## **Supplementary Materials**

## **A.1 Sets and indices, parameters and decision variables**

Sets and indices, parameters and decision variables used in the **Mathematical formulation** are listed as below:

*Sets and indices:*

*N* Set of all nodes, indexed by *i*, *j*, *l*

*K* Set of all orders, indexed by *k*

*M* Set of all transport modes including road, rail, and waterways, indexed by *m*

Set of origin of orders

Set of destination of orders

Set of speed levels of transport mode *m*,indexed by *v*

*Parameters:*

Variable cost of transporting one hazmat container on link *(i, j)* by transport mode *m,* at speed level *v*

Variable cost of transporting one non-hazmat container on link *(i, j)* by transport mode *m,* at speed level *v*

Distance between node *i* and *j* by transport mode *m*

Fixed cost of shipping commodities on link *(i, j)* by transport mode *m*

Speed of vehicle from transport mode *m* at speed level *v*

Upper limit of safe speed zone at link *(i, j)* by transport mode *m*

Lower limit of safe speed zone at link *(i, j)* by transport mode *m*

*TCj* Unit transfer cost for containers at terminal *j*

Number of hazmat containers in order *k* that is to be sent from *o(k)* to *d(k)*

Number of non-hazmat containers in order *k* that is to be sent from *o(k)* to *d(k)*

The capacity of link *(i, j)* by transport mode *m* (in containers)

The capacity of vehicles from transport mode *m* (in containers)

*Tk* The due date of order *k*

Time delay at terminal *j* for transferring a shipment from one transport mode to another mode

Lost sale cost for one hazmat container of order *k* (£/container)

Lost sale cost for one non-hazmat container of order *k* (£/container)

Emissions in kg for transferring one container from one transport mode to another at terminal *j*

Emissions in kg for shipping a container by transport mode *m* at speed level *v* (kg of CO2e/container-mile)

Socio-environmental cost conversion factor for emissions (£/kg)

Socio-environmental cost conversion factor for noise pollution in road travel at speed level *v* (£/container-mile)

Socio-environmental cost conversion factor for road congestion at speed level *v* (£/container-mile)

Social cost conversion factor for accidents in road travel at speed level *v* (£/container-mile)

Combined socio-environmental cost conversion factor for negative externalities in rail travel at speed level *v* (£/container-mile)

Combined socio-environmental cost conversion factor for negative externalities in waterway travel at speed level *v* (£/container-mile)

Unit delay cost for each time unit violated from due date, for order *k* (£/container)

Capacity underutilization penalty for one percentage of underutilized container in transport mode *m (*£*)*

Maximum number of containers can be transferred at terminal *j*

Probability of transportation accidents for a hazmat container on link (*i*, *j*) by transport mode *m* at speed level *v*

Consequence of transportation accidents for a hazmat container on link (*i*, *j*) by transport mode *m* at speed level *v*

Probability of transportation accidents for a hazmat container on link (*i*, *j*) by transport mode *m*, with 1 mph overspeeding

Consequence of transportation accidents for a hazmat container on link (*i*, *j*) by transport mode *m,* with 1 mph overspeeding

Probability of transportation accidents for a hazmat container on link (*i*, *j*) by transport mode *m*, with 1 mph underspeeding

Consequence of transportation accidents for a hazmat container on link (*i*, *j*) by transport mode *m,* with 1 mph underspeeding

Probability of transportation accidents for a hazmat container transferred at terminal *j*

Consequence of transportation accidents for a hazmat container transferred at terminal *j*

Probability of hazmat load-related accidents for a vehicle from transport mode *m* carrying a hazmat load on a link with the capacity utilization within interval *w*

Consequence of hazmat load-related accidents for a vehicle from transport mode *m* carrying a hazmat load on a link with the capacity utilization within interval *w*

The degree of overspeeding on link (*i, j*), by transport mode *m* passing at speed level *v* (mph)

The degree of underspeeding on link (*i, j*), by transport mode *m* passing at speed level *v* (mph)

Very small number

*Decision variables:*

Number of hazmat containers of order *k* on link (*i, j*) by transport mode *m* at speed level *v*

Number of non-hazmat containers of order *k* on link (*i, j*) by transport mode *m* at speed level *v*

The number of hazmat containers of order *k* transferred at terminal *j*

The number of non-hazmat containers of order *k* transferred at terminal *j*

Binary variable, equal to 1 if order *k* passes through (*i, j*) using transport mode *m* with speed level *v*; 0, otherwise

Number of hazmat containers of order *k* that cannot be satisfied

Number of non-hazmat containers of order *k* that cannot be satisfied

The required number of vehicles from transport mode *m* on link (*i, j*) passing with speed level *v*

Transportation delay of order *k*

Arrival time of order *k* at destination

Mean capacity utilization factor of transport mode *m*

Percentage of capacity of link (*i, j*) by transport mode *m* occupied by hazmat containers

Probability of hazmat load-related accidents on link (*i, j*) for a vehicle of transport mode *m*

Consequence of hazmat load-related accidents on link (*i, j*) for a vehicle of transport mode *m*