SUPPLEMENTAL DATA

System Dynamics Equations

"% Sustainable Construction"=0
Units: Dmnl   (S1)

"% Sustainable Demolition"=0
Units: Dmnl   (S2)

"% Sustainable Maintenance"=0
Units: Dmnl   (S3)

"% Sustainable Rehabilitation"= 0
Units: Dmnl   (S4)

"%Reconstruction"=0.05
Units: Dmnl   (S4)

Annual road growth=0.0427187
Units: 1/Year   (S5)

Available budget=MAX((Budget-Gray Rehabilitation costs-Gray recosntruction costs-Green rehabilitation costs-Green reconstruction costs),0)
Units: $/Year   (S6)

Available budget for green maintenance=MAX(Available budget*Budget fraction for maintenance*("% Sustainable Maintenance"), 0)
Units: $/ Year   (S7)

Available budget for maintenance=MAX(Available budget*Budget fraction for maintenance*(1-"% Sustainable Maintenance"), 0)
Units: $/Year   (S8)

Available for green maintenance gray stock=Available budget for green maintenance-"Final Budget for green maintenance (green)"
Units: $/Year   (S9)

Average time to fix roads=1.5469
Units: Year   (S10)

Budget=1.33192e+12
Units: $/Year   (S11)

Budget for construction=MAX(MIN(Budget needed for construction, available budget new construction), 0)
Units: $/Year   (S12)

Budget needed for construction=Total Gray Pavements*Annual road growth*Unit cost construction+Total green pavements*Annual road growth*Unit cost green construction
Units: $/Year   (S13)

"Budget needed for green maintenance (Gray)"=(("Fair (Gray)"+"Perceived Deteriorated Roads G-F")*("% Sustainable Maintenance")*Unit cost green maintenance/Average time to fix roads)
Units: $/Year (S14)

"Budget needed for green maintenance (green)"=(("Fair (Green)"+"Perceived deteriorated green roads G-F")*"% Sustainable Maintenance"*Unit cost green maintenance/Average time to fix roads)
Units: $/Year (S15)

"Budget needed for maintenace (Gray)"=("Fair (Gray)"+"Perceived Deteriorated Roads G-F")*(1-"% Sustainable Maintenance")*Unit cost for maintenance/Average time to fix roads
Units: $/Year (S16)

"Budget needed for maintenance (green)"=("Fair (Green)"+"Perceived deteriorated green roads G F")*(1-"% Sustainable Maintenance")*Unit cost for maintenance/Average time to fix roads
Units: $/Year (S17)

Demolition=IF THEN ELSE("Poor (Gray)">0 , MIN(SMOOTH(("%Reconstruction")*(1-"% Sustainable Demolition")* ("Poor (Gray)"+"Perceived Deteriorated Roads F-P"+Shortfall)/Time reconstruction, 1.12987), ("%Reconstruction")*"Poor (Gray)"/Time reconstruction), 0)
Units: km-roadway/Year (S18)

"Demolition (Green)"=IF THEN ELSE("Poor (Green)">0 , MIN(SMOOTH(("%Reconstruction")*(1-"% Sustainable Demolition")* ("Poor (Green)"+"Perceived deteriorated green roads F-P"+Shortfall)/Time reconstruction, 1.12987), ("%Reconstruction")*"Poor (Green)"/Time reconstruction), 0)
Units: km-roadway/Year (S19)

Desired Deteriorated Roads=Total Roads*0.2
Units: km-roadway (S20)

Emission factor gray construction=172368
Units: CO_2/km-roadway (S21)

Emission factor green flexible=134835
Units: CO_2/km-roadway (S22)

Emission factor green reconstruction=153647
Units: CO_2/km-roadway (S23)
Emission factor reconstruction=191520
Units: CO_2/km-roadway (S24)

"Fair (Gray)"= SINTEG (Superficial deterioration-Maintenance-Green Maintenance-Structural deterioration,3819.51,0,:NA:,:NA:,:NA:,:NA:)
Units: km-roadway (S25)

"Fair (Green)"= SINTEG ("Superficial deterioration (Green)"-"Maintenance (Green)"-"Green maintenance (Green)"-"Structural deterioration (Green)",0,0,:NA:,:NA:,:NA:,:NA:)
Units: km-roadway (S26)

Gray construction costs=New gray pavements*Unit cost construction
Units: $/Year (S27)

Gray maintenance costs=("Maintenance (Green)"+Maintenance)*Unit cost for maintenance
Units: $/Year (S28)

Gray recosntruction costs=(Demolition+"Demolition (Green)")*Unit Cost recosntruction
Units: $/Year (S29)

Gray Rehabilitation costs="Rehabilitation (Green)"+Rehabilitation)*Unit cost Rehabilitation
Units: $/Year (S30)

Green Demolition=IF THEN ELSE("Poor (Gray)">0 , MIN(SMOOTH(("%Reconstruction")*("%
Sustainable Demolition")* ("Poor (Gray)"
+"Perceived Deteriorated Roads F-P"+Shortfall)/Time reconstruction, 1.12987),
("%Reconstruction")*"Poor (Gray)"/Time reconstruction), 0)
Units: km-roadway/Year (S31)

"Green demolition (Green)"=IF THEN ELSE("Poor (Green)">0 , MIN(SMOOTH(
("%Reconstruction")*("% Sustainable Demolition")* ("Poor (Green)"+"Perceived deteriorated green
roads F-P"+Shortfall)/Time reconstruction, 1.12987), ("%Reconstruction")*"Poor (Green)"/Time
reconstruction), 0)
Units: km-roadway/Year (S32)

available budget new construction=Available budget*(1-Budget fraction for
maintenance)+MAX(Available budget for maintenance+Available budget for green maintenance-
"Final Budget for green maintenance (Gray)"-"Final Budget for green maintenance (green)"-"Final
Budget for maintenace (Gray)"-"Final Budget for maintenance (green)",0)
Units: $/Year (S33)

Budget fraction for maintenance=0.865921
Units: Dmnl (S34)

Emission factor green maintenance=12700.8
Units: CO_2/km-roadway (S35)

Emission factor green rehabilitation=62945
Units: CO_2/km-roadway (S36)

Emission factor maintenance=14112
Units: CO_2/km-roadway (S37)

Emission factor rehabilitation=86226
Units: CO_2/km-roadway (S38)
Factor=1/(1+Interest rate)^(Time-INITIAL TIME)
Units: Dmnl (S39)

"Final Budget for green maintenance (Gray)"=MAX(MIN("Budget needed for green maintenance
(Gray)",Available for green maintenance gray stock), 0)
Units: $/Year (S40)

"Final Budget for green maintenance (green)"=MAX(MIN("Budget needed for green maintenance
(green)", Available budget for green maintenance), 0)
Units: $/Year (S41)

"Final Budget for maintenace (Gray)"=MAX(MIN("Budget needed for maintenace (Gray)", Available
budget for maintenance), 0)
Units: $/Year (S42)

"Final Budget for maintenance (green)"=MAX(MIN("Budget needed for maintenance (green)", Available budget for maintenance-"Final Budget for maintenace (Gray)"), 0)
Units: $/Year   (S43)

"Good   (Gray)"=   SINTEG   (Service   condition   improvement-Superficial deterioration,9944.5,0,:NA:,:NA:,:NA:,:NA:)
Units: km-roadway   (S44)

"Good (Green)"= SINTEG ("Service condition improvement(Sust. Roads)"-"Superficial deterioration (Green)",0,0,:NA:,:NA:,:NA:,:NA:)
Units: km-roadway   (S45)

Gray construction emissions=New gray pavements*Emission factor gray construction
Units: CO2/Year   (S46)

Gray maintenance emissions=Emission factor maintenance*(Maintenance+"Maintenance (Green)")
Units: CO2/Year   (S47)

gray reconstruction emissions=(Demolition+"Demolition (Green)")*Emission factor reconstruction
Units: CO2/Year   (S48)

Gray   rehabilitation   emissions=("Rehabilitation   (Green)"+Rehabilitation)*Emission   factor rehabilitation
Units: CO2/Year   (S49)

Green construction costs=New green pavements*Unit cost green construction
Units: $/Year   (S50)

Green construction emissions=Emission factor green flexible*New green pavements
Units: CO2/Year   (S51)

Green Maintenance=("Final Budget for green maintenance (Gray)"/Unit cost green maintenance)
Units: km-roadway/Year   (S52)

"Green maintenance (Green)"=("Final Budget for green maintenance (green)"/Unit cost green maintenance)
Units: km-roadway/Year   (S53)

Green maintenance costs=(Green Maintenance+"Green maintenance (Green)")*Unit cost green maintenance
Units: $/Year   (S54)

Green maintenance emissions=(Green Maintenance+"Green maintenance (Green)")*Emission factor green maintenance
Units: CO2/Year   (S55)

Green reconstruction costs=(Green Demolition+"Green demolition (Green)")*Unit cost green reconstrction
Units: $/Year   (S56)

Green reconstruction emissions=(Green Demolition+"Green demolition (Green)")*Emission factor green reconstruction

Units: CO2/Year (S57)

Green Rehabilitation=IF THEN ELSE("Poor (Gray)">0 , MIN(SMOOTH(("% Sustainable Rehabilitation")* ("Poor (Gray)"+"Perceived Deteriorated Roads F-P"
+Shortfall)/Time to rehabilitate roads, 0.8), "Poor (Gray)"/Time to rehabilitate roads), 0)
Units: km-roadway/Year (S58)

"Green Rehabilitation (Green)"=IF THEN ELSE("Poor (Green)">0 , MIN(SMOOTH((1-"%Reconstruction")*("% Sustainable Rehabilitation")* ("Poor (Green)"+"Perceived deteriorated green roads F-P"+Shortfall)/Time to rehabilitate roads, 0.8), (1-"%Reconstruction")*"Poor (Green)"/Time to rehabilitate roads), 0)
Units: km-roadway/Year

Green rehabilitation costs=Unit cost Green rehabilitation*(Green Rehabilitation+"Green Rehabilitation (Green)")
Units: $/Year (S59)

Green rehabilitation emissions=Emission factor green rehabilitation*(Green Rehabilitation+"Green Rehabilitation (Green)")
Units: CO2/Year (S60)

Increase in costs=-"Total Cost/year"*Factor
Units: $/Year (S61)

INITIAL TIME = 0
Units: Year
The initial time for the simulation. (S62)

Interest rate=0.085
Units: Dmnl (S63)

Maintenance=("Final Budget for maintenace (Gray)"/Unit cost for maintenance)
Units: km-roadway/Year (S64)

"Maintenance (Green)"=("Final Budget for maintenance (green)"/Unit cost for maintenance)
Units: km-roadway/Year (S65)

New gray pavements=(Budget for construction/Unit cost construction)*(1-"% Sustainable Construction")
Units: km-roadway/Year (S66)

New green pavements=(Budget for construction/Unit cost green construction)*("% Sustainable Construction")
Units: km-roadway/Year (S67)

"Perceived deteriorated green roads F-P"=SMOOTH("Structural deterioration (Green)" , 0.49)
Units: Dmnl (S68)

"Perceived deteriorated green roads G-F"=SMOOTH("Superficial deterioration (Green)" , 1)
Units: km-roadway/Year (S69)

"Perceived Deteriorated Roads F-P"=MAX(SMOOTH(Structural deterioration , 0.49) , 0)

Units: km-roadway/Year   (S70)

"Perceived Deteriorated Roads G-F"=SMOOTH(Superficial deterioration,0.0396758)
Units: km-roadway/Year   (S71)

"Poor (Gray)"= SINTEG (Structural deterioration-Demolition-Green Rehabilitation-Rehabilitation-Green Demolition,3441,0,:NA:,:NA:,:NA:,:NA:)
Units: km-roadway   (S72)

"Poor (Green)"= SINTEG ("Structural deterioration (Green)"-"Demolition (Green)"-"Green demolition (Green)-"Green Rehabilitation (Green)"-"Rehabilitation (Green)",0,0,:NA:,:NA:,:NA:,:NA:)
Units: km-roadway   (S73)

Rehabilitation=IF THEN ELSE("Poor (Gray)">0 , MIN(SMOOTH((1-"%Reconstruction")*(1-"% Sustainable Rehabilitation")* ("Poor (Gray)"+"Perceived Deteriorated Roads F-P"+Shortfall)/Time to rehabilitate roads, 0.8), (1-"%Reconstruction")*"Poor (Gray)"/Time to rehabilitate roads), 0)
Units: km-roadway/Year   (S74)

"Rehabilitation (Green)"=IF THEN ELSE("Poor (Green)">0 , MIN(SMOOTH((1-"%Reconstruction")*(1-"% Sustainable Rehabilitation")* ("Poor (Green)"+"Perceived deteriorated green roads F-P"+Shortfall)/Time to rehabilitate roads, 0.8), (1-"%Reconstruction")*"Poor (Green)"/Time to rehabilitate roads),0)
Units: km-roadway/Year   (S75)

Service condition improvement=Rehabilitation+New gray pavements+Maintenance+"Rehabilitation (Green)"+"Maintenance (Green)"+"Demolition (Green)"+Demolition
Units: km-roadway/Year   (S76)

"Service condition improvement(Sust. Roads)"=+Green Demolition+"Green demolition (Green)"+Green Maintenance+"Green maintenance (Green)"+Green Rehabilitation+"Green Rehabilitation (Green)"+New green pavements
Units: km-roadway/Year   (S77)

Shortfall=MAX(Total poor-Desired Deteriorated Roads, 0)
Units: km-roadway   (S78)

Structural deterioration="Fair (Gray)"/Time structural failures
Units: km-roadway/Year   (S79)

"Structural deterioration (Green)"="Fair (Green)"/Time structural failures
Units: km-roadway/Year   (S80)

Superficial deterioration="Good (Gray)"/Time superficial failures
Units: km-roadway/Year   (S81)

"Superficial deterioration (Green)"="Good (Green)"/Time superficial failures
Units: km-roadway/Year   (S82)

Time reconstruction=7.39556
Units: Year   (S83)

Time structural failures=8
Units: Year   (S84)

Time superficial failures=1.52378
Units: Year (S85)

Time to rehabilitate roads=1.94531
Units: Year (S86)

"Total Cost/year"="Total Gray cost /year"+"Total Sust. Cost/year"
Units: $/Year (S87)

"Total Emissions /year"="Total emissions sust/year"+"Total emmisions gray/year"
Units: CO2/Year (S88)

"Total emissions sust/year"=Green rehabilitation emissions+Green construction emissions+Green maintenance emissions+Green reconstruction emissions
Units: CO2/Year (S89)

"Total emmisions gray/year"=Gray construction emissions+Gray maintenance emissions+Gray rehabilitation emissions+gray reconstruction emissions
Units: CO2/Year (S90)

Total fair="Fair (Gray)"+"Fair (Green)"
Units: km-roadway (S91)

Total good="Good (Gray)"+"Good (Green)"
Units: km-roadway (S92)

"Total Gray cost /year"=Gray construction costs+Gray maintenance costs+Gray Rehabilitation costs+Gray recosntruction costs
Units: $/Year (S93)

Total gray costs= INTEG (Gray construction costs+Gray maintenance costs+Gray Rehabilitation costs+Gray recosntruction costs,0)
Units: $ (S94)

Total Gray Emissions= INTEG (Gray construction emissions+Gray maintenance emissions+gray reconstruction emissions+Gray rehabilitation emissions,0)
Units: CO2 (S95)

Total Gray Pavements="Fair (Gray)"+"Good (Gray)"+"Poor (Gray)"
Units: km-roadway (S96)

Total green pavements="Fair (Green)"+"Good (Green)"+"Poor (Green)"
Units: km-roadway (S97)

Total poor="Poor (Gray)"+"Poor (Green)"
Units: km-roadway (S98)

Total Roads=Total Gray Pavements+Total green pavements
Units: km-roadway (S99)

"Total Sust. Cost/year"=Green construction costs+Green rehabilitation costs+Green maintenance costs
+Green reconstruction costs
Units: $/Year   (S100)

"Total Sust. Costs"= INTEG (Green construction costs+Green maintenance costs+Green reconstruction
costs+Green rehabilitation costs,0)
Units: $ (S101)

"Total Sust. Emissions"= INTEG (Green construction emissions+Green maintenance emissions+Green
reconstruction emissions+Green rehabilitation emissions,0)
Units: CO_2 (S102)

Unit cost construction=3.88049e+08
Units: $/km-roadway   (S103)

Unit cost for maintenance=1.52341e+08
Units: $/km-roadway   (S104)

Unit cost green construction=2.81917e+08
Units: $/km-roadway   (S105)

Unit cost green maintenance=1.49294e+08
Units: $/km-roadway   (S106)

Unit cost green reconstrction=3.06728e+08
Units: $/km-roadway   (S107)

Unit cost Green rehabilitation=1.70721e+08
Units: $/km-roadway   (S108)

Unit Cost recosntruction=4.10888e+08
Units: $/km-roadway   (S109)

Unit cost Rehabilitation=2.6956e+08
Units: $/km-roadway   (S110)