TransComp modeling tool — Mathematical description

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Table 1. Sets, decision variables and parameters used for the formulation of the linear program.

Notation	Description	Unit
$y \in \mathcal{Y}$	year	
$p \in \mathcal{M}$	product type (incl. passengers)	p/T
$m \in \mathcal{M}$	mode	
$r \in \mathcal{R}$	O-D pair	
$k \in \mathcal{K}$	route	
$v \in \mathcal{V}$	vehicle type	
$t \in \mathcal{T}$	drive-train technology - fuel pair	
$l \in \mathcal{L}_t$	fuel supply options for technology t	
$e \in \mathcal{E}$	location	
$ic \in \mathcal{IC}$	income class	
$b \in \mathcal{B}_{kmtg}$	subset defined for each route k and technology t for year y	
$g \in \mathcal{G}$	generation of vehicle fleet	
$\mathcal{V}_k$	$(e_1, e_2, e_3, \ldots, e_I)$	
$\mathcal{U}_k$	$\{(i, e_i) \| e_i \in \mathcal{V}_k, 1 \leq i \leq I\}$	
$\mathcal{Y}_y$	$\{0, \ldots, y\}$	
$\mathcal{E}_{kmtgb}$	subset of edges within the driving range of technology t in year y along route k	
$f_{yprkmvtg}$	transport volumes transported using technology t on mode m along route k in year y	T
h_{yprmtg}	vehicle fleet for mode m with technology t	#
h^{+}_{yprmtg}	vehicle fleet growth for mode m with technology t	#
h^{-}_{yprmtg}	vehicle fleet reduction for mode m with technology t	#
h^{exist}_{yprmtg}	vehicle fleet existing for mode m with technology t at the beginning of year y	#
$s_{ypkmvtle}$	fueling demand during annual peak hour covered at edge e of technology t with fuel supplied with supply option l along route k in year y	kWh
$s_{ypkmtln}$	fueling demand during annual peak hour covered at node n of technology t with fuel supplied with supply option l along route k in year y	kWh
$q^{+,mode\_infr}_{yet}$	installed mode infrastructure for technology t along edge e in year y	kW
$q^{+,fuel\_infr}_{yet}$	installed fueling infrastructure for technology t along edge e in year y	kW
$q^{+,supply\_infr}_{yle}$	capacity of supply infrastructure l installed along edge e in year y	kW
LoS_{yktv}	level of service	h
F_{yrp}	transport demand between O-D pair r for product p in year y	T
D^{spec}_{yvtg}	specific energy consumption of drive-train technology t in year y	kWh/km
W_{yvtg}	average load of a vehicle of technology t bought in year g	T
L^{a}_{gmvt}	maximum annual mileage of vehicle	km
L_k	length of path k	km
$Q^{mode\_infr}_{et}$	initial transport capacity for edge e on mode m	T
$Q^{fuel\_infr}_{et}$	initial fueling capacity for technology t at edge e	kW
$Q^{supply\_infr}_{le}$	initial capacity for supply l at edge e	kW
Q^{tank}_{gmt}	tank size	kWh
δ	maximum substitution rate	
α	Bass diffusion coefficient	
β	Bass diffusion coefficient	
κ	Discount rate	

1. Methodology and Data

Objective function

$$minimize_x \mathrm{Z} \tag{1}$$

$$\mathrm{Z} = \sum_{y} \frac{1}{(1+\kappa)^{(y-y_0)}} \left(\mathrm{C}^{infrastructure,total} + \mathrm{C}^{vehiclestock,total} + \mathrm{C}^{transportactivity,total} + \mathrm{C}^{intangiblecosts,total} + \mathrm{C}^{paneltycosts,total} \right) \tag{2}$$

$$\begin{aligned}
\mathrm{C}^{infrastructure,total} = & \sum_{t} \sum_{y} \left(\sum_{e} C_{yte}^{fuel_infr} q_{yte}^{+,fuel_infr} + \sum_{y' \in \mathcal{Y}^y} C_{yte}^{fuel_infr,OM,fix} \left(Q_{te}^{fuel_infr} + q_{y'te}^{+,fuel_infr} \right) \right) \\
& + \sum_{m} \sum_{y} \left(\sum_{e} C_{yme}^{mode_infr} q_{yme}^{+,mode_infr} + \sum_{y' \in \mathcal{Y}^y} C_{yme}^{mode_infr,OM,fix} \left(Q_{me}^{fuel_infr} + q_{y'me}^{+,fuel_infr} \right) \right) \\
& + \sum_{l} \sum_{y} \left(\sum_{e} C_{yle}^{supply_infr} q_{yle}^{+,supply_infr} + \sum_{y' \in \mathcal{Y}^y} C_{yle}^{supply_infr,OM,fix,supply} \left(Q_{te}^{supply_infr} + q_{y'te}^{+,supply_infr} \right) \right)
\end{aligned} \tag{3}$$

$$\mathrm{C}^{vehiclestock,total} = \sum_{y} \sum_{m} \sum_{v} \sum_{t} \sum_{g} \left(C_{yvtg}^{CAPEX} h_{yprvtg}^{+} + C_{yvtg}^{h,OM,fix} h_{yprvtg} + \sum_{l} \sum_{e \in E^k} C_{yle}^{fuelcosts} * s_{ypkmvtle} \right) \tag{4}$$

$$\mathrm{C}^{transportactivity,total} = \sum_{y} \left(C_{mvt}^{OM,fix,dist} f_{y,prkmvtg} + \sum_{k} C_{mvt}^{OM,var,dist} \sum_{k} L_k f_{y,prkmvtg} \right) \tag{5}$$

$$\mathrm{C}^{intangiblecosts,total} = \sum_{y}\sum_{m}\sum_{r}\sum_{kvt} VoT_{ykvt,ic} * LoS^{f}_{ykvt} * f_{yprkmvtg} \tag{6}$$

$$LoS^{f}_{yk} = \frac{L_k}{Speed_y vmt} + Fueling\_time_{ykvmt} + Waiting\_time_{ykm} \tag{7}$$

$$\mathrm{C}^{paneltycosts,total} = \sum_{y}\sum_{p}\sum_{r} penalty^{budget}_{pry} \tag{8}$$

Demand coverage

$$\sum_{kmvtg} f_{yprkmvtg} = F_{yrp} \quad : \forall y \in \mathcal{Y}, r \in \mathcal{R}, p \in \mathcal{P} \tag{9}$$

Vehicle stock sizing

$$h_{yprmvtg} \geq \sum_{k\in\mathcal{K}_r}\sum_{e\in\mathcal{E}_k}\sum_{n\in\mathcal{N}_k}\sum_{a\in\mathcal{A}^p} \frac{L_e}{W_{ymvtg}L^{a}_{ymvtg}} f_{yprkmvtg} : \forall y \in \mathcal{Y}, r \in \mathcal{R}, p \in \mathcal{P}, m \in \mathcal{M}, v \in \mathcal{V}, t \in \mathcal{T}, g \in \mathcal{G} \tag{10}$$

Vehicle stock aging

$$h_{yprmvtg} = h^{exist}_{yprmvt(g-1)} + h^{+}_{yprmvtg} - h^{-}_{yprmvtg} : \forall y \in \mathcal{Y} \setminus \{y_0\}, r \in \mathcal{R}, p \in \mathcal{P}, m \in \mathcal{M}, v \in \mathcal{V}, t \in \mathcal{T}, g \in \mathcal{G} \tag{11}$$

$$h^{exist}_{yprmvt(g-1)} = h_{(y-1)prmvtg} \quad : y = y_0, r \in \mathcal{R}, p \in \mathcal{P}, m \in \mathcal{M}, v \in \mathcal{V}, t \in \mathcal{T}, g \in \mathcal{G} \tag{12}$$

Fueling demand

$$\sum_{l\in\mathcal{L}_t}\sum_{e\in\mathcal{E}_{kmvtbg}} s_{ypkmvtle} \geq \sum_{g}\sum_{e\in\mathcal{E}_{pkmvtbg}} \gamma\frac{D^{spec}_{gmt}L_{ke}}{W_{gmvt}} f_{ypkmvtg}$$
$$: \forall y\in\mathcal{Y}, p\in\mathcal{P}, k\in\mathcal{K}, m\in\mathcal{M}, t\in\mathcal{T}_m, b\in\mathcal{B}_{kmvtg} \tag{13}$$

Spatial fueling flexibility

$$\sum_{l\in\mathcal{L}_t}\sum_{e\in\mathcal{E}_k} s_{ypkmvtle} = \sum_{g\in\mathcal{G}}\sum_{a\in\mathcal{A}^p}\sum_{e\in\mathcal{E}_k}\sum_{n\in\mathcal{N}_k} \gamma\frac{D^{spec}_{yt}L_{ke}}{W_{ymvt}} f_{ypakmvtg} : \forall y\in\mathcal{Y}, p\in\mathcal{P}, k\in\mathcal{K}, m\in\mathcal{M}, t\in\mathcal{T}_m \tag{14}$$

$$\sum_{l\in\mathcal{L}_t}\sum_{e\in\mathcal{U}_{ke}} s_{ypkmvtle} \leq \gamma\sum_{g\in\mathcal{G}}\frac{1}{W_{gmvt}} f_{ypkmvtg} * Q^{tank}_{gmvt} : \forall y, p, k, m, t \tag{15}$$

Vehicle stock shift

$$\pm\left(\sum_{g} h_{yprmvt} - \sum_{g} h_{(y-1)prmvt}\right) \leq \alpha\sum_{gvt} h_{yprmvt} + \beta\sum_{g} h_{(y-1)prmvtg} : \forall y\in\mathcal{Y}\setminus\{y_0\}, r\in\mathcal{R}, m\in\mathcal{M}, v\in\mathcal{V}, t\in\mathcal{T}_m \tag{16}$$

$$\pm\left(\sum_{g} h_{yprmvtg} - \sum_{g} h^{exist}_{yprmvtg}\right) \leq \alpha\sum_{gvt} h_{yprmvt} + \beta\sum_{g} h^{exist}_{yprmvtg} : \forall y\in\{y_0\}, r\in\mathcal{R}, m\in\mathcal{M}, v\in\mathcal{V}, t\in\mathcal{T}_m \tag{17}$$

Mode shift

$$\pm\left(\sum_{kg} f_{yprkmvtg} - \sum_{kg} f_{(y-1)prkmvtg}\right) \leq \alpha F_{yrp} + sum_{kg} f_{(y-1)prkmvtg} : \forall y \in \mathcal{Y} \setminus \{y_0\}, r \in \mathcal{R}, m \in \mathcal{M} \tag{18}$$

Mode infrastructure expansion

$$Q^{mode\_infr}_{me} + \sum_{y \in \mathcal{Y}_y} q^{+,mode\_infr}_{yme} \geq \gamma \sum_{e \in \mathcal{K}_e} \sum_{p \in \mathcal{P}} \sum_{t \in T_m} f_{ypkmtg} : \forall y \in \mathcal{Y}, m \in \mathcal{M}, e \in \mathcal{E} \tag{19}$$

Fueling infrastructure expansion

$$Q^{fuel\_infr}_{te} + \sum_{y \in \mathcal{Y}_y} q^{+,fuel\_infr}_{yte} \geq \sum_{k \in \mathcal{K}_e} \sum_{p \in \mathcal{P}} \sum_{m \in \mathcal{M}} \sum_{l \in \mathcal{L}_t} s_{ypkmtle} : \forall y \in \mathcal{Y}, t \in \mathcal{T}, e \in \mathcal{E} \tag{20}$$

Supply infrastructure expansion

$$Q^{supply\_infr}_{le} + \sum_{y \in \mathcal{Y}_y} q^{+,supply\_infr}_{yle} \geq \sum_{e \in \mathcal{K}_e} \sum_{p \in \mathcal{P}} \sum_{m \in M} \sum_{t \in \mathcal{T}_l} s_{ypkmtle} : \forall y \in \mathcal{Y}, l \in \mathcal{L}, e \in \mathcal{E} \tag{21}$$

Monetary budget constraints

$$\sum_{y} C^{CAPEX}_{yvtg} * h^{+}_{yr} \leq Budget_{ic} * f * |Y| + penalty^{+,invbudget} \tag{22}$$

$$\sum_{y} C^{CAPEX}_{yvtg} * h^{+}_{yr} \geq Budget_{ic} * f * |Y| - penalty^{-,invbudget} \tag{23}$$

$$\sum_{y'_Y i} C^{CAPEX}_{y'vtg} * h^{+}_{y'r} \leq Budget_{ic} * f * \tau^{i} + penalty^{+,invbudget} \tag{24}$$

$$\sum_{y'_Y i} C^{CAPEX}_{y'vtg} * h^{+}_{y'r} \geq Budget_{ic} * f * \tau^{i} - penalty^{+,invbudget} \tag{25}$$