
Summary of mathematical notation glossary for the fuzzy-stochastic fleet planning model

Indices & sets:

- $i \in I$ seaports in Turkey for import/export marine transport operations, $I = \{1, \dots, |I|\}$
 $j, j', j^* \in J$ seaports in Europe for import/export marine transport operations, $J = \{1, \dots, |J|\}$
 $k, k', k^* \in K$ rail stations in Europe for import/export railway transport operations, $K = \{1, \dots, |K|\}$
 $l \in L$ order countries in Europe (aggregated customers), $L = \{1, \dots, |L|\}$
 $t \in T$ monthly time period, $T = \{1, \dots, |T|\}$

Marine transport network subsets:

- $(i, j) \in L_{ij}$ set of marine links where import/export transport operations can be performed by only other logistics service providers' Ro-Ro vessels,
 $(i, j) \in C_{ij}$ set of marine links where transport operations can be performed by only company-owned Ro-Ro vessels,
 $(i, j) \in B_{ij}$ set of marine links where import/export transport operations can be performed by both company-owned and other logistics service providers' Ro-Ro vessels,
 $j' \in T_j$ set of transshipment seaports where the extra freights can be loaded/unloaded during the transportation services,
 $j^* \in \gamma_j$ set of main origin and destination seaports including at least one transshipment seaport on its marine route,
 $j \in D_j$ set of seaports in Europe which are directly connected with a railway station,

Railway transport network subsets:

- $(j, k) \in L_{jk}$ set of rail lines where import/export transport operations can be performed by only public train services,
 $(j, k) \in C_{jk}$ set of rail lines where import/export transport operations can be performed by only chartering block trains,
 $(j, k) \in B_{jk}$ set of rail lines where transport operations can be performed by both block train and public train services,
 $k' \in T_k$ set of transshipment stations which also have railway connections with other main stations,
 $k^* \in G_k$ set of main origin and destination stations including at least one transshipment station on its rail route,
 $k \in D_k$ set of railway stations which are directly connected with a seaport in Europe,

Road transport network subsets:

- $l \in PR_L$ set of order countries where newly purchased European plated trucks can join or second hand trucks leave the intermodal transportation system,
 $i \in PR_i$ set of seaports in Turkey where newly purchased Turkish plated trucks and trailers can join or second hand trucks/trailers leave the intermodal transportation system,
 $l \in G_l$ set of order countries that can be served by road freight transport from the main railway stations, $k^* \in G_k$ involving railway transshipments

Fuzzy cost parameters:

- \widetilde{C}_{ij}^{exp} marine transport cost per TU of export operation by company owned Ro-Ro vessels on marine link $(i, j) \in L_{ij}$
 \widetilde{C}_{ji}^{imp} marine transport cost per TU by other logistics service providers' Ro-Ro vessels on $(j, i) \in C_{ji}$
 \widetilde{C}_{jk}^{exp} railway transport cost per block train chartered for export operation on rail line $(j, k) \in L_{jk}$
 \widetilde{C}_{jk}^{exp} railway transport cost per TU of export operation by public trains on rail line $(j, k) \in C_{jk}$
 $\widetilde{C}_{k^*k'}^{imp}$ railway transport cost per TU of import operation by public trains on rail line $(k^*, k') \mid k^* \in G_k \text{ and } k' \in T_k$
 $\widetilde{SC}_{lit}^{imp}$ outsourcing cost per TU of import operation from order country l to seaport in Turkey i in time period t
 \widetilde{CR} road freight transport cost per km of per TU by European/Turkish plated trucks for both import/export operations
 \widetilde{RC}^v empty repositioning cost per km of European or Turkish plated trucks
 \widetilde{RC}^{tr} empty repositioning cost per km of trailers
 $\widetilde{OWC}_{Euro}^{Truck}$ monthly fixed ownership cost per European plated truck
 $\widetilde{OWC}_{Turk}^{Truck}$ monthly fixed ownership cost per Turkish plated truck
 $\widetilde{OWN}^{Trailer}$ monthly fixed ownership cost per trailer
 \widetilde{PCV}^E annual cost of purchasing a new European plated truck
 \widetilde{PCV}^T annual cost of purchasing a new Turkish plated truck
 \widetilde{PCT} annual cost of purchasing a new trailer
 \widetilde{SV}^E revenue obtained from the sales of a second-hand European plated truck
 \widetilde{SV}^T revenue obtained from the sales of a second-hand Turkish plated truck
 \widetilde{ST} revenue obtained from the sales of a second-hand trailer

Deterministic road, marine and rail travel distances:

- d_{ii}^r road travel distance between seaports in Turkey $i \in I$ and order country $l \in L$
 d_{jl}^r road travel distance between seaports in Europe $j \in J$ and order country $l \in L$
 d_{kl}^r road travel distance between railway stations $k \in D_k \cup T_k$ and order country $l \in L$
 d_{jk}^r road travel distance between seaports in Europe $j \in J$ and rail stations $k \in K$ for empty flows
 d_{kj}^r road travel distance between rail stations $k \in K$ and seaports in Europe $j \in J$ for empty flows
 $d_{j'j}^r$ road travel distance among the seaports themselves in Europe $j \in J$ for empty flows
 d_{ll}^r road travel distance among the order countries themselves $l \in L$ for empty flows
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$d_{i'l}^r$	road travel distance among the seaports themselves in Turkey $i \in I$ for empty flows
$d_{k'k}^r$	road travel distance among the railway stations themselves in Europe $k \in K$ for empty flows
$d_{k^*l}^r$	road travel distance between rail stations $k^* \in G_k$ and order country $l \in G_l$
d_{ij}^m	marine travel distance between seaports in Turkey and Europe, $(i, j) \in L_{ij} \cup C_{ij} \cup B_{ij}$
d_{jk}^r	railway travel distance between seaports in Europe and rail stations, $(j, k) \in L_{jk} \cup C_{jk} \cup B_{jk}$ and $k \notin G_k$
$d_{k'k^*}^r$	railway travel distance between transshipment and main stations, $(k', k^*) \in L_{k'k^*}$, $k' \in T_k$ and $k^* \in G_k$
<i>Fuzzy road, marine and rail transit times:</i>	
\tilde{T}_{il}^r	road transit time between seaports in Turkey $i \in I$ and order country $l \in L$
\tilde{T}_{lj}^r	road transit time between order country $l \in L$ and seaports in Europe $j \in J$
\tilde{T}_{kl}^r	road transit time between railway stations $k \in D_k \cup T_k$ and order country $l \in L$
\tilde{T}_{jk}^r	road transit time between seaports in Europe $j \in J$ and rail stations $k \in K$
\tilde{T}_{ij}^r	road transit time among the seaports themselves in Europe $j \in J$
$\tilde{T}_{l'l}^r$	road transit time among the order countries themselves $l \in L$
$\tilde{T}_{i'l}^r$	road transit time among the seaports themselves in Turkey $i \in I$
$\tilde{T}_{k'k}^r$	road transit time among the railway stations themselves in Europe $k \in K$
$\tilde{T}_{k^*l}^r$	road transit time between rail stations $k^* \in G_k$ and order country $l \in G_l$
\tilde{T}_{ij}^m	marine transit time between seaports in Turkey and Europe, $(i, j) \in L_{ij} \cup C_{ij} \cup B_{ij}$
\tilde{T}_{jk}^r	railway transit time between seaports and rail stations, $(j, k) \in L_{jk} \cup C_{jk} \cup B_{jk}$ and $k \notin G_k$
$\tilde{T}_{jk'}^r$	railway transit time between seaports in Europe and transshipment rail stations, $(j, k') \in C_{jk'}$ and $k' \in T_k$
$\tilde{T}_{k'k^*}^r$	railway transit time between transshipment and main stations, $(k', k^*) \in L_{k'k^*}$, $k' \in T_k$ and $k^* \in G_k$
<i>Fuzzy environmental impact parameters:</i>	
\tilde{CO}_2^M	amount of CO ₂ emissions (in kg) by marine transport services per km of per TU
\tilde{CO}_2^R	amount of CO ₂ emissions (in kg) of loaded truck positions by road transport per km of per TU
\tilde{CO}_2^{RE}	amount of CO ₂ emissions (in kg) of empty truck repositions by road transport per km
\tilde{CO}_2^T	amount of CO ₂ emissions (in kg) by railway transport services per km of per TU
<i>Stochastic transport demands and their parameters:</i>	
De_{ilt}^{exp}	random export transport demand of order country l from seaport in Turkey i in time period t
μ_{ilt}^{imp}	mean value of the import transport demand, De_{ilt}^{imp} (in TUs)
σ_{ilt}^{exp}	standard deviation of the export transport demand, De_{ilt}^{exp} (in TUs)
α_{ilt}	probability of chance-constrained set for probabilistic export transport demand satisfaction of order country l from seaport in Turkey i in time period t
β_{ilt}	probability of chance-constrained set for probabilistic import transport demand satisfaction of order country l to seaport in Turkey i in time period t
<i>Fuzzy capacities and lower/upper bounds in marine and railway transports:</i>	
\tilde{Cap}_{ji}^{imp}	transport capacity of a company-owned Ro-Ro vessel per trip of import operation on marine link $(j, i) \notin L_{ji}$
$\tilde{Cap}_{ij^*}^{exp}$	transport capacity of a company-owned Ro-Ro vessel per trip of export operation on marine link $(i, j^*) \notin L_{ij^*}$ by including a main destination seaport $j^* \in \gamma_j$
\tilde{N}_{jit}^{imp}	maximum number of import marine trips that can be performed by company-owned Ro-Ro vessels on marine link $(j, i) \notin L_{ji}$ in time period t
$\tilde{N}_{ij^*t}^{exp}$	maximum number of export marine trips that can be performed by company-owned Ro-Ro vessels to the main destination seaport in Europe $j^* \in \gamma_j$ in time period t
\tilde{UB}_{jkt}^{exp}	maximum number of export block train services on rail line $(j, k) \notin L_{jk}$ and $k \in D_k \cup T_k$ in period t
\tilde{LB}_{kjt}^{imp}	lower bounds on number of import block train services on rail line $(k, j) \notin L_{kj}$ and $k \in D_k \cup T_k$ in period t
\tilde{LB}_{ijt}^{exp}	lower bound on utilization rate of company-owned Ro-Ro vessels for export on $(i, j) \notin L_{ij}$ in period t
<i>Deterministic transport capacities of block trains:</i>	
Cap_{jk}^{exp}	transport capacity of a block train per service of export operation on rail line $(j, k) \notin L_{jk}$ and $k \in D_k$
$Cap_{k'j}^{imp}$	transport capacity of a block train per service of import operation on rail line $(k', j) \notin L_{k'j}$ by including a transshipment station, $k' \in T_k$
<i>Other deterministic and fuzzy parameters for truck and trailer fleet size optimization:</i>	
Γ	the duration (in hrs) of time period t
$\tilde{\phi}_{lt}$	number of working days at order country l in time period t
δ^E	the percent of time that a European plated truck is available
δ^T	the percent of time that a Turkish plated truck is available
ε	the percent of time that a trailer is available
<i>Deterministic initial truck and trailer inventory levels:</i>	
VJ_{j0}	number of European plated trucks initially allocated to seaport in Europe $j \in J$

VK_{k0}	number of European plated trucks initially allocated to railway station $k \in K$
VL_{l0}^E	number of European plated trucks initially allocated to order country $l \in L$
VL_{l0}^T	number of Turkish plated trucks initially allocated to order country $l \in L$
VI_{i0}^E	number of European plated trucks initially allocated to seaport in Turkey $i \in I$
VI_{i0}^T	number of Turkish plated trucks initially allocated to seaport in Turkey $i \in I$
TL_{l0}	number of trailers initially allocated to order country $l \in L$
TI_{i0}	number of trailers initially allocated to seaport in Turkey $i \in I$
<i>Decision variables:</i>	
<i>Different transport services and outsourcing:</i>	
X_{lit}^{exp}	export quantity of TUs shipped by direct road freight transport on road network $(l, l) \in I \cup L$ in period t
Y_{ijt}^{imp}	import quantity of TUs shipped by combined marine and road transport on marine link $(j, i) \in L_{jt} \cup C_{jt} \cup B_{jt}$ and road network $(l, j) \in L \cup J$ in time period t
$Y_{lj^*t}^{exp}$	export quantity of TUs shipped by combined marine and road transport to the order country $l \in L$ through the main destination seaport in Europe $j^* \in \gamma_j$ in time period t
$Y_{lj^*t}^{imp}$	import quantity of TUs shipped by combined marine and road transport from the order country $l \in L$ through the transshipment seaport in Europe $j^* \in T_j$ in time period t
Z_{ijklt}^{exp}	export quantity of TUs shipped by intermodal transport on marine link $(i, j) \in L_{ij} \cup C_{ij} \cup B_{ij}$ and rail line $(j, k) \in L_{jk} \cup C_{jk} \cup B_{jk}$ and then road network $(k, l) \in K \cup L$ in time period t
$Z_{lkj^*t}^{imp}$	import quantity of TUs shipped by intermodal transport from the order country $l \in L$ through the main origin seaport in Europe $j^* \in \gamma_j$ in time period t
$Z_{ij^*klt}^{exp}$	export quantity of TUs shipped by intermodal transport to the order country $l \in L$ through the transshipment seaport in Europe $j^* \in T_j$ in time period t
O_{lit}^{imp}	import quantity of TUs via outsourcing option from order country l to seaport in Turkey i in period t
<i>Specific marine transport variables:</i>	
MS_{ijt}^{exp}	number of trips by company-owned Ro-Ro vessels for export operation on marine link $(i, j) \notin L_{ij}$ in time period t
$MS_{j^*t}^{imp}$	number of trips by company-owned Ro-Ro vessels for import operation from the main origin seaport in Europe $j^* \in \gamma_j$ in time period t
R_{ijt}^{exp}	export quantity of TUs shipped by company-owned Ro-Ro vessels on marine link $(i, j) \notin L_{ij}$ in period t
$R_{j^*t}^{imp}$	import quantity of TUs shipped by company-owned Ro-Ro vessels from the main origin seaport in Europe $j^* \in \gamma_j$ in period t
P_{ijt}^{exp}	export quantity of TUs shipped by other logistics service providers' Ro-Ro vessels on $(i, j) \notin C_{ij}$ in period t
U_{jit}^{imp}	utilization rate of company-owned Ro-Ro vessels for import operation on $(j, i) \notin L_{ji}$ in time period t
<i>Specific rail transport variables:</i>	
S_{jkt}^{exp}	number of chartered block trains for export operation on rail line $(j, k) \notin L_{jk}$ in time period t
$S_{k^*jt}^{imp}$	number of chartered block trains for import from the transshipment railway station $k^* \in T_k$ in time period t
Pt_{jkt}^{exp}	export quantity of TUs shipped by public train services on rail line $(j, k) \in C_{jk}$ and $k \in G_k$ in period t
$Pt_{k^*k't}^{imp}$	import quantity of TUs shipped by public trains on rail line $(k^*, k') \mid k^* \in G_k$ and $k' \in T_k$ in period t
<i>Loaded truck positions on road transport network:</i>	
V_{jlt}^{exp}	number of loaded positions performed by European plated trucks for export operation on road transport network $(j, l) \in J \cup L$ in time period t
V_{lkt}^{imp}	number of loaded positions performed by European plated trucks for import operation on road transport network $(l, k) \in L \cup K$ in time period t
VE_{lit}^{exp}	number of loaded positions performed by European plated trucks for export operation on road transport network $(i, l) \in I \cup L$ in time period t
VT_{lit}^{exp}	number of loaded positions performed by Turkish plated trucks for export operation on road transport network $(i, l) \in I \cup L$ in time period t
<i>Truck and trailer fleet size and fleet allocation:</i>	
VS_{ijt}^{imp}	European plated truck fleet size for import operations on road transport network $(l, j) \in L \cup J$ in time period t
VS_{klt}^{exp}	European plated truck fleet size for export operations on road transport network $(k, l) \in K \cup L$ in time period t
EP_{lit}^{imp}	European plated truck fleet size for import operations on road transport network $(l, i) \in L \cup I$ in time period t
TP_{lit}^{exp}	Turkish plated truck fleet size for export operations on road transport network $(i, l) \in I \cup L$ in period t
TS_{lit}^{imp}	trailer fleet size required by all of the transportation modes for import operations between order country l and seaport in Turkey i in time period t
<i>Truck and trailer inventories on the intermodal logistics network:</i>	

VJ_{jt}	number of European plated trucks present at the seaport in Europe j in the end of time period t
VK_{kt}	number of European plated trucks present at the railway station k in the end of time period t
VL_{lt}^E	number of European plated trucks present at the order country l in the end of time period t
VL_{lt}^T	number of Turkish plated trucks present at the order country l in the end of time period t
VI_{it}^E	number of European plated trucks present at seaport in Turkey i in the end of time period t
VI_{it}^T	number of Turkish plated trucks present at the seaport in Turkey i in the end of time period t
TL_{lt}	number of trailers present at the order country l in the end of time period t
TI_{it}	number of trailers present at the seaport in Turkey i in the end of time period t
<i>Internal empty truck and trailer repositioning:</i>	
V_{jt}^{rep}	number of European plated internal empty truck repositions carried on road transport network $(j, l) \in J \cup L$ during time period t
V_{kl}^{rep}	number of European plated internal empty truck repositions carried on road transport network $(k, l) \in K \cup L$ during time period t
VE_{lt}^{rep}	number of European plated internal empty truck repositions carried on road transport network $(l, i) \in L \cup I$ during time period t
VT_{it}^{rep}	number of Turkish plated internal empty truck repositions carried on road transport network $(i, l) \in I \cup L$ during time period t
TR_{it}^{rep}	number of internal empty trailer repositions carried on road transport network $(i, l) \in I \cup L$ during period t
<i>External empty truck & trailer repositioning:</i>	
VR_{jt}^{rep}	number of European plated external empty truck repositions carried on $(j, l) \in J \cup L$ in time period t
VR_{kl}^{rep}	number of European plated external empty truck repositions carried on $(k, l) \in K \cup L$ in time period t
VR_{li}^{rep}	number of European plated external empty truck repositions carried on $(l, i) \in L \cup I$ in time period t
VRT_{it}^{rep}	number of Turkish plated external empty truck repositions carried on $(i, l) \in I \cup L$ in time period t
VR_{jkt}^{rep}	number of European plated external empty truck repositions carried on $(j, k) \in J \cup K$ in time period t
$VR_{jj't}^{rep}$	number of European plated external empty truck repositions carried among the seaports themselves in Europe $j \in J$ and $j' \in J \setminus \{j\}$ in time period t
$VR_{kk'k't}^{rep}$	number of European plated external empty truck repositions carried among the railway stations themselves in Europe $k \in K$ and $k' \in K \setminus \{k\}$ in time period t
$VR_{ll'l't}^{rep}$	number of European plated external empty truck repositions carried among the order countries themselves $l \in L$ and $l' \in L \setminus \{l\}$ in time period t
$VR_{ll'i't}^{rep}$	number of Turkish plated external empty truck repositions carried among the seaports themselves in Turkey $i \in I$ and $i' \in I \setminus \{i\}$ in time period t
$TR_{ll'l't}^{rep}$	number of Turkish plated external empty truck repositions with their own empty trailers carried among the order countries themselves $l \in L$ and $l' \in L \setminus \{l\}$ in time period t
$TR_{ll'i't}^{rep}$	number of external empty trailer repositions performed by Turkish plated trucks among the seaports themselves in Turkey $i \in I$ and $i' \in I \setminus \{i\}$ in time period t
$XTR_{ll't}^{rep}$	number of external empty trailer repositions performed by both European and Turkish plated trucks on road transport network $(i, l) \in I \cup L$ in time period t
<i>Idle trucks and trailers awaiting at different locations on the logistics network:</i>	
IVJ_{jt}	number of European plated idle trucks awaiting at seaport in Europe j in time period t
IVK_{kt}	number of European plated idle trucks awaiting at railway station k in time period t
IVL_{lt}^E	number of European plated idle trucks awaiting at order country l in time period t
IVL_{lt}^T	number of Turkish plated idle trucks awaiting at order country l in time period t
IVI_{it}^E	number of European plated idle trucks awaiting at seaport in Turkey i in time period t
IVL_{it}^T	number of Turkish plated idle trucks awaiting at seaport in Turkey i in time period t
ITI_{it}	number of idle trailers awaiting at seaport in Turkey i in time period t
ITL_{lt}	number of idle trailers awaiting at order country l in time period t
<i>Truck and trailer fleet expansion and reduction decisions:</i>	
Pr_{it}^T	purchasing quantity of Turkish plated new trucks at seaport in Turkey i in time period t
Pr_{it}^E	purchasing quantity of European plated new trucks at order country l in time period t
Pr_{it}	purchasing quantity of new trailers at seaport in Turkey i in time period t
Sp_{it}^T	sales quantity of Turkish plated second-hand trucks at seaport in Turkey i in time period t
Sp_{it}^E	sales quantity of European plated second-hand trucks at order country l in time period t
Sp_{it}	sales quantity of second-hand trailers at seaport in Turkey i in time period t
