sustainability

MDPI

Mathematical Equations of the SD Model

Table S1 presents the variables of the proposed model, separated by modules, which identifies the type (stock, flow and auxiliary), as well as the mathematical equations related to the unit.

Table 1. Mathematical Equations of the SD model.

Module	Type	Variable	Equation	Unit	Number
Load Volume Forecast	Stock	Total freight volume	$(Increase\ of\ total\ freight\ volume)dt + S(t_0)$	ton	1
	Stock	Freight volume route #1	$(Increase\ of\ freight\ volume\ route\ \#1)dt + S(t_0)$	ton	2
	Stock	Freight volume route #2	$(Increase\ of\ freight\ volume\ route\ \#2)dt + S(t_0)$	ton	3
	Flow	Increase of total freight volume	$Total\ freight\ volume\ .Growth\ rate\ of\ freight\ volume/SAVEPER$	ton/year	4
	Flow	Increase of freight volume route #1	$Freight\ volume\ in\ next\ year\ of\ route\ \#1 - Freight\ volume\ route\ \#1/SAVEPER$	ton/year	5
	Flow	Increase of freight volume route #2	$Freight\ volume\ in\ next\ year\ of\ route\ \#2 - Freight\ volume\ route\ \#2/SAVEPER$	ton/year	6
	Auxiliary	Freight volume in next year of route #1	$Total\ freight\ volume\ .split\ proportion\ of\ freight\ volume\ \#1$	ton	7
	Auxiliary	Freight volume in next year of route #2	$Total\ freight\ volume\ .split\ proportion\ of\ freight\ volume\ \#2$	ton	8
	Auxiliary	Freight volume of #1	$Freight\ volume\ route\ \#1/SAVEPER$	ton/year	9
	Auxiliary	Freight volume of #2	$Freight\ volume\ route\ \#2/SAVEPER$	ton/year	10
Speed Flow	Auxiliary	Truck loadage #1	$Truck\ loadage\ of\ statutory\ limit\ .(1 + overweight\ percentage)$	ton/vehicle	11
	Auxiliary	Truck loadage #2	$Truck\ loadage\ of\ statutory\ limit$	ton/vehicle	12
	Flow	Vehicle with ornamental stones #1	$Freight\ volume\ of\ \#1/Truck\ loadage\ \#1\ .(1 + overweight\ percentage)$	vehicle/year	13
	Flow	Increase in heavy vehicle traffic #1	$Heavy\ vehicle\ traffic\ \#1\ .AADT\ growth\ rate/SAVEPER$	vehicle/year	14
	Stock	Heavy vehicle traffic #1	$(Increase\ in\ heavy\ vehicle\ traffic\ \#1)dt + S(t_0)$	vehicle	15
	Auxiliary	Accumulated heavy vehicle in the next year #1	$Heavy\ vehicle\ traffic\ \#1$	vehicle	16
	Flow	Heavy vehicle flow #1	$Accum.heavy\ vehicle\ in\ next\ year\ \#1 - Accum.heavy\ vehicle\ \#1/SAVEPER$	vehicle/year	17
	Stock	Accumulated heavy vehicle #1	$(Heavy\ vehicle\ flow\ \#1)dt + S(t_0)$	vehicle	18
	Flow	Heavy vehicle #1	$(Accum\ heavy\ vehicle/SAVEPER) - (freight\ volume/truck\ loadage)$	vehicle/year	19

Table 1. Equations of the SD model (continue).

	Stock	Total traffic #1	$(Vehicle\ with\ ornamental\ stones\ \#1 + heavy\ vehicles\ \#1\ + light\ vehicles\ \#1 - total\ vehicles\ \#1) + S(t_0)$	vehicle	20
	Flow	Total vehicles #1	$Total\ traffic\ \#1/SAVEPER$	vehicle/year	21
	Auxiliary	V_{vhp}	$Total\ vehicles\ \#1/Hours\ per\ year\ .peak\ hour\ factor$	vehicle/hour	22
	Auxiliary	Percentage of heavy vehicle #1 (P_{HV})	$(heavy\ vehicle\ \#1 + vehicle\ with\ ornamental\ stones\ \#1)/total\ vehicles\ \#1$	vehicle/vehicle	23
	Auxiliary	Heavy vehicle adjustment factor (f_{HV}) for volume	$1/(1 + P_{HV})\ .(Equivalent\ of\ heavy\ vehicle\ volume\ adjustment - 1)\ )$	vehicle/pce	24
	Auxiliary	Traffic equivalent volume #1	$V_{vhp}/(grade\ adjustment\ (f_g)\ for\ volume\ .f_{HV}\ for\ volume)$	pce/hour	25
	Auxiliary	f_{HV} for capacity	$1/(1 + P_{HV}\ .(Equivalent\ of\ heavy\ vehicles\ capacity\ adjustment - 1))$	dimensionless	26
	Auxiliary	Average capacity #1	$maximum\ capacity\ .fg\ for\ capacity\ .\ f_{HV}\ for\ capacity$	pce/hour	27
	Auxiliary	Volume/Capacity (v/c)	$traffic\ equivalent\ volume\ \#1/average\ capacity\ \#1$	dimensionless	28
	Auxiliary	Average travel time #1	$Free\ flow\ time\ \#1\ .(1 + \alpha\ .(v/c\ \#1)^{\beta}\ )$	hour/vehicle	29
	Auxiliary	Free flow time #1	$distance\#1/free\ flow\ speed\ \#1$	hour/vehicle	30
	Auxiliary	Total travel time route #i	$(Average\ travel\ time\ \#i1 + Average\ travel\ time\ \#i2)$	hour/vehicle	31
	Auxiliary	Route distance #i	$Distance\ \#i1 + Distance\ \#i2$	km	32
Modal Split	Auxiliary	Split proportion of freight volume #1	$exp^{(-\text{generalized cost of route \# 1})} \Big/ \sum_{i=1}^{2} exp^{(-\text{generalized cost of route \#i})}$	dimensionless	33
	Auxiliary	Split proportion of freight volume #2	$1 - Split\ proportion\ of\ freight\ volume\ \#1$	dimensionless	34
	Auxiliary	Generalized cost	$((operational\ cost\ per\ distance\ .distance\ route) + (operational\ cost\ per\ time\ .total\ travel\ time) + toll\ of\ unit\ freight\ volume + fine\ costs)$	R$/ton	35
	Auxiliary	Operational cost per distance	$(distance\ cost\ \#1/truck\ loadage\ \#1).cost\ growth\ rate$	R$/Km/ton	36
	Auxiliary	Operational cost per time	$time\ cost\ \#1/truck\ loadage\ \#1\ .cost\ growth\ rate$	(R$/hour)/(ton/vehicle)	37
	Auxiliary	Toll of unit freight volume #1	$Toll\ \#1/truck\ loadage\ \#1$	R$/ton	38
	Auxiliary	Cost growth rate	$(1 + inflation\ rate)^{(Time - Initial\ Time)/SAVEPER}$	dimensionless	39
Pavement Maintenance	Auxiliary	Design ESAL #1	$fleet\ vehicle\ factor\ .total\ volume\ of\ vehicles\ \#1$	times	40
	Auxiliary	Total volume of vehicles #1	$average\ volume\ of\ vehicles\ \#1\ .(days/year)\ .service\ life\ of\ project$	vehicle	41
	Auxiliary	Average volume of vehicles #1	$AADT\ initial\ year\ \#1\ .((2 + service\ life\ of\ project\ .AADT\ growth\ rate)/2)$	vehicle/day	42
	Auxiliary	Current life spam #1	$IF\ THEN\ ELSE(x > service\ life\ of\ project, service\ life\ of\ project, x)$	year	43
	Auxiliary	x	$Design\ ESAL\ \#1/Current\ ESAL\ \#1$	year	44

Table 1. Equations of the SD model (continue).

	Auxiliary	Current ESAL #1	$(TF\ light\ truck\ + TF\ bus\ + TF\ single\ trailer + TF\ multi\ trailer)\ .total\ vehicles\ \#1\ .regional\ climate\ factor$	times/year	45
	Auxiliary	TF bus #1	$(LF\ single\ tyres\ B\# + LF\ twin\ tyres\ B\#1)\ .axle\ factor\ bus\ \#1\ .axis\ requests$	times/vehicle	46
	Constant	Axle factor bus #1	$2\ .(0.03)$	axle/vehicle	47
	Auxiliary	LF single tyres	$(wl\ single\ tyres/7.77)^{4.32}$	dimensionless	48
	Auxiliary	LF twin tyres	$(wl\ twin\ tyres/8.17)^{4.32}$	dimensionless	49
	Auxiliary	LF double tandem	$(wl\ double\ tandem/15.08)^{4.14}$	dimensionless	50
	Auxiliary	LF triple tandem	$(wl\ triple\ tandem/22.95)^{4.22}$	dimensionless	51
	Auxiliary	Wl single tyres B #1	$6.6\ .(1 + overweight\ per\ axle\ percentage\ \#1)$	dimensionless	52
	Auxiliary	Parameter α	$IF\ THEN\ ELSE(y > 2, (y\ .(0.6)), (y\ .(0.3)))$	dimensionless	53
	Auxiliary	Parameter β	$IF\ THEN\ ELSE(y > 1.5, IF\ THEN\ ELSE\ (y < 2, (0.5)\ , (0.1\ )\ , 0.8\ ))$	dimensionless	54
	Auxiliary	Y	$current\ life\ spam\ \#1/SAVEPER$	dimensionless	55
	Flow	Decrease of PCI	$Value\ of\ PCI\#1\ .(exp^{(-Parameter\ \alpha\ \#1)^{Parameter\ \beta\ \#1}})/SAVEPER$	points/year	56
	Stock	Value of PCI	$(decrease\ in\ maintenance\ effect\ \#1 - decrease\ of\ PCI\#1)\ dt + S(t_0)$	points	57
	Flow	Increase in maintenance effect (IME) #1	$maintenance/SAVEPER$	points/year	58
	Stock	Maintenance effect #1	$(increase\ in\ maintenance\ effect\ \#1 - decrease\ in\ maintenance\ effect\#1)dt + S(t_0)$	points	59
	Flow	Decrease in maintenance effect #1	$DELAY\ FIXED(IME\ \#1, 2, IME\ \#1)$	points/year	60
Social Costs	Stock	Cumulative pavement maintenance cost	$(Yearly\ pavement\ maintenance\ cost)dt + S(t_0)$	R$	61
	Flow	Yearly pavement maintenance cost	$\sum_{i=1}^{3}(Pavement\ maintenance\ cost\ \#i)$	R$/year	62
	Auxiliary	Corrective maintenance (CM) cost	$CM\ cost/Km\ .distance\ route\ .cost\ growth\ rate$	R$/year	63
	Auxiliary	Restorative maintenance (RM) cost	$RM\ cost/Km\ .distance\ route\ .cost\ growth\ rate$	R$/year	64
	Stock	Cumulative traffic accident cost	$(Yearly\ traffic\ accident\ cost)dt + S(t_0)$	R$	65

Table 1. Equations of the SD model (conclusion).

	Flow	Yearly traffic accident cost	$\sum_{i=1}^{3}(Traffic\ accident\ cost\ \#i)$	R$/year	66
	Auxiliary	Traffic accident cost #1	$accident\ forecast\ \#1\ .\ (\sum_{i=1}^{3}(accident\ type\ i\ .cost\ of\ accident\ type\ i)\ .cost\ growth\ rate)$	R$/year	67
	Auxiliary	Accident forecast #1	$vehicle\ with\ orn.stones\ .distance\ route\ .10^{-6}\ .exp^{-0.312}\ .(correction\ factor\ for\ accident\ prediction)$	accident/year	68
Policies Evaluation	Stock	Cumulative transportation cost	$(Yearly\ transportation\ cost)dt + S(t_0)$	R$	69
	Flow	Yearly transportation cost	$\sum_{i=1}^{2}(freight\ volume\ of\ \#i\ .generalized\ cost\ of\ route\ \#i)$	R$/year	70
	Auxiliary	Weighed cumulative operational cost	$cumulative\ transportation\ cost\ .Weight\ of\ operational\ cost$	R$	71
	Auxiliary	Weighed cumulative social cost	$(cumulative\ pavement\ maintenance\ cost + cumulative\ traffic\ accident\ cost)\ .weight\ of\ social\ cost$	R$	72
	Auxiliary	Weight of operational cost	$1 - weight\ of\ social\ cost$	dimensionless	73
	Auxiliary	Cumulative total cost	$Weighed\ cumulative\ operational\ cost + Weighed\ cumulative\ social\ cost$	R$	74