cdot X-(Omega5)\cdot Ybintang+Omega7\cdot Qtbintang-Omega2\cdot Ybintang$

$$\omega X - \frac{\Omega 5\,(\Omega 3+\Omega 4)\left(-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}+\mu}+X\,\beta 2+\Omega 1\right)}{\beta 2\,\Omega 2}$$

$$+\frac{\Omega 7\,\Omega 6\,(\Omega 3+\Omega 4)\left(-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}+\mu}+X\,\beta 2+\Omega 1\right)}{\beta 2\,\Omega 2\,(\Omega 7+\mu)}$$

$$-\frac{(\Omega 3+\Omega 4)\left(-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}+\mu}+X\,\beta 2+\Omega 1\right)}{\beta 2}$$

> *Xbintang* := *solve*(*subs_semuanilai*, *X*)

$$((\Omega 3+\Omega 4)\,(\Lambda\,\beta 1\,\beta 2-\Omega 1\,\Omega 3\,\beta 1-\Omega 1\,\Omega 4\,\beta 1-\Omega 1\,\beta 2\,\mu)\,(\Omega 2\,\Omega 7+\Omega 2\,\mu+\Omega 5\,\Omega 7+\Omega 5\,\mu-\Omega 6\,\Omega 7))\,/\,(\beta 2\,(\Omega 3\,\beta 1+\Omega 4\,\beta 1+\beta 2\,\mu)\,(\Omega 2\,\Omega 3\,\Omega 7+\Omega 2\,\Omega 3\,\mu+\Omega 2\,\Omega 4\,\Omega 7+\Omega 2\,\Omega 4\,\mu-\Omega 2\,\Omega 7\,\omega-\Omega 2\,\mu\,\omega+\Omega 3\,\Omega 5\,\Omega 7+\Omega 3\,\Omega 5\,\mu-\Omega 3\,\Omega 6\,\Omega 7+\Omega 4\,\Omega 5\,\Omega 7+\Omega 4\,\Omega 5\,\mu-\Omega 4\,\Omega 6\,\Omega 7))$$

LAMPIRAN 2. Linearisasi dan Kestabilan Titik Kesetimbangan Bebas Perokok

> *restart*

> $with(linalg) : with(DEtools) : with(LinearAlgebra) : with(VectorCalculus) : with(linalg) : with(VectorCalculus) : with(Student[LinearAlgebra]) :$

> $f1 := \text{Lambda} - beta1 \cdot P \cdot S - \text{mu} \cdot P$

$$-P\,S\,\beta 1 - P\,\mu + \Lambda$$

> $f2 := beta1 \cdot P \cdot S - beta2 \cdot S \cdot X - (Omega1) \cdot S + Omega2 \cdot Y$

$$P\,S\,\beta 1 - S\,X\,\beta 2 - \Omega 1\,S + \Omega 2\,Y$$

> $f3 := beta2 \cdot S \cdot X - (Omega3) \cdot X - Omega4 \cdot X$

$$S\,X\,\beta 2 - \Omega 3\,X - \Omega 4\,X$$

> $f4 := \text{omega} \cdot X - (Omega5) \cdot Y + Omega7 \cdot Qt - Omega2 \cdot Y$

$$-\Omega 2\,Y - \Omega 5\,Y + \Omega 7\,Qt + X\,\omega$$

> $f5 := Omega6 \cdot Y - \text{mu} \cdot Qt - (Omega7) \cdot Qt$

$$\Omega 6\,Y - \Omega 7\,Qt - Qt\,\mu$$

> $f6 := Omega8 \cdot Y - \text{mu} \cdot Qp$

$$\Omega 8\,Y - Qp\,\mu$$

> $J := Jacobian(\langle f1, f2, f3, f4, f5, f6 \rangle, [P, S, X, Y, Qt, Qp])$

$$\begin{bmatrix} -S\,\beta 1 - \mu & -\beta 1\,P & 0 & 0 & 0 & 0 \\ S\,\beta 1 & P\,\beta 1 - X\,\beta 2 - \Omega 1 & -\beta 2\,S & \Omega 2 & 0 & 0 \\ 0 & X\,\beta 2 & S\,\beta 2 - \Omega 3 - \Omega 4 & 0 & 0 & 0 \\ 0 & 0 & \omega & -\Omega 2 - \Omega 5 & \Omega 7 & 0 \\ 0 & 0 & 0 & \Omega 6 & -\Omega 7 - \mu & 0 \\ 0 & 0 & 0 & \Omega 8 & 0 & -\mu \end{bmatrix}$$

> $TKfix := \left[P = \dfrac{\text{Lambda}}{\text{mu}}, S = 0, X = 0, Y = 0, Qt = 0, Qp = 0\right]$

$$\left[P = \frac{\Lambda}{\mu}, S = 0, X = 0, Y = 0, Qt = 0, Qp = 0\right]$$

> $Jac\_bintang := subs(TKfix, J)$

$$\begin{bmatrix} -\mu & -\frac{\beta 1\,\Lambda}{\mu} & 0 & 0 & 0 & 0 \\ 0 & \frac{\beta 1\,\Lambda}{\mu} - \Omega 1 & 0 & \Omega 2 & 0 & 0 \\ 0 & 0 & -\Omega 3 - \Omega 4 & 0 & 0 & 0 \\ 0 & 0 & \omega & -\Omega 2 - \Omega 5 & \Omega 7 & 0 \\ 0 & 0 & 0 & \Omega 6 & -\Omega 7 - \mu & 0 \\ 0 & 0 & 0 & \Omega 8 & 0 & -\mu \end{bmatrix}$$

> $La := \begin{bmatrix} \text{lambda} & 0 & 0 & 0 & 0 & 0 \\ 0 & \text{lambda} & 0 & 0 & 0 & 0 \\ 0 & 0 & \text{lambda} & 0 & 0 & 0 \\ 0 & 0 & 0 & \text{lambda} & 0 & 0 \\ 0 & 0 & 0 & 0 & \text{lambda} & 0 \\ 0 & 0 & 0 & 0 & 0 & \text{lambda} \end{bmatrix}:$

> $Jac\_bintang - La$

$$\begin{bmatrix} -\mu - \lambda & -\frac{\beta 1\,\Lambda}{\mu} & 0 & 0 & 0 & 0 \\ 0 & \frac{\beta 1\,\Lambda}{\mu} - \Omega 1 - \lambda & 0 & \Omega 2 & 0 & 0 \\ 0 & 0 & -\Omega 3 - \Omega 4 - \lambda & 0 & 0 & 0 \\ 0 & 0 & \omega & -\Omega 2 - \Omega 5 - \lambda & \Omega 7 & 0 \\ 0 & 0 & 0 & \Omega 6 & -\Omega 7 - \mu - \lambda & 0 \\ 0 & 0 & 0 & \Omega 8 & 0 & -\mu - \lambda \end{bmatrix}$$

> $Determinant(Jac\_bintang - La)$

$$\frac{1}{\mu}\Big((-\Omega 3 - \Omega 4 - \lambda)\,\big(\Omega 2\,\Omega 7 + \Omega 2\,\lambda + \Omega 2\,\mu + \Omega 5\,\Omega 7 + \Omega 5\,\lambda + \Omega 5\,\mu - \Omega 6\,\Omega 7 + \Omega 7\,\lambda + \lambda^2 + \lambda\,\mu\big)\,(\Lambda\,\beta 1 - \Omega 1\,\mu - \lambda\,\mu)\,(-\mu - \lambda)^2\Big)$$

> $eigenvalues(Jac\_bintang)$

$$-\Omega 3 - \Omega 4, \frac{\Lambda\,\beta 1 - \Omega 1\,\mu}{\mu}, -\frac{1}{2}\Omega 2 - \frac{1}{2}\Omega 5 - \frac{1}{2}\Omega 7 - \frac{1}{2}\mu + \frac{1}{2}\left(\Omega 2^2 + 2\,\Omega 2\,\Omega 5 - 2\,\Omega 2\,\Omega 7 - 2\,\Omega 2\,\mu + \Omega 5^2 - 2\,\Omega 5\,\Omega 7 - 2\,\Omega 5\,\mu + 4\,\Omega 6\,\Omega 7 + \Omega 7^2 + 2\,\Omega 7\,\mu + \mu^2\right)^{1/2}, -\frac{1}{2}\Omega 2 - \frac{1}{2}\Omega 5 - \frac{1}{2}\Omega 7 - \frac{1}{2}\mu - \frac{1}{2}\left(\Omega 2^2 + 2\,\Omega 2\,\Omega 5 - 2\,\Omega 2\,\Omega 7 - 2\,\Omega 2\,\mu + \Omega 5^2 - 2\,\Omega 5\,\Omega 7 - 2\,\Omega 5\,\mu + 4\,\Omega 6\,\Omega 7 + \Omega 7^2 + 2\,\Omega 7\,\mu + \mu^2\right)^{1/2}, -\mu, -\mu$$

LAMPIRAN 3. Linearisasi dan Kestabilan Titik Kesetimbangan Adanya Perokok

> *restart* :

> *with*(*linalg*) : *with*(*DEtools*) : *with*(*LinearAlgebra*) : *with*(*VectorCalculus*) : *with*(*linalg*) : *with*(*VectorCalculus*) : *with*(*Student*[*LinearAlgebra*]) :

> $f1 := \text{Lambda} - beta1 \cdot P \cdot S - \text{mu} \cdot P$

$$-P S \beta 1 - P \mu + \Lambda$$

> $f2 := beta1 \cdot P \cdot S - beta2 \cdot S \cdot X - (Omega1) \cdot S + Omega2 \cdot Y$

$$P S \beta 1 - S X \beta 2 - \Omega 1\, S + \Omega 2\, Y$$

> $f3 := beta2 \cdot S \cdot X - (Omega3) \cdot X - Omega4 \cdot X$

$$S X \beta 2 - \Omega 3\, X - \Omega 4\, X$$

> $f4 := \text{omega} \cdot X - (Omega5) \cdot Y + Omega7 \cdot Qt - Omega2 \cdot Y$

$$-\Omega 2\, Y - \Omega 5\, Y + \Omega 7\, Qt + X \omega$$

> $f5 := Omega6 \cdot Y - \text{mu} \cdot Qt - (Omega7) \cdot Qt$

$$\Omega 6\, Y - \Omega 7\, Qt - Qt\, \mu$$

> $f6 := Omega8 \cdot Y - \text{mu} \cdot Qp$

$$\Omega 8\, Y - Qp\, \mu$$

> $J := Jacobian(\langle f1, f2, f3, f4, f5, f6 \rangle, [P, S, X, Y, Qt, Qp])$

$$\begin{bmatrix} -S\beta 1 - \mu & -\beta 1\, P & 0 & 0 & 0 & 0 \\ S\beta 1 & P\beta 1 - X\beta 2 - \Omega 1 & -\beta 2\, S & \Omega 2 & 0 & 0 \\ 0 & X\beta 2 & S\beta 2 - \Omega 3 - \Omega 4 & 0 & 0 & 0 \\ 0 & 0 & \omega & -\Omega 2 - \Omega 5 & \Omega 7 & 0 \\ 0 & 0 & 0 & \Omega 6 & -\Omega 7 - \mu & 0 \\ 0 & 0 & 0 & \Omega 8 & 0 & -\mu \end{bmatrix}$$

$$> TKfix := \left[P = \frac{\Lambda}{\frac{(\Omega 3 + \Omega 4)\,\beta 1}{\beta 2} + \mu}, S = \frac{\Omega 3 + \Omega 4}{\beta 2}, X = \big((\Omega 3 + \Omega 4)\,(\Lambda\,\beta 1\,\beta 2 - \Omega 1\,\Omega 3\,\beta 1 - \Omega 1\,\Omega 4\,\beta 1 - \Omega 1\,\beta 2\,\mu)\,(\Omega 2\,\Omega 7 + \Omega 2\,\mu + \Omega 5\,\Omega 7 + \Omega 5\,\mu - \Omega 6\,\Omega 7) \big) \Big/ \big(\beta 2\,(\Omega 3\,\beta 1 + \Omega 4\,\beta 1 + \beta 2\,\mu)\,(\Omega 2\,\Omega 3\,\Omega 7 + \Omega 2\,\Omega 3\,\mu + \Omega 2\,\Omega 4\,\Omega 7 + \Omega 2\,\Omega 4\,\mu - \Omega 2\,\Omega 7\,\omega - \Omega 2\,\mu\,\omega + \Omega 3\,\Omega 5\,\Omega 7 + \Omega 3\,\Omega 5\,\mu - \Omega 3\,\Omega 6\,\Omega 7 + \Omega 4\,\Omega 5\,\Omega 7 + \Omega 4\,\Omega 5\,\mu - \Omega 4\,\Omega 6\,\Omega 7) \big), Y = \frac{(\Omega 3 + \Omega 4)\left(-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3 + \Omega 4)\,\beta 1}{\beta 2} + \mu} + Xbin\,\beta 2 + \Omega 1 \right)}{\beta 2\,\Omega 2}, Qt = \frac{\Omega 6\,(\Omega 3 + \Omega 4)\left(-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3 + \Omega 4)\,\beta 1}{\beta 2} + \mu} + Xbin\,\beta 2 + \Omega 1 \right)}{\beta 2\,\Omega 2\,(\Omega 7 + \mu)}, Qp = \frac{\Omega 8\,(\Omega 3 + \Omega 4)\left(-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3 + \Omega 4)\,\beta 1}{\beta 2} + \mu} + Xbin\,\beta 2 + \Omega 1 \right)}{\beta 2\,\Omega 2\,\mu} \right]:$$

> *Jac_bintang* := *subs*(*TKfix*, *J*)

$$\left[\left[-\frac{(\Omega 3+\Omega 4)\beta 1}{\beta 2}-\mu, -\frac{\Lambda\beta 1}{\frac{(\Omega 3+\Omega 4)\beta 1}{\beta 2}+\mu}, 0, 0, 0, 0\right],\right.$$

$$\left[\frac{(\Omega 3+\Omega 4)\beta 1}{\beta 2}, \frac{\Lambda\beta 1}{\frac{(\Omega 3+\Omega 4)\beta 1}{\beta 2}+\mu} - ((\Omega 3+\Omega 4)(\Lambda\beta 1\beta 2-\Omega 1\Omega 3\beta 1 - \Omega 1\Omega 4\beta 1-\Omega 1\beta 2\mu)(\Omega 2\Omega 7+\Omega 2\mu+\Omega 5\Omega 7+\Omega 5\mu-\Omega 6\Omega 7))/((\Omega 3\beta 1 + \Omega 4\beta 1+\beta 2\mu)(\Omega 2\Omega 3\Omega 7+\Omega 2\Omega 3\mu+\Omega 2\Omega 4\Omega 7+\Omega 2\Omega 4\mu-\Omega 2\Omega 7\omega-\Omega 2\mu\omega + \Omega 3\Omega 5\Omega 7+\Omega 3\Omega 5\mu-\Omega 3\Omega 6\Omega 7+\Omega 4\Omega 5\Omega 7+\Omega 4\Omega 5\mu-\Omega 4\Omega 6\Omega 7))-\Omega 1, -\Omega 3 - \Omega 4, \Omega 2, 0, 0\right],$$

$$[0, ((\Omega 3+\Omega 4)(\Lambda\beta 1\beta 2-\Omega 1\Omega 3\beta 1-\Omega 1\Omega 4\beta 1-\Omega 1\beta 2\mu)(\Omega 2\Omega 7+\Omega 2\mu + \Omega 5\Omega 7+\Omega 5\mu-\Omega 6\Omega 7))/((\Omega 3\beta 1+\Omega 4\beta 1+\beta 2\mu)(\Omega 2\Omega 3\Omega 7+\Omega 2\Omega 3\mu + \Omega 2\Omega 4\Omega 7+\Omega 2\Omega 4\mu-\Omega 2\Omega 7\omega-\Omega 2\mu\omega+\Omega 3\Omega 5\Omega 7+\Omega 3\Omega 5\mu-\Omega 3\Omega 6\Omega 7 + \Omega 4\Omega 5\Omega 7+\Omega 4\Omega 5\mu-\Omega 4\Omega 6\Omega 7)), 0, 0, 0, 0],$$

$$[0, 0, \omega, -\Omega 2-\Omega 5, \Omega 7, 0],$$

$$[0, 0, 0, \Omega 6, -\Omega 7-\mu, 0],$$

$$\left.[0, 0, 0, \Omega 8, 0, -\mu]\right]$$

> $La := \begin{bmatrix} \text{lambda} & 0 & 0 & 0 & 0 & 0 \\ 0 & \text{lambda} & 0 & 0 & 0 & 0 \\ 0 & 0 & \text{lambda} & 0 & 0 & 0 \\ 0 & 0 & 0 & \text{lambda} & 0 & 0 \\ 0 & 0 & 0 & 0 & \text{lambda} & 0 \\ 0 & 0 & 0 & 0 & 0 & \text{lambda} \end{bmatrix}:$

#agar lebih pendek misalkan saja per entry nya

#misalkan

#k11= $\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}+\mu$

#k12= $\frac{\Lambda\,\beta 1}{\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}+\mu}$

#k21= $\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}$

#k22= $((\Omega 3+\Omega 4)\,(\Lambda\,\beta 1\,\beta 2-\Omega 1\,\Omega 3\,\beta 1-\Omega 1\,\Omega 4\,\beta 1-\Omega 1\,\beta 2\,\mu)\,(\Omega 2\,\Omega 7+\Omega 2\,\mu+\Omega 5\,\Omega 7+\Omega 5\,\mu-\Omega 6\,\Omega 7))\,/\,((\Omega 3\,\beta 1+\Omega 4\,\beta 1+\beta 2\,\mu)\,(\Omega 2\,\Omega 3\,\Omega 7+\Omega 2\,\Omega 3\,\mu+\Omega 2\,\Omega 4\,\Omega 7+\Omega 2\,\Omega 4\,\mu-\Omega 2\,\Omega 7\,\omega-\Omega 2\,\mu\,\omega+\Omega 3\,\Omega 5\,\Omega 7+\Omega 3\,\Omega 5\,\mu-\Omega 3\,\Omega 6\,\Omega 7+\Omega 4\,\Omega 5\,\Omega 7+\Omega 4\,\Omega 5\,\mu-\Omega 4\,\Omega 6\,\Omega 7))+\Omega 1-\frac{\Lambda\,\beta 1}{\frac{(\Omega 3+\Omega 4)\,\beta 1}{\beta 2}+\mu}$

#k23= $\Omega 3+\Omega 4$

#k24= $\Omega 2$

#k32= $((\Omega 3+\Omega 4)\,(\Lambda\,\beta 1\,\beta 2-\Omega 1\,\Omega 3\,\beta 1-\Omega 1\,\Omega 4\,\beta 1-\Omega 1\,\beta 2\,\mu)\,(\Omega 2\,\Omega 7+\Omega 2\,\mu+\Omega 5\,\Omega 7+\Omega 5\,\mu-\Omega 6\,\Omega 7))\,/\,((\Omega 3\,\beta 1+\Omega 4\,\beta 1+\beta 2\,\mu)\,(\Omega 2\,\Omega 3\,\Omega 7+\Omega 2\,\Omega 3\,\mu+\Omega 2\,\Omega 4\,\Omega 7+\Omega 2\,\Omega 4\,\mu-\Omega 2\,\Omega 7\,\omega-\Omega 2\,\mu\,\omega+\Omega 3\,\Omega 5\,\Omega 7+\Omega 3\,\Omega 5\,\mu-\Omega 3\,\Omega 6\,\Omega 7+\Omega 4\,\Omega 5\,\Omega 7+\Omega 4\,\Omega 5\,\mu-\Omega 4\,\Omega 6\,\Omega 7))$

#k43= ω

#k44= $\Omega 2+\Omega 5$

#k45= $\Omega 7$

#k54= $\Omega 6$

#k55= $\Omega 7+\mu$

#k64= $\Omega 8$

#k66= μ

> $Jac\_bintangg := \begin{bmatrix} -k11 & -k12 & 0 & 0 & 0 & 0 \\ k21 & -k22 & -k23 & k24 & 0 & 0 \\ 0 & k32 & 0 & 0 & 0 & 0 \\ 0 & 0 & k43 & -k44 & k45 & 0 \\ 0 & 0 & 0 & k54 & -k55 & 0 \\ 0 & 0 & 0 & k64 & 0 & -k66 \end{bmatrix}$

> $Jac\_bintangg - La$

$$\begin{bmatrix} -k11-\lambda & -k12 & 0 & 0 & 0 & 0 \\ k21 & -k22-\lambda & -k23 & k24 & 0 & 0 \\ 0 & k32 & -\lambda & 0 & 0 & 0 \\ 0 & 0 & k43 & -k44-\lambda & k45 & 0 \\ 0 & 0 & 0 & k54 & -k55-\lambda & 0 \\ 0 & 0 & 0 & k64 & 0 & -k66-\lambda \end{bmatrix}$$

> $Determinant(Jac\_bintangg - La)$

$$\begin{aligned}&(-k11\,k22\,k44\,\lambda^2 - k11\,k22\,k55\,\lambda^2 - k11\,k44\,k55\,\lambda^2 + k11\,k45\,k54\,\lambda^2 - k11\,k23\,k32\,\lambda^2 \\ &\quad - k22\,k44\,k55\,\lambda^2 + k22\,k45\,k54\,\lambda^2 - k23\,k32\,k44\,\lambda^2 - k23\,k32\,k55\,\lambda^2 + k24\,k32\,k43\,\lambda^2 \\ &\quad - k12\,k21\,k44\,\lambda^2 - k12\,k21\,k55\,\lambda^2 - k11\,k22\,k44\,k55\,\lambda + k11\,k22\,k45\,k54\,\lambda \\ &\quad - k11\,k23\,k32\,k44\,k55 - k11\,k23\,k32\,k44\,\lambda + k11\,k23\,k32\,k45\,k54 - k11\,k23\,k32\,k55\,\lambda \\ &\quad + k11\,k24\,k32\,k43\,k55 + k11\,k24\,k32\,k43\,\lambda - \lambda\,k23\,k32\,k44\,k55 + \lambda\,k23\,k32\,k45\,k54 \\ &\quad + \lambda\,k24\,k32\,k43\,k55 - k12\,k21\,k44\,k55\,\lambda + k12\,k21\,k45\,k54\,\lambda - k11\,\lambda^4 - k22\,\lambda^4 - k44\,\lambda^4 \\ &\quad - k55\,\lambda^4 - \lambda^5 - k11\,k22\,\lambda^3 - k11\,k44\,\lambda^3 - k11\,k55\,\lambda^3 - k22\,k44\,\lambda^3 - k22\,k55\,\lambda^3 \\ &\quad - k44\,k55\,\lambda^3 + k45\,k54\,\lambda^3 - k23\,k32\,\lambda^3 - k12\,k21\,\lambda^3)\,(-k66-\lambda)\end{aligned}$$

LAMPIRAN 4. State, Costate, dan Syarat Stationer

> *restart* :

> $H := A1 \cdot S + A2 \cdot X + A3 \cdot Y + \frac{B1}{2} \cdot u1^2 + \frac{B2}{2} \cdot u2^2 + lambda1 \cdot (\mathrm{Lambda} - beta1 \cdot P \cdot S - \mathrm{mu} \cdot P) + lambda2 \cdot (beta1 \cdot P \cdot S - beta2 \cdot S \cdot X - (\mathrm{rho} + \mathrm{mu}) \cdot S + tau2 \cdot u2 \cdot Y) + lambda3 \cdot (beta2 \cdot S \cdot X - (\mathrm{eta} + \mathrm{omega} + \mathrm{mu}) \cdot X - tau1 \cdot u1 \cdot X) + lambda4 \cdot (\mathrm{omega} \cdot X - (\mathrm{gamma} + \mathrm{mu}) \cdot Y + \mathrm{alpha} \cdot (1 - u1) \cdot Qt - tau2 \cdot u2 \cdot Y) + lambda5 \cdot (\mathrm{gamma} \cdot (1 + u2) \cdot \mathrm{delta} \cdot Y - (\mathrm{mu} + \mathrm{alpha} \cdot (1 - u1)) \cdot Qt) + lambda6 \cdot (\mathrm{gamma} \cdot (1 + u2) \cdot (1 - \mathrm{delta}) \cdot Y - \mathrm{mu} \cdot Qp)$

#state

> $\frac{\partial}{\partial \lambda 1} H$

$$-P S \beta 1 - P \mu + \Lambda$$

> $\frac{\partial}{\partial \lambda 2} H$

$$\beta 1 P S - \beta 2 S X - (\rho + \mu) S + \tau 2 u2 Y$$

> $\frac{\partial}{\partial \lambda 3} H$

$$\beta 2 S X - (\eta + \omega + \mu) X - \tau 1 u1 X$$

> $\frac{\partial}{\partial \lambda 4} H$

$$\omega X - (\gamma + \mu) Y + \alpha (1 - u1) Qt - \tau 2 u2 Y$$

> $\frac{\partial}{\partial \lambda 5} H$

$$\gamma (1 + u2) \delta Y - (\mu + \alpha (1 - u1)) Qt$$

> $\frac{\partial}{\partial \lambda 6} H$

$$\gamma (1 + u2) (1 - \delta) Y - \mu Qp$$

#costate

> $-\frac{\partial}{\partial P} H$

$$-\lambda 1 (-S \beta 1 - \mu) - \lambda 2 \beta 1 S$$

> $-\frac{\partial}{\partial S} H$

$$-A1 + \lambda 1 \beta 1 P - \lambda 2 (P \beta 1 - X \beta 2 - \mu - \rho) - \lambda 3 \beta 2 X$$

> $-\frac{\partial}{\partial X} H$

$$-A2 + \lambda 2 \beta 2 S - \lambda 3 (S \beta 2 - \tau 1 u1 - \eta - \mu - \omega) - \lambda 4 \omega$$

> $-\frac{\partial}{\partial Y} H$

$$-A3 - \lambda 2 \tau 2 u2 - \lambda 4 (-\tau 2 u2 - \gamma - \mu) - \lambda 5 \gamma (1 + u2) \delta - \lambda 6 \gamma (1 + u2) (1 - \delta)$$

> $-\frac{\partial}{\partial Qt} H$

$$-\lambda 4\, \alpha\, (1-u1) - \lambda 5\, (-\mu - \alpha\, (1-u1))$$

> $-\frac{\partial}{\partial Qp} H$

$$\lambda 6\, \mu$$

#syarat stationer

> $Hu1 := \frac{\partial}{\partial u1} H$

$$-Qt\, \alpha\, \lambda 4 + Qt\, \alpha\, \lambda 5 - X\, \lambda 3\, \tau 1 + B1\, u1$$

> $solve(Hu1, u1)$

$$\frac{Qt\, \alpha\, \lambda 4 - Qt\, \alpha\, \lambda 5 + X\, \lambda 3\, \tau 1}{B1}$$

> $Hu2 := \frac{\partial}{\partial u2} H$

$$B2\, u2 + \lambda 2\, \tau 2\, Y - \lambda 4\, \tau 2\, Y + \lambda 5\, \gamma\, \delta\, Y + \lambda 6\, \gamma\, (1-\delta)\, Y$$

> $solve(Hu2, u2)$

$$-\frac{Y\, (\delta\, \gamma\, \lambda 5 - \delta\, \gamma\, \lambda 6 + \gamma\, \lambda 6 + \lambda 2\, \tau 2 - \lambda 4\, \tau 2)}{B2}$$

LAMPIRAN 5. Simulasi Numerik

- **Subprogram**

```
 function Kontrol
=simulasi_tesis(lambdaP0,lamda,beta1,beta2,rho,miu,eta,omega,alpha
,gamma,delta,tau1,tau2,u11,u22,u111,u222,A1,A2,A3,B1,B2,P0,S0,X0,Y
0,Qt0,Qp0,TP0,Ta)
M =500;
t=linspace(0,Ta,M+1); %dari waktu ke 0 sampai ke T sebanyak M+1
h=Ta/M; %panjang langkah
h2 = h/2; %panjang langkah dalam RK4

%membentuk matriks baris isinya nol 1 baris, M+1 kolom
P=zeros(1,M+1);
S=zeros(1,M+1);
X=zeros(1,M+1);
Y=zeros(1,M+1);
Qt=zeros(1,M+1);
Qp=zeros(1,M+1);
TP=zeros(1,M+1);

P1=zeros(1,M+1);
S1=zeros(1,M+1);
X1=zeros(1,M+1);
Y1=zeros(1,M+1);
Qt1=zeros(1,M+1);
Qp1=zeros(1,M+1);

P2=zeros(1,M+1);
S2=zeros(1,M+1);
X2=zeros(1,M+1);
Y2=zeros(1,M+1);
Qt2=zeros(1,M+1);
Qp2=zeros(1,M+1);

lambdaP=zeros(1,M+1);
lambdaS=zeros(1,M+1);
lambdaX=zeros(1,M+1);
lambdaY=zeros(1,M+1);
lambdaQt=zeros(1,M+1);
lambdaQp=zeros(1,M+1);


u1=zeros(1,M+1);
u2=zeros(1,M+1);

%nilai awal keadaan
P(1)=P0;
S(1)=S0;
X(1)=X0;
Y(1)=Y0;
Qt(1)=Qt0;
Qp(1)=Qp0;
```

```
P1(1)=P0;
S1(1)=S0;
X1(1)=X0;
Y1(1)=Y0;
Qt1(1)=Qt0;
Qp1(1)=Qp0;

P2(1)=P0;
S2(1)=S0;
X2(1)=X0;
Y2(1)=Y0;
Qt2(1)=Qt0;
Qp2(1)=Qp0;


lambdaP(1)= lambdaP0;


kk=0
test=-1 %variabel uji konvergensi
deta=0.0001; %nilai toleransi


while (test<0) %supaya diperoleh hasil fungsi tujuan yang non
negatif
%nilai awal dari iterasi while
%mengganti nilai lama dengan nilai yang baru
oldu1 = u1;
oldu2 = u2;

oldP  =P;
oldS  =S;
oldX  =X;
oldY  =Y;
oldQt =Qt;
oldQp =Qp;

oldlambdaP =lambdaP;
oldlambdaS = lambdaS;
oldlambdaX = lambdaX;
oldlambdaY = lambdaY;
oldlambdaQt = lambdaQt;
oldlambdaQp = lambdaQp;

for i = 1:M
kk=kk+1; %menunjukkan setiap kali iterasi selalu bertambah satu
oldu1 = u1;
oldu2 = u2;

fprintf('iterasi ke = %i \n ',kk)
```

```
%STATE
for i = 1:M
m1P = lamda - beta1*P(i)*S(i) - miu*P(i);
m1S = beta1*P(i)*S(i) - beta2*S(i)*X(i) - (rho+miu)*S(i) +
tau2*u2(i)*Y(i);
m1X = beta2*S(i)*X(i)-(eta+omega+miu)*X(i)-tau1*u1(i)*X(i);
m1Y = omega*X(i) - (gamma+miu)*Y(i) + alpha*(1-u1(i))*Qt(i) -
tau2*u2(i)*Y(i);
m1Qt = gamma*(1+u2(i))*delta*Y(i) - (miu + alpha*(1-u1(i)))*Qt(i);
m1Qp= gamma*(1+u2(i))*(1-delta)*Y(i)-miu*Qp(i);


m2P = lamda - beta1*(P(i)+h2*m1P)*(S(i)+h2*m1S)-miu*(P(i)+h2*m1P);
m2S = beta1*(P(i)+h2*m1P)*(S(i)+h2*m1S) -
beta2*(S(i)+h2*m1S)*(X(i)+h2*m1X) - (rho+miu)*(S(i)+h2*m1S) +
tau2*0.5*(u2(i)+u2(i+1))*(Y(i)+h2*m1Y);
m2X = beta2*(S(i)+h2*m1S)*(X(i)+h2*m1X)-
(eta+omega+miu)*(X(i)+h2*m1X)-
tau1*0.5*(u1(i)+u1(i+1))*(X(i)+h2*m1X);
m2Y = omega*(X(i)+h2*m1X) - (gamma+miu)*(Y(i)+h2*m1Y) +
alpha*0.5*((1-u1(i))+(1-u1(i+1)))*(Qt(i)+h2*m1Qt) -
tau2*0.5*(u2(i)+u2(i+1))*(Y(i)+h2*m1Y);
m2Qt = gamma*0.5*((1+u2(i))+(1+u2(i+1)))*delta*(Y(i)+h2*m1Y) -
(miu + alpha*0.5*((1-u1(i))+(1-u1(i+1))))*(Qt(i)+h2*m1Qt);
m2Qp= gamma*0.5*((1+u2(i))+(1+u2(i+1)))*(1-delta)*(Y(i)+h2*m1Y)-
miu*(Qp(i)+h2*m1Qp);


m3P = lamda - beta1*(P(i)+h2*m2P)*(S(i)+h2*m2S)-miu*(P(i)+h2*m2P);
m3S = beta1*(P(i)+h2*m2P)*(S(i)+h2*m2S) -
beta2*(S(i)+h2*m2S)*(X(i)+h2*m2X) - (rho+miu)*(S(i)+h2*m2S) +
tau2*0.5*(u2(i)+u2(i+1))*(Y(i)+h2*m2Y);
m3X = beta2*(S(i)+h2*m2S)*(X(i)+h2*m2X)-
(eta+omega+miu)*(X(i)+h2*m2X)-
tau1*0.5*(u1(i)+u1(i+1))*(X(i)+h2*m2X);
m3Y = omega*(X(i)+h2*m2X) - (gamma+miu)*(Y(i)+h2*m2Y) +
alpha*0.5*((1-u1(i))+(1-u1(i+1)))*(Qt(i)+h2*m2Qt) -
tau2*0.5*(u2(i)+u2(i+1))*(Y(i)+h2*m2Y);
m3Qt = gamma*0.5*((1+u2(i))+(1+u2(i+1)))*delta*(Y(i)+h2*m2Y) -
(miu + alpha*0.5*((1-u1(i))+(1-u1(i+1))))*(Qt(i)+h2*m2Qt);
m3Qp= gamma*0.5*((1+u2(i))+(1+u2(i+1)))*(1-delta)*(Y(i)+h2*m2Y)-
miu*(Qp(i)+h2*m2Qp);


m4P = lamda - beta1*(P(i)+h*m3P)*(S(i)+h*m3S)-miu*(P(i)+h*m3P);
m4S = beta1*(P(i)+h*m3P)*(S(i)+h*m3S) -
beta2*(S(i)+h*m3S)*(X(i)+h*m3X) - (rho+miu)*(S(i)+h*m3S) +
tau2*u2(i+1)*(Y(i)+h*m3Y);
m4X = beta2*(S(i)+h*m3S)*(X(i)+h*m3X)-
(eta+omega+miu)*(X(i)+h*m3X)-tau1*(u1(i+1))*(X(i)+h*m3X);
m4Y = omega*(X(i)+h*m3X) - (gamma+miu)*(Y(i)+h*m3Y) + alpha*(1-
u1(i+1))*(Qt(i)+h*m3Qt) - tau2*u2(i+1)*(Y(i)+h*m3Y);
m4Qt = gamma*(1+u2(i+1))*delta*(Y(i)+h*m3Y) - (miu + alpha*(1-
u1(i+1)))*(Qt(i)+h*m3Qt);
m4Qp= gamma*(1+u2(i+1))*(1-delta)*(Y(i)+h*m3Y)-miu*(Qp(i)+h*m3Qp);
```

```
P(i+1) = P(i) + (h/6)*(m1P + 2*m2P + 2*m3P + m4P);
S(i+1) = S(i) + (h/6)*(m1S + 2*m2S + 2*m3S + m4S);
X(i+1) = X(i) + (h/6)*(m1X + 2*m2X + 2*m3X +  m4X);
Y(i+1) = Y(i) + (h/6)*(m1Y + 2*m2Y + 2*m3Y + m4Y);
Qt(i+1)= Qt(i)+ (h/6)*(m1Qt + 2*m2Qt + 2*m3Qt + m4Qt);
Qp(i+1)= Qp(i)+ (h/6)*(m1Qp+ 2*m2Qp+ 2*m3Qp+  m4Qp);

end


%COSTATE
for i = 1:M
    j = M + 2 - i;
m1P = -lambdaP(j).*(-beta1*S(j)-miu)-lambdaS(j).*beta1*S(j);
m1S = -A1+lambdaP(j).*beta1*P(j)-lambdaS(j).*(beta1*P(j)-
beta2*X(j)-miu-rho)-lambdaX(j).*beta2*X(j);
m1X = -A2+lambdaS(j).*beta2*S(j)-lambdaX(j).*(beta2*S(j)-
tau1*u1(j)-eta-miu-omega)-lambdaY(j)*omega;
m1Y = -A3-lambdaS(j).*tau2*u2(j)-lambdaY(j).*(-tau2*u2(j)-gamma-
miu)-lambdaQt(j).*gamma*(1+u2(j))*delta-
lambdaQp(j).*gamma*(1+u2(j))*(1-delta);
m1Qt= -lambdaY(j).*alpha*(1-u1(j))-lambdaQt(j).*(-miu-alpha*(1-
u1(j)));
m1Qp= lambdaQp(j)*miu;

m2P = -(lambdaP(j)-h2*m1P).*(-beta1*(S(j)-S(j-1))-miu)-
(lambdaS(j)-h2*m1S).*beta1*(S(j)+S(j-1));
m2S = -A1+(lambdaP(j)-h2*m1P).*beta1*(P(j)+P(j-1))-(lambdaS(j)-
h2*m1S).*(beta1*(P(j)+P(j-1))-beta2*(X(j)+X(j-1))-miu-rho)-
(lambdaX(j)-h2*m1X).*beta2*(X(j)+X(j-1));
m2X = -A2+(lambdaS(j)-h2*m1S).*beta2*(S(j)+S(j-1))-(lambdaX(j)-
h2*m1X).*(beta2*(S(j)+S(j-1))-tau1*0.5*(u1(j)+u1(j-1))-eta-miu-
omega)-(lambdaY(j)-h2*m1Y)*omega;
m2Y = -A3-(lambdaS(j)-h2*m1S).*tau2*0.5*(u2(j)+u2(j-1))-
(lambdaY(j)-h2*m1Y).*(-tau2*0.5*(u2(j)+u2(j-1))-gamma-miu)-
(lambdaQt(j)-h2*m1Qt).*gamma*0.5*((1+u2(j))+(1+u2(j-1)))*delta-
(lambdaQp(j)-h2*m1Qp).*gamma*0.5*((1+u2(j))+(1+u2(j-1)))*(1-
delta);
m2Qt= -(lambdaY(j)-h2*m1Y).*alpha*0.5*((1-u1(j))+(1-u1(j-1)))-
(lambdaQt(j)-h2*m1Qt).*(-miu-alpha*0.5*((1-u1(j))+(1-u1(j-1))));
m2Qp= (lambdaQp(j)-h2*m1Qp)*miu;

m3P = -(lambdaP(j)-h2*m2P).*(-beta1*(S(j)-S(j-1))-miu)-
(lambdaS(j)-h2*m2S).*beta1*(S(j)+S(j-1));
m3S = -A1+(lambdaP(j)-h2*m2P).*beta1*(P(j)+P(j-1))-(lambdaS(j)-
h2*m2S).*(beta1*(P(j)+P(j-1))-beta2*(X(j)+X(j-1))-miu-rho)-
(lambdaX(j)-h2*m2X).*beta2*(X(j)+X(j-1));
m3X = -A2+(lambdaS(j)-h2*m2S).*beta2*(S(j)+S(j-1))-(lambdaX(j)-
h2*m2X).*(beta2*(S(j)+S(j-1))-tau1*0.5*(u1(j)+u1(j-1))-eta-miu-
omega)-(lambdaY(j)-h2*m2Y)*omega;
m3Y = -A3-(lambdaS(j)-h2*m2S).*tau2*0.5*(u2(j)+u2(j-1))-
(lambdaY(j)-h2*m2Y).*(-tau2*0.5*(u2(j)+u2(j-1))-gamma-miu)-
(lambdaQt(j)-h2*m2Qt).*gamma*0.5*((1+u2(j))+(1+u2(j-1)))*delta-
```

```
(lambdaQp(j)-h2*m2Qp).*gamma*0.5*((1+u2(j))+(1+u2(j-1)))*(1-
delta);
m3Qt= -(lambdaY(j)-h2*m2Y).*alpha*0.5*((1-u1(j))+(1-u1(j-1)))-
(lambdaQt(j)-h2*m2Qt).*(-miu-alpha*0.5*((1-u1(j))+(1-u1(j-1))));
m3Qp= (lambdaQp(j)-h2*m2Qp)*miu;

m4P = -(lambdaP(j)-h*m3P).*(-beta1*S(j-1)-miu)-(lambdaS(j)-
h*m3S).*beta1*(S(j-1));
m4S = -A1+(lambdaP(j)-h*m3P).*beta1*(P(j-1))-(lambdaS(j)-
h*m3S).*(beta1*(P(j-1))-beta2*(X(j-1))-miu-rho)-(lambdaX(j)-
h*m3X).*beta2*(X(j-1));
m4X = -A2+(lambdaS(j)-h*m3S).*beta2*(S(j-1))-(lambdaX(j)-
h*m3X).*(beta2*(S(j-1))-tau1*(u1(j-1))-eta-miu-omega)-(lambdaY(j)-
h*m3Y)*omega;
m4Y = -A3-(lambdaS(j)-h*m3S).*tau2*(u2(j-1))-(lambdaY(j)-
h*m3Y).*(-tau2*(u2(j-1))-gamma-miu)-(lambdaQt(j)-
h*m3Qt).*gamma*(1+u2(j-1))*delta-(lambdaQp(j)-
h*m3Qp).*gamma*(1+u2(j-1))*(1-delta);
m4Qt= -(lambdaY(j)-h*m3Y).*alpha*(1-u1(j-1))-(lambdaQt(j)-
h*m3Qt).*(-miu-alpha*(1-u1(j-1)));
m4Qp= (lambdaQp(j)-h*m3Qp)*miu;


lambdaP(j-1)  = lambdaP(j)  -  (h/6)*(m1P + 2*m2P + 2*m3P + m4P);
lambdaS(j-1)  = lambdaS(j)  -  (h/6)*(m1S + 2*m2S + 2*m3S + m4S);
lambdaX(j-1)  = lambdaX(j)  -  (h/6)*(m1X + 2*m2X + 2*m3X + m4X);
lambdaY(j-1)  = lambdaY(j)  -  (h/6)*(m1Y + 2*m2Y + 2*m3Y + m4Y);
lambdaQt(j-1)= lambdaQt(j)-  (h/6)*(m1Qt+ 2*m2Qt+ 2*m3Qt+ m4Qt);
lambdaQp(j-1)= lambdaQp(j)-  (h/6)*(m1Qp+ 2*m2Qp+ 2*m3Qp+ m4Qp);


u1(j)= min(1,max((-(lambdaQt(j)-
lambdaY(j)).*alpha*Qt(i)+lambdaX(j).*tau1*X(i))/B1));
u2(j)= min(1,max((-(lambdaS(j)-lambdaY(j)).*tau2*Y(i)-
(lambdaQt(j)*delta+lambdaQp(j)*(1-delta).*gamma*Y(i)))/B2));

end


for i = 1:M
%LANJUT KE TANPA KONTROL (u11=0, u22=0)

m1P1 = lamda - beta1*P1(i)*S1(i) - miu*P1(i);
m1S1 = beta1*P1(i)*S1(i) - beta2*S1(i)*X1(i) - (rho+miu)*S1(i) +
tau2*u22*Y1(i);
m1X1 = beta2*S1(i)*X1(i)-(eta+omega+miu)*X1(i)-tau1*u11*X1(i);
m1Y1 = omega*X1(i) - (gamma+miu)*Y1(i) + alpha*(1-u11)*Qt1(i) -
tau2*u22*Y1(i);
m1Qt1 = gamma*(1+u22)*delta*Y1(i) - (miu + alpha*(1-u11))*Qt1(i);
m1Qp1= gamma*(1+u22)*(1-delta)*Y1(i)-miu*Qp1(i);


m2P1 = lamda - beta1*(P1(i)+h2*m1P1)*(S1(i)+h2*m1S1)-
miu*(P1(i)+h2*m1P1);
```

```
m2S1 = beta1*(P1(i)+h2*m1P1)*(S1(i)+h2*m1S1) -
beta2*(S1(i)+h2*m1S1)*(X1(i)+h2*m1X1) - (rho+miu)*(S1(i)+h2*m1S1)
+ tau2*u22*(Y1(i)+h2*m1Y1);
m2X1 = beta2*(S1(i)+h2*m1S1)*(X1(i)+h2*m1X1)-
(eta+omega+miu)*(X1(i)+h2*m1X1)-tau1*u11*(X1(i)+h2*m1X1);
m2Y1 = omega*(X1(i)+h2*m1X1) - (gamma+miu)*(Y1(i)+h2*m1Y1) +
alpha*(1-u11)*(Qt1(i)+h2*m1Qt1) - tau2*u22*(Y1(i)+h2*m1Y1);
m2Qt1 = gamma*(1+u22)*delta*(Y1(i)+h2*m1Y1) - (miu + alpha*(1-
u11))*(Qt1(i)+h2*m1Qt1);
m2Qp1= gamma*(1+u22)*(1-delta)*(Y1(i)+h2*m1Y1)-
miu*(Qp1(i)+h2*m1Qp1);


m3P1 = lamda - beta1*(P1(i)+h2*m2P1)*(S1(i)+h2*m2S1)-
miu*(P1(i)+h2*m2P1);
m3S1 = beta1*(P1(i)+h2*m2P1)*(S1(i)+h2*m2S1) -
beta2*(S1(i)+h2*m2S1)*(X1(i)+h2*m2X1) - (rho+miu)*(S1(i)+h2*m2S1)
+ tau2*u22*(Y1(i)+h2*m2Y1);
m3X1 = beta2*(S1(i)+h2*m2S1)*(X1(i)+h2*m2X1)-
(eta+omega+miu)*(X1(i)+h2*m2X1)-tau1*u11*(X1(i)+h2*m2X1);
m3Y1 = omega*(X1(i)+h2*m2X1) - (gamma+miu)*(Y1(i)+h2*m2Y1) +
alpha*(1-u11)*(Qt1(i)+h2*m2Qt1) - tau2*u22*(Y1(i)+h2*m2Y1);
m3Qt1 = gamma*u22*delta*(Y1(i)+h2*m2Y1) - (miu + alpha*(1-
u11))*(Qt1(i)+h2*m2Qt1);
m3Qp1= gamma*(1+u22)*(1-delta)*(Y1(i)+h2*m2Y1)-
miu*(Qp1(i)+h2*m2Qp1);

m4P1 = lamda - beta1*(P1(i)+h*m3P1)*(S1(i)+h*m3S1)-
miu*(P1(i)+h*m3P1);
m4S1 = beta1*(P1(i)+h*m3P1)*(S1(i)+h*m3S1) -
beta2*(S1(i)+h*m3S1)*(X1(i)+h*m3X1) - (rho+miu)*(S1(i)+h*m3S1) +
tau2*u22*(Y1(i)+h*m3Y1);
m4X1 = beta2*(S1(i)+h*m3S1)*(X1(i)+h*m3X1)-
(eta+omega+miu)*(X1(i)+h*m3X1)-tau1*u22*(X1(i)+h*m3X1);
m4Y1 = omega*(X1(i)+h*m3X1) - (gamma+miu)*(Y1(i)+h*m3Y1) +
alpha*(1-u11)*(Qt1(i)+h*m3Qt1) - tau2*u22*(Y1(i)+h*m3Y1);
m4Qt1 = gamma*(1+u22)*delta*(Y1(i)+h*m3Y1) - (miu + alpha*(1-
u11))*(Qt1(i)+h*m3Qt1);
m4Qp1= gamma*(1+u22)*(1-delta)*(Y1(i)+h*m3Y1)-
miu*(Qp1(i)+h*m3Qp1);


P1(i+1) = P1(i) + (h/6)*(m1P1 + 2*m2P1 + 2*m3P1 + m4P1);
S1(i+1) = S1(i) + (h/6)*(m1S1 + 2*m2S1 + 2*m3S1 + m4S1);
X1(i+1) = X1(i) + (h/6)*(m1X1 + 2*m2X1 + 2*m3X1 + m4X1);
Y1(i+1) = Y1(i) + (h/6)*(m1Y1 + 2*m2Y1 + 2*m3Y1 + m4Y1);
Qt1(i+1)= Qt1(i)+ (h/6)*(m1Qt1+ 2*m2Qt1+ 2*m3Qt1+ m4Qt1);
Qp1(i+1)= Qp1(i)+ (h/6)*(m1Qp1+ 2*m2Qp1+ 2*m3Qp1+ m4Qp1);


end

%temp1 = nilai u1, temp2 = nilai u2
temp1 = (-(lambdaQt-lambdaY).*alpha.*Qt+lambdaX.*tau1.*X)/B1;
```

```
temp2 = (-(lambdaS-lambdaY).*tau2.*Y-
(lambdaQt.*delta+lambdaQp.*(1-delta).*gamma.*Y))/B2;

 %ua = u1*, ub = u2*
ua = min(1,max(0,temp1));
ub = min(1,max(0,temp2));

%u diperbaharui dengan (u_awal+u_baru)/2
u1 = 0.5*(ua + oldu1);
u2 = 0.5*(ub + oldu2);

%uji konvergensi
%tempu1 = solusi optimal dari u1 diuji dengan = delta*||u1||-||u1-
u_lama||>=0
%tempu2 = solusi optimal dari u1 diuji dengan = delta*||u2||-||u2-
u_lama||>=0
 tempu1 = deta*sum(abs(u1)) - sum(abs(oldu1 - u1));
 tempu2 = deta*sum(abs(u2)) - sum(abs(oldu2 - u2));

  tempP = deta*sum(abs(P)) - sum(abs(oldP - P));
  tempS = deta*sum(abs(S)) - sum(abs(oldS - S));
  tempX = deta*sum(abs(X)) - sum(abs(oldX - X));
  tempY = deta*sum(abs(Y)) - sum(abs(oldY - Y));
  tempQt= deta*sum(abs(Qt)) - sum(abs(oldQt - Qt));
  tempQp= deta*sum(abs(Qp)) - sum(abs(oldQp - Qp));

  templP = deta*sum(abs(lambdaP)) - sum(abs(oldlambdaP -
lambdaP));
  templS = deta*sum(abs(lambdaS)) - sum(abs(oldlambdaS -
lambdaS));
  templX = deta*sum(abs(lambdaX)) - sum(abs(oldlambdaX -
lambdaX));
  templY = deta*sum(abs(lambdaY)) - sum(abs(oldlambdaY -
lambdaY));
  templQt= deta*sum(abs(lambdaQt))- sum(abs(oldlambdaQt-
lambdaQt));
  templQp= deta*sum(abs(lambdaQp))- sum(abs(oldlambdaQp-
lambdaQp));


  test = min(tempu1,min(tempu2,min(tempP,min(tempS,
  min(tempX,min(tempY, min(tempQt, min(tempQp, min( templP,
  min(templS, min(templX, min(templY, min(templQt,
  templQp)))))))))))));
   disp(['it: ', num2str(kk),', Test: ', num2str(test)]);

end
end

fprintf('jumlah iterasi = %i ',kk)
Kontrol(1,:) = t;

Kontrol(2,:) = P;
Kontrol(3,:) = S;
```

```
Kontrol(4,:) = X;
Kontrol(5,:) = Y;
Kontrol(6,:) = Qp;
Kontrol(7,:) = Qt;

Kontrol(8,:) = u1;
Kontrol(9,:) = u2;

Kontrol(10,:) = P1;
Kontrol(11,:) = S1;
Kontrol(12,:) = X1;
Kontrol(13,:) = Y1;
Kontrol(14,:) = Qp1;
Kontrol(15,:) = Qt1;

Kontrol(16,:) = P2;
Kontrol(17,:) = S2;
Kontrol(18,:) = X2;
Kontrol(19,:) = Y2;
Kontrol(20,:) = Qp2;
Kontrol(21,:) = Qt2;

fprintf('Hasil Akhir = Ko(:,end) ')
```

- **Program utama**

```
 clc
pilih1=0;
pilih2=0;

lamda = 1000;
beta1 =0.003 ;
beta2 =0.002;
rho =0.003;
miu =0.002;
eta =0.003;
omega =0.004;
alpha =1;

gamma =0.1183;

delta =0.5;
tau1 =0.5;  %asumsi
tau2 =0.5;  %asumsi

TP0=500000;
u11 =0;
u22 =0;

u111 =0.5; %asumsi
```

```
u222 =0.5; %asumsi

A1=20;
A2=20;
A3=60;
B1=50;
B2=50;

P0=3000; %3000
S0=2000; %2000
X0=1000; %1000
Y0=2000; %2000
Qt0=1000; %1000
Qp0=1000; %1000
lambdaP0=0;

Ta=20 ;

Ko =
simulasi_tesis(lambdaP0,lamda,beta1,beta2,rho,miu,eta,omega,alpha,
gamma,delta,tau1,tau2,u11,u22,u111,u222,A1,A2,A3,B1,B2,P0,S0,X0,Y0
,Qt0,Qp0,TP0,Ta);
disp(' ')
clc

while(pilih1==0)
disp(' PILIH GRAFIK HASIL SIMULASI YANG INGIN DI TAMPILKAN')
disp(' ATAU MENGAKHIRI SIMULASI')
disp('========================================================')
disp('')
disp(' 1. INDIVIDU POTENTIAL SMOKERS   (P)')
disp(' 2. INDIVIDU SNUFFING CLASS      (S) ')
disp(' 3. INDIVIDU IRREGULAR SMOKERS   (X)')
disp(' 4. INDIVIDU REGULAR SMOKERS     (Y)')
disp(' 5. INDIVIDU TEMPORARY QUITTERS  (Qt)')
disp(' 6. INDIVIDU PERMANENT QUITTERS  (Qp)')
disp(' 7. TINGKAT KONTROL U1 dan U2 ')
disp(' 8. SELESAI')
disp(' 9. LambdaP')
disp('')
disp('')
pilih2=input('SILAHKAN PILIH 1, 2, 3, 4, 5 , 6, 7 atau 8 :');
disp('')
disp('')


if pilih2==1
    figure (1)
plot(Ko(1,:),Ko(2,:),'blue','linewidth',1.5);
hold on
plot(Ko(1,:),Ko(10,:),'red','linewidth',1.5);
xlabel('Waktu (dalam tahun)')
ylabel('P(t)')
legend('P dengan  kontrol ','P tanpa  kontrol')
grid on;
```

```
pilih1=0;
elseif(pilih2==2)
    figure (2)
plot(Ko(1,:),Ko(3,:),'blue',Ko(1,:),Ko(11,:),'red','linewidth',1.5
);
xlabel('Waktu (dalam tahun)')
ylabel('S(t)')
legend('S dengan kontrol Optimal','S tanpa  kontrol')
grid on;

pilih1=0;
elseif(pilih2==3)
    figure (3)
plot(Ko(1,:),Ko(4,:),'blue',Ko(1,:),Ko(12,:),'red','linewidth',1.5
);
xlabel('Waktu (dalam tahun)')
ylabel('X(t)')
legend('X dengan kontrol Optimal','X tanpa  kontrol')
grid on;

pilih1=0;
elseif(pilih2==4)
    figure (4)
plot(Ko(1,:),Ko(5,:),'blue',Ko(1,:),Ko(13,:),'red','linewidth',1.5
);
xlabel('Waktu (dalam tahun)')
ylabel('Y(t)')
legend('Y dengan kontrol Optimal','Y tanpa  kontrol')
grid on;

pilih1=0;
elseif(pilih2==5)
    figure (5)
plot(Ko(1,:),Ko(6,:),'blue',Ko(1,:),Ko(14,:),'red','linewidth',1.5
);
xlabel('Waktu (dalam tahun)')
ylabel('Qt(t)')
legend('Qt dengan kontrol Optimal','Qt tanpa  kontrol')
grid on;

pilih1=0;
elseif(pilih2==6)
    figure (6)
plot(Ko(1,:),Ko(7,:),'blue',Ko(1,:),Ko(15,:),'red','linewidth',1.5
);
xlabel('Waktu (dalam tahun)')
ylabel('Qp(t)')
legend('Qp dengan kontrol Optimal','Qp tanpa  kontrol')
grid on;

pilih1=0;
elseif(pilih2==7)
    figure (7)
```

```
plot(Ko(1,:),Ko(8,:),'blue',Ko(1,:),Ko(9,:),'red','linewidth',1.5)
;
xlabel('Waktu (dalam tahun)')
ylabel('u1*, u2*')
legend('u1','u2')
grid on;

elseif (pilih2==8)
    pilih1=1;
end
end


%SIMULASI VARIASI PARAMETER,
%simulasi satu per satu, nanti grafiknya tinggal di copy untuk
digabungkan

%CATATAN
%lurus = nilai standar
%....= nilai dibawah tandar
%--- = nilai di atas standar

%clc
%figure (2)
%plot(Ko(1,:),Ko(3,:),'blue',Ko(1,:),Ko(11,:),'red','linewidth',1.
5);
%xlabel('Waktu (dalam tahun)')
%ylabel('S(t)')
%legend('S dengan kontrol Optimal','S tanpa  kontrol')
%grid on;

%figure (2)
%plot(Ko(1,:),Ko(4,:),'blue',Ko(1,:),Ko(12,:),'red','linewidth',1.
5);
%xlabel('Waktu (dalam tahun)')
%ylabel('X(t)')
%legend('X dengan kontrol Optimal','X tanpa  kontrol')
%grid on;

%figure (2)
%plot(Ko(1,:),Ko(5,:),'blue',Ko(1,:),Ko(13,:),'red','linewidth',1.
5);
%xlabel('Waktu (dalam tahun)')
%ylabel('Y(t)')
%legend('Y dengan kontrol Optimal','Y tanpa  kontrol')
%grid on;

disp('')
disp('')
disp('')
disp('')
disp('HASIL AKHIR SIMULASI')
Ko(:,end)
pilih1=1;
disp('SELESAI')
```