A multi-modal vehicle routing model for post-disaster relief supply in inaccessible mountainous regions

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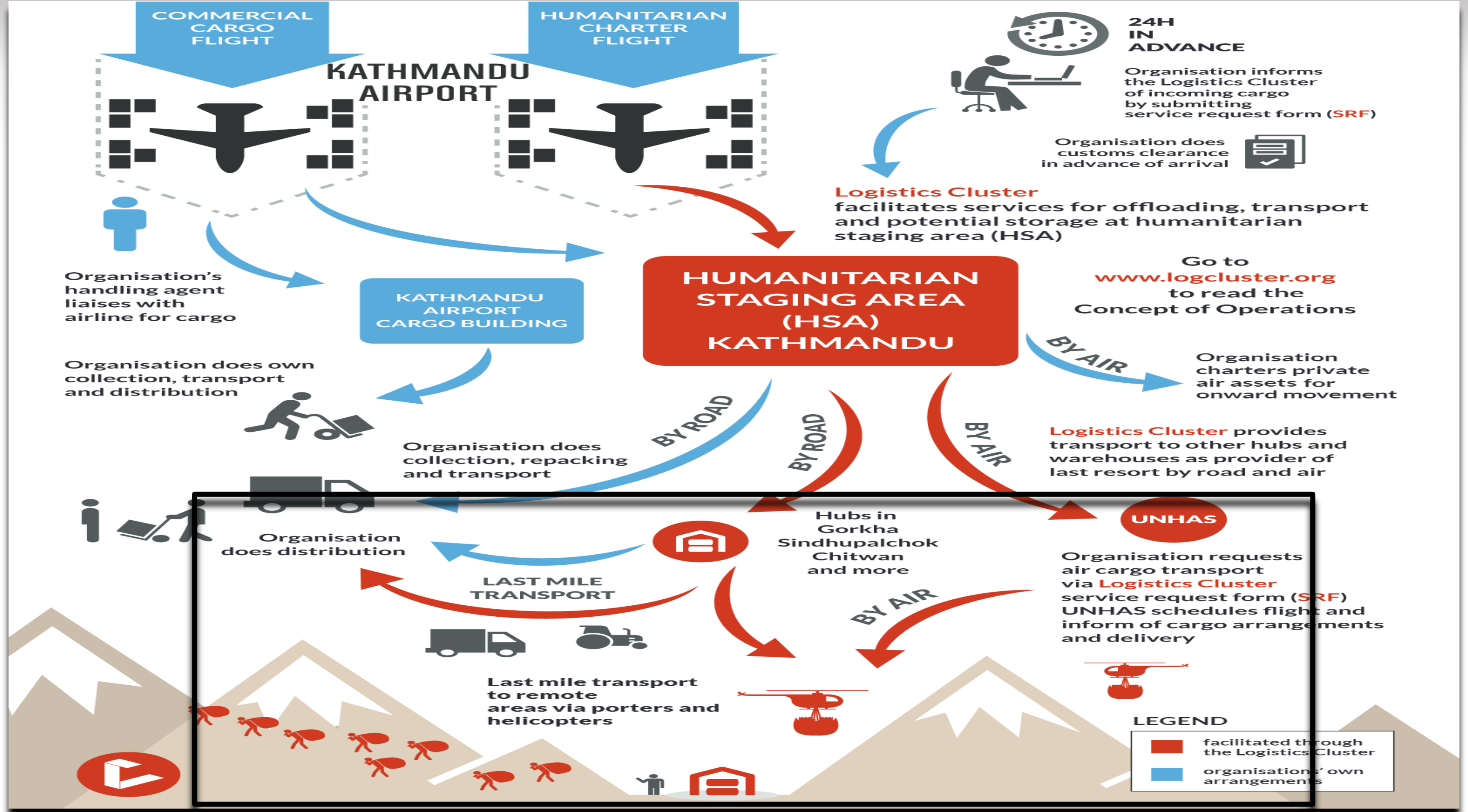
Motivation (Nepal Earthquake)

- On 25 April 2015, an earthquake (7.8 Richter scale) was recorded in Nepal
- A second major earthquake (7.3 Richter scale) registered on 12 May 2015
- Killed more than 8,800 and injured nearly three times as many people
- 2.8 million people were in need of assistance due to the earthquake
- **Large population in mountainous, remote and difficult-to-reach areas.**

Motivation (Nepal Earthquake)

- On 27th April 2015, Logistic Cluster, Kathmandu was activated
- Logistic Cluster is a coordination mechanism hosted by WFP -UN (World Food Program)
- Activated to fill response and coordination gaps in addressing humanitarian needs
- To support the humanitarian community a number of logistics services were set up-
- **Storage**
- **Air transport**
- **Road transport**
- **Remote Access Operation (RAO)**


COMMERCIAL CARGO FLIGHT
HUMANITARIAN CHARTER FLIGHT
KATHMANDU AIRPORT
24H IN ADVANCE
Organisation informs the Logistics Cluster of incoming cargo by submitting service request form (SRF)
Organisation does customs clearance in advance of arrival
Logistics Cluster facilitates services for offloading, transport and potential storage at humanitarian staging area (HSA)
Organisation's handling agent liaises with airline for cargo
KATHMANDU AIRPORT CARGO BUILDING
HUMANITARIAN STAGING AREA (HSA) KATHMANDU
Go to www.logcluster.org to read the Concept of Operations
Organisation does own collection, transport and distribution
BY AIR
Organisation charters private air assets for onward movement
BY ROAD
BY ROAD
BY AIR
Logistics Cluster provides transport to other hubs and warehouses as provider of last resort by road and air
Organisation does collection, repacking and transport
Hubs in Gorkha Sindhupalchok Chitwan and more
UNHAS
Organisation does distribution
LAST MILE TRANSPORT
BY AIR
Organisation requests air cargo transport via Logistics Cluster service request form (SRF) UNHAS schedules flight and inform of cargo arrangements and delivery
Last mile transport to remote areas via porters and helicopters
LEGEND
facilitated through the Logistics Cluster
organisations' own arrangements

Motivation (Nepal Earthquake)

Remote Access Operation (RAO)

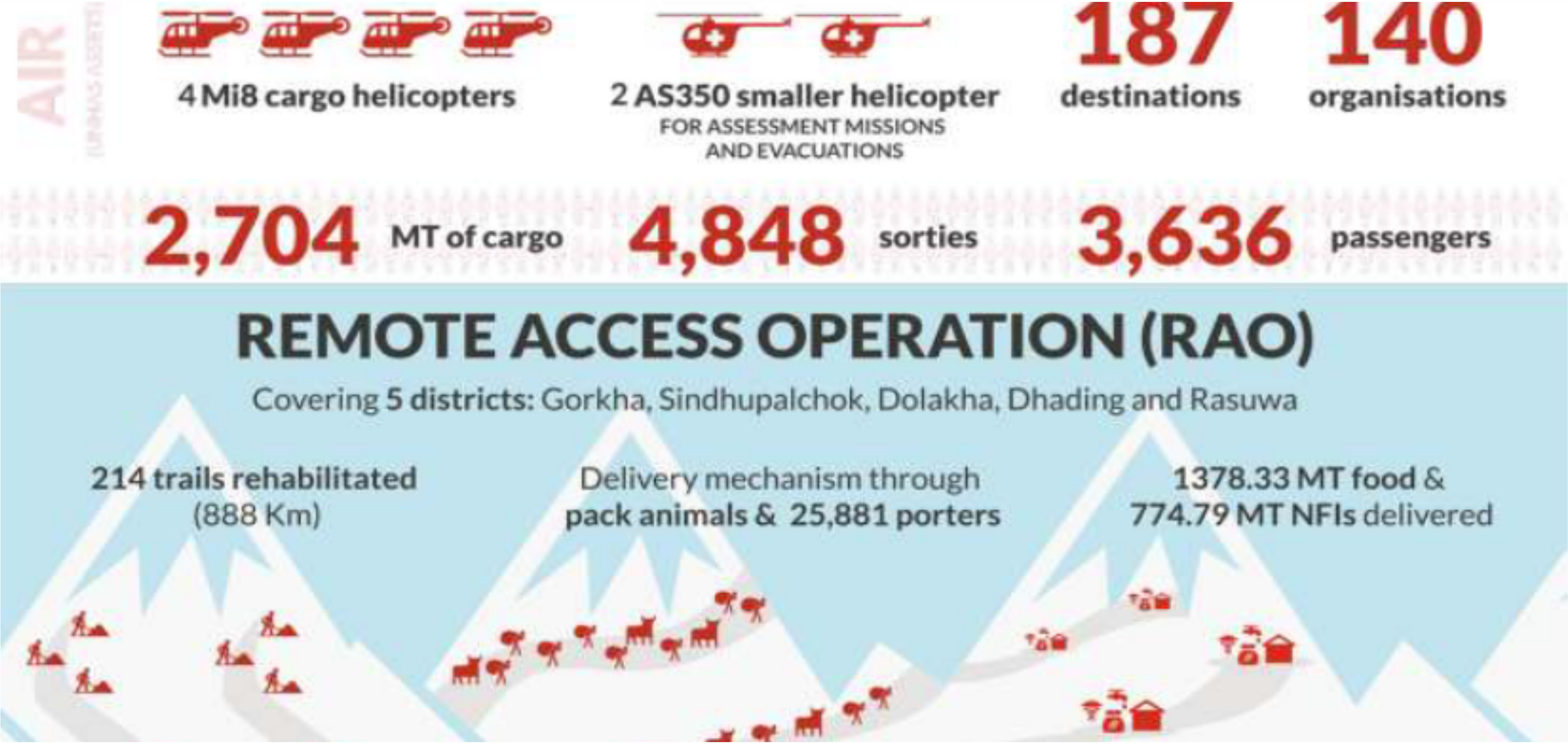
- To facilitate access to areas inaccessible by road transport and by air
- Provide all aid requirements including shelter items, food and WASH
- Relief supplies with porters and pack animals was set-up to these areas

Motivation (Nepal Earthquake)

Remote Access Operation (RAO)

- 20,000 porters & mules from Trekking Assoc. of Nepal & Nepal Mountaineering Assoc.
- 5 Mi8 cargo helicopters & 3 smaller AS 350 helicopters up to an altitude of 3,500 meters
- Cargo & porters delivered to landing zones at forward locations for onward movement
- 5 districts covered : Gorkha, Dhading, Rasuwa, Sindhupalchok and Dolakha

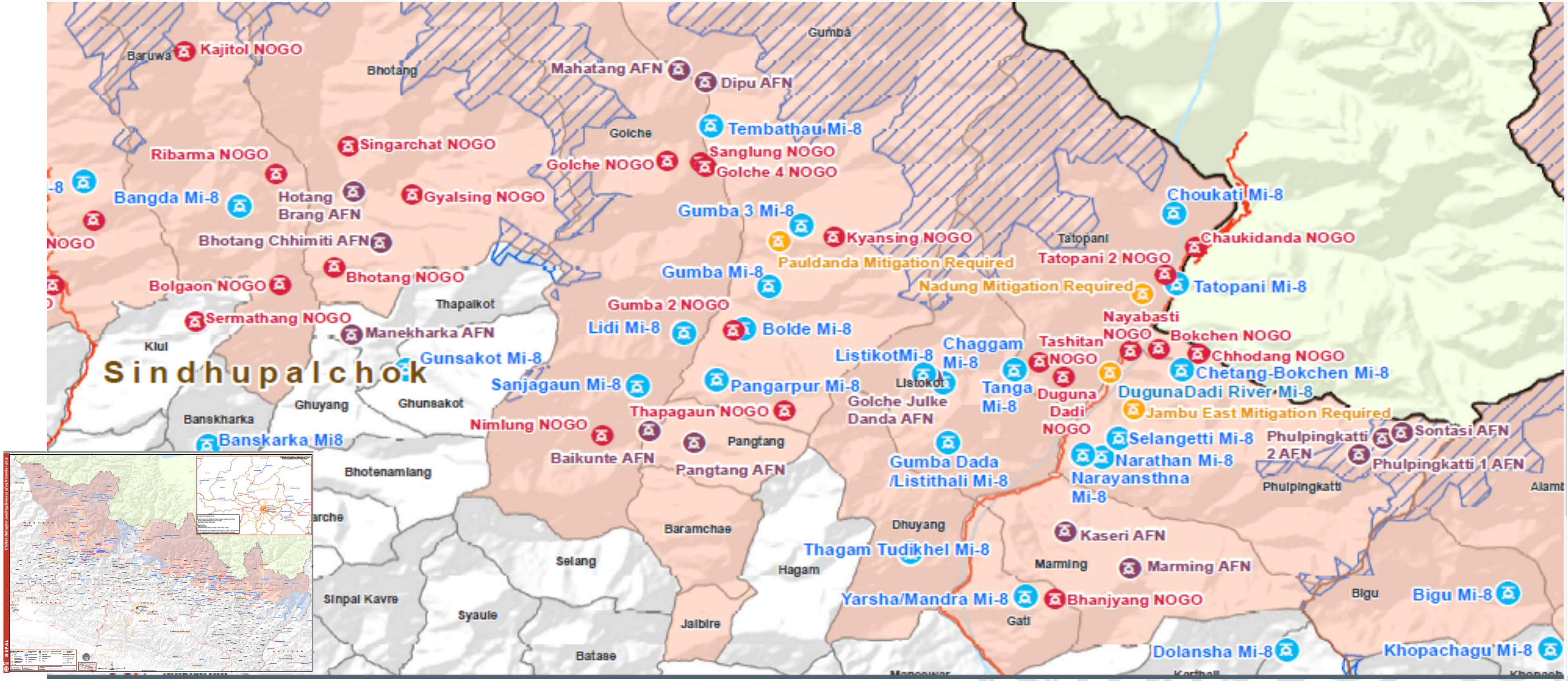
Motivation (Nepal Earthquake)



Model Requirements

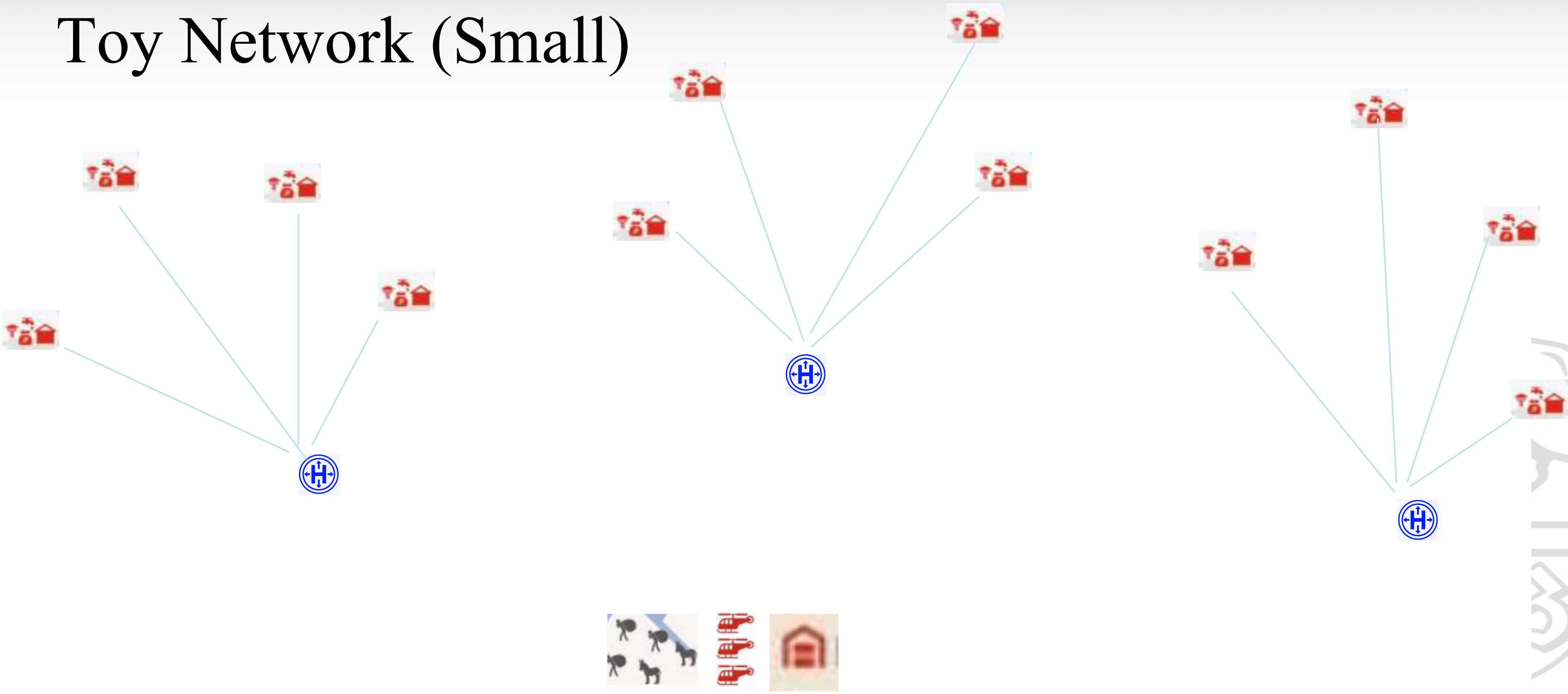
- **Vehicle routing** : two sets of routing, one for helicopters & other for porters/mules
- **Helicopter network** : b/w district headquarter (depot) & helicopter landing zones(HLZ)
- **Porter network** : between landing zones and villages along the mountain trails
- **Multi-modal** : last mile deliveries using porters & mules in conjunction with choppers
- **Multi-period** : relief supply to be done for multiple periods over a period of a month or 2
- **Mode Delivery** : porter transport b/w HLZ's via chopper in case of scarcity of porters
- **Coordination** : coordination of time and relief supply b/w the 2 networks at the HLZ's

Helicopter Network



Porter Network (Mountain Trails)

Toy Network (Small)



Model – Decision Variables

$x^t_{ijk} \in \{0,1\}$, 1 if there is porter/animal pack k from node *i* to node *j* in period t, and 0 otherwise,
$y^t_{ijl} \in \{0,1\}$, 1 if there is helicopter l from node *i* to node *j* in period t, and 0 otherwise,
$z^t_{ijk} \in \{0,1,2,3\ldots\ldots\ldots\}$,is the load transferred by porter k from node *i* to node *j* in period t
$v^t_{ijl} \in \{0,1,2,3\ldots\ldots\ldots\}$,is the load transferred by helicopter l from node *i* to node *j* in period t

$r^t_{ik} \in \{0,1\}$, if there is porter/animal pack k at HLZ *i* in period t, and 0 otherwise,
d^t_i Load dropped by porters at node *i* in time period t
D^t_i Load dropped by helicopters at node *i* in time period t

$i \neq j; i, j \in V = \{0,1,\ldots, N,\}$
$i, j \in S = \{,\ldots\ldots\ldots\} =$ (set of nodes with Helicopter landing zones/ Depots for porter network
i,j =0 is the depot for helicopters.
t $\in$ {0,1,……..P} is the time period

Model – Parameters

K total number of porters/animal packs to be carried to one depot
L total number of helicopters
N total number of nodes (villages)
H total number of nodes with Helicopter Landing Zone/ number of depots (for porters)
a_{ij} Travel time for a porter/animal pack between node i and j
h_{ij} Travel time for a helicopter between node i and j
m_i Demand at node i
qk capacity of porter/ animal pack k
ql capacity of a helicopter
ei service time for a helicopter i
fi service time for a porter pack at node i
gi service time for a helicopter at node i
rk maximum route distance allowed for porter pack k
rh maximum route time allowed for helicopter h
sk average speed of a porter pack k

Model – Objective

- **Minimize total time of travel in the network/ total cost**

Arc lengths

Arcs travelled

$$\sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1, i \neq j}^{HK} a_{ij} x_{ijk}^{t} + \sum_{i \in S} \sum_{j \in S, j \neq i} \sum_{l=1}^{H} h_{ij} y_{ijl}^{t}$$

Arc lengths

Arc lengths

Model – Constraint

- **Cycling Constraints**

$$\sum_{i \in S} y_{ijl}^{t} = \sum_{i \in S} y_{jil}^{t} \qquad for\ \ j \in S \,\&\, l \in (1,2,\ldots L) \,\&\, t \in (1,2,\ldots P)$$

$$\sum_{j \in S} y_{jil}^{t} \leq 1 \qquad for\ \ i \in S \,\&\, l \in (1,2 \ldots L) \,\&\, t \in (1,2,\ldots P)$$

$$\sum_{i \in V} x_{ijk}^{t} = \sum_{i \in V} x_{jik}^{t} \qquad for\ \ j \in V \,\&\, k \in (1,2,\ldots KH) \,\&\, t \in (1,2,\ldots P)$$

$$\sum_{j \in V} x_{jik}^{t} \leq 1 \qquad for\ \ i \in V \,\&\, k \in (1,2,\ldots KH) \,\&\, t \in (1,2,\ldots P)$$

Model – Constraint

- **Sub-tour elimination constraints**

$$\sum_{i\in W}\sum_{j\in W, j\neq i} y_{ijl}^{t} \leq |n_w| - 1 \quad for\ W \subseteq V - S \quad for\ l \in (1,2,\dots L)\ \&\ t \in (1,2,\dots P)$$

$$\sum_{i\in U}\sum_{j\in U, j\neq i} x_{ijk}^{t} \leq |n_U| - 1 \quad for\ U \subseteq S - \{0\} \quad for\ K \in (1,2,\dots KH)\ \&\ t \in (1,2,\dots P)$$

Model – Constraint

- **Relation b/w movement and load variables**

$$z_{ijk}^{t} \geq x_{ijk}^{t} \qquad for\ i \in V\ \&\ j \in V\ \&\ k \in (1,2, \ldots KH)$$

$$z_{ijk}^{t} \leq Mx_{ijk}^{t} \qquad for\ i \in V\ \&\ j \in V\ \&\ k \in (1,2, \ldots KH)$$

$$v_{ijl}^{t} \geq y_{ijl}^{t} \qquad for\ i \in S\ \&\ j \in S + \{0\}\ \&\ l \in (1,2, \ldots L)\ \&\ k \in (1,2, \ldots KH)$$

$$v_{ijl}^{t} \leq My_{ijl}^{t} \qquad for\ i \in S\ \&\ j \in S + \{0\}\ \&\ l \in (1,2, \ldots L)\ \&\ k \in (1,2, \ldots KH)$$

Model – Constraint

- **Capacity and time constraint**

$$\sum_{j \in S} v_{ijl}^{t} \leq q_k \qquad for\ i = 0, l \in (1,2,\ldots L)\ \&t \in (1,2,\ldots P)$$

$$\sum_{i \in S} \sum_{j \in S, j \neq i} y_{ijl}^{t}(h_{ij} + g_i) \leq r_h \qquad for\ l \in (1,2,\ldots L)\ \&t \in (1,2,\ldots P)$$

$$\sum_{j \in V-S} z_{ijk}^{t} \leq q_l \qquad for\ i \in S\ k \in (1,2,\ldots KH)\ \&t \in (1,2,\ldots P)$$

$$\sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} x_{ijk}^{t}(t_{ij} + f_i) \leq r_k / s_k \qquad for\ k \in (1,2,\ldots KH)\ \&t \in (1,2,\ldots P)$$

Model – Constraint

- **For a porter one or less arc coming into HLZ in a period**

$$\sum_{i \in V} x_{ijk}^{t} \leq 1 \qquad for\ j \in S\ \&\ k \in (1,2,\ldots KH)\ \ \&\ t \in (1,2,\ldots P)$$

- **No porter going from one HLZ to another in any period**

$$x_{ijk}^{t} = 0 \qquad for\ i \in S\ \&\ j \in S\ \&\ k \in (1,2,\ldots KH)\ \&\ t \in (1,2,\ldots P)$$

Model – Constraint

- **Relief supply coordination at HLZ's and demand constraint**

$$\sum_{k=1}^{K*H} \sum_{j \in V-S, i \neq j} z_{ijk}^{t} - \sum_{k=1}^{K*H} \sum_{j \in V-S, i \neq j} z_{jik}^{t} = d_i^t \qquad for\ i \in V-S$$

$$\sum_{l=1}^{L} \sum_{j \in S, i \neq j} v_{ijl}^{t} - \sum_{l=1}^{L} \sum_{j \in S, i \neq j} v_{jil}^{t} = D_i^t \qquad for\ i \in S$$

$$D_i^t = \sum_{k=1}^{KH} \sum_{j \in S} z_{ijk} + d_i^t \qquad for\ i \in S$$

$$D_0^t = 0$$

$$\sum_{t=1}^{P} d_i^t \geq m_i \quad for\ \ i \in V$$

Model – Constraint

- **Load variable equal to zero for arcs entering HLZ**

$$z_{ijk}^{t} = 0 \qquad for\ \ i \in V - S \,\&\, j \in S \,\&\, k \in (1,2,\ldots KH) \,\&\, t \in (1,2,\ldots P)$$

- **Load variable equal to zero for arcs entering depot**

$$v_{ijl}^{t} = 0 \qquad for\ \ i \in V - S \,\&\, j \in S \,\&\, l \in (1,2,\ldots l) \,\&\, t \in (1,2,\ldots P)$$

Model – Constraint

- **Porter and HLZ relation in a time period**

$$r_{ik}^{t} \geq x_{ijk}^{t} \qquad for\ \ i \in S - \{0\}\ \&\ j\ \in V\ \ \&\ k \in (\,1{,}2, \ldots KH)\ \&\ t \in (\,1{,}2, \ldots P)$$

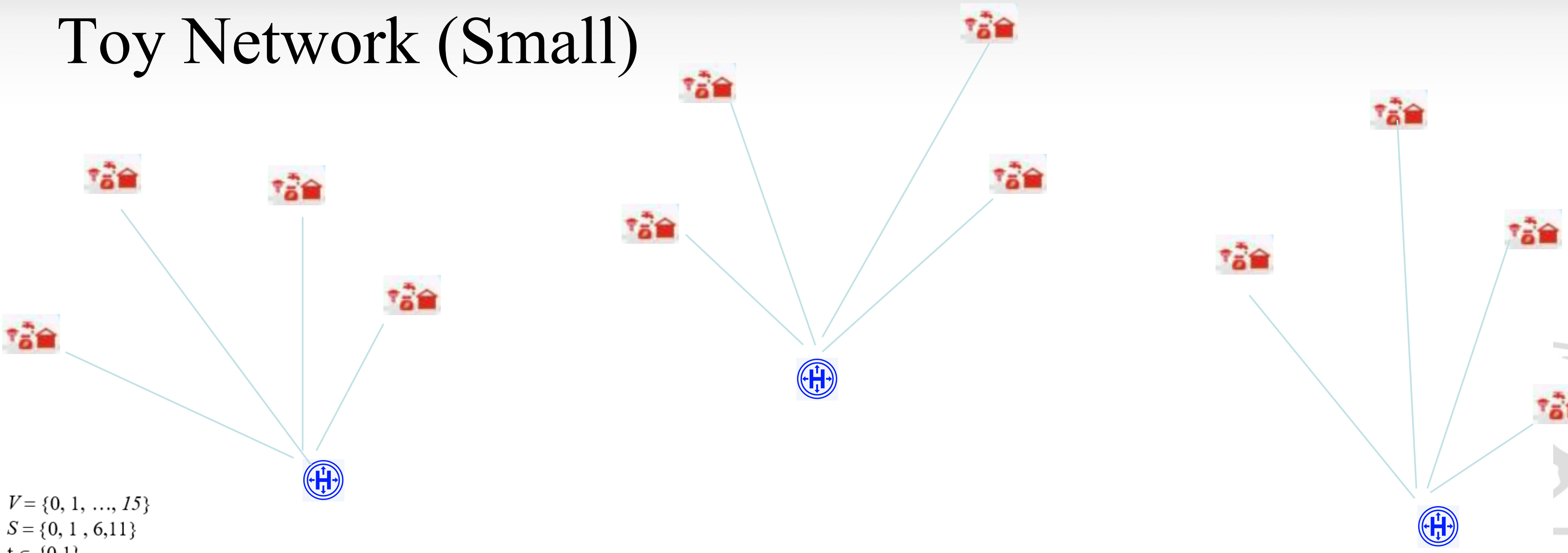
- **One Porter for one HLZ in time period**

$$\sum_{i \in S-\{0\}} r_{ik}^{t} \ = 0 \qquad for\ \ j\ \in V\ \ \&\ k \in (\,1{,}2, \ldots KH)\ \&\ t \in (\,1{,}2, \ldots P)$$

- **Constraint to transfer porter via chopper**

$$\sum_{(l=1)}^{L} y_{ijl}^{t+1} - r_{ik}^{t} - r_{ik}^{t+1} \leq 1 \qquad for\ i\ \in S - \{0\}\ \&\ j\ \in S - \{0\}\ \&\ k \in (\,1{,}2, \ldots KH)\ \&\ t \in (\,1{,}2, \ldots P)$$

Toy Network (Small)

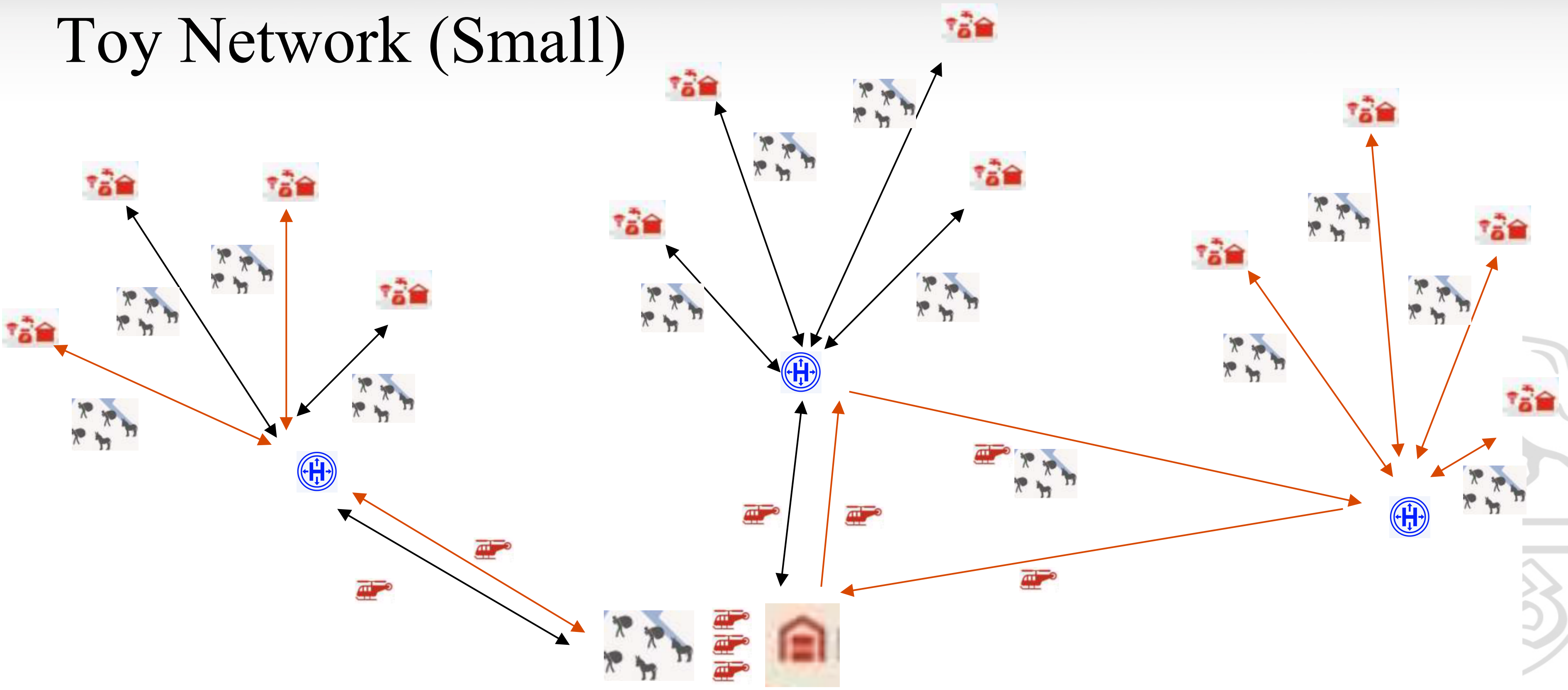


$V = \{0, 1, \ldots, 15\}$
$S = \{0, 1, 6, 11\}$
$t \in \{0,1\}$
$K = 2$
$L = 2$
$N = 2$
$H = 3$
m_i 30 kg
qk 30 kg
ql 150 kg

Solution

xijkt	xijkt2	zijkt	yijlt	vijlt	rikt	dit	dit2	Dit3
x.1.2.2.1	x.7.6.5.0	z.1.2.2.1	y.0.1.0.1	v.0.1.0.1	r.1.1.0	d.1.1	d.13.1	D.1.0
1	1	30	1	90	1	30	30	60
x.1.3.1.1	x.8.6.0.0	z.1.3.1.1	y.0.1.1.0	v.0.1.1.0	r.1.1.1	d.2.1	d.14.1	D.1.1
1	1	30	1	60	1	30	30	90
x.1.4.2.0	x.9.6.4.0	z.1.4.2.0	y.0.6.0.0	v.0.6.0.0	r.1.2.0	d.3.1	d.15.1	D.6.0
1	1	30	1	150	1	30		150
x.1.5.1.0	x.10.6.3.0	z.1.5.1.0	y.0.6.1.1	v.0.6.1.1	r.1.2.1	d.4.0		D.11.1
1	1	30	1	150	1	30		150
x.2.1.2.1	x.11.12.4.1	z.6.7.5.0	y.1.0.0.1	v.6.11.1.1	r.6.0.0	d.5.0		
1	1	30	1	150	1	30		
x.3.1.1.1	x.11.13.0.1	z.6.8.0.0	y.1.0.1.0		r.6.3.0	d.6.0		
1	1	30	1		1	30		
x.4.1.2.0	x.11.14.5.1	z.6.9.4.0	y.6.0.0.0		r.6.4.0	d.7.0		
1	1	30	1		1	30		
x.5.1.1.0	x.11.15.3.1	z.6.10.3.0	y.6.11.1.1		r.6.5.0	d.8.0		
1	1	30	1		1	30		
x.6.7.5.0	x.12.11.4.1	z.11.12.4.1	y.11.0.1.1		r.11.0.1	d.9.0		
1	1	30	1		1	30		
x.6.8.0.0	x.13.11.0.1	z.11.13.0.1			r.11.3.1	d.10.0		
1	1	30			1	30		
x.6.9.4.0	x.14.11.5.1	z.11.14.5.1			r.11.4.1	d.11.1		
1	1	30			1	30		
x.6.10.3.0	x.15.11.3.1	z.11.15.3.1				d.12.1		
1		30				30		

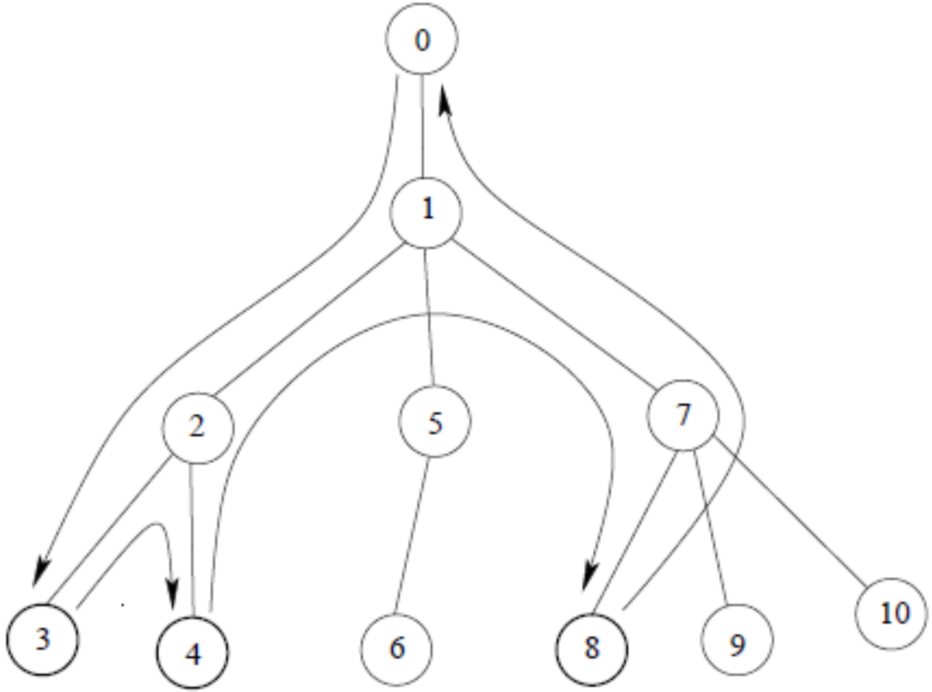
Toy Network (Small)



Porter Network (Mountain Trails)

Alternate Solution method

- Depth first numbering of the nodes
- Shortest path when one follows the order of numbers

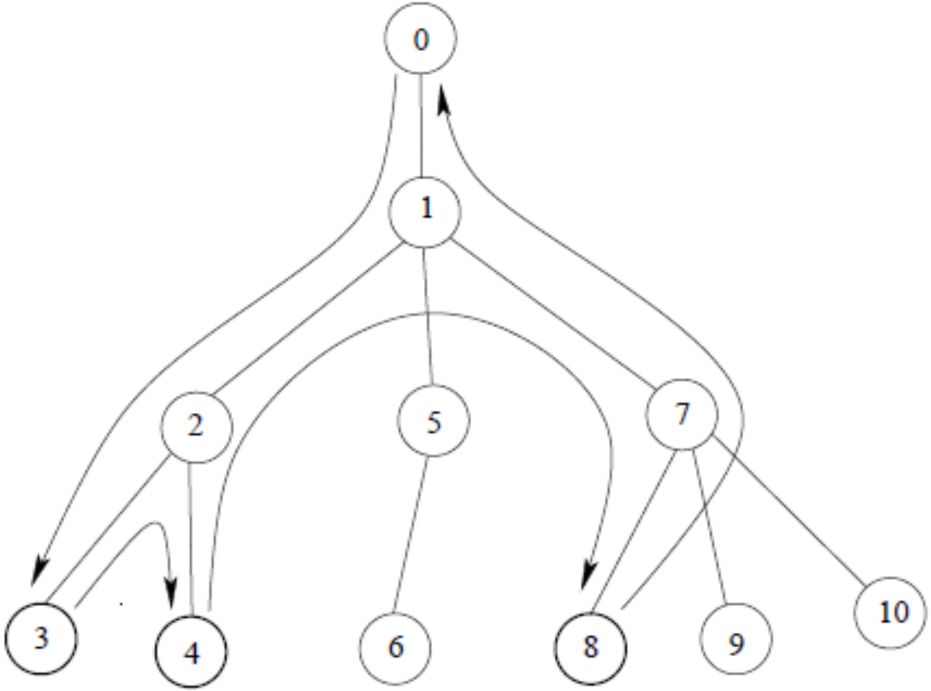


Alternate Solution method

- **Solution Approach for porter network**

Decide a vehicle “k” would serves which nodes

Route route for each vehicle followed by the depth first rule.



Future Plan

- Applying the (Depth First Rule) new approach for solution
- Dividing demand and load variables into its components like shelter material, food etc.
- A model for HLZ selection from a vast number of available HLZ's

THANK YOU

ANY QUESTIONS?