Stochastic Service Network Design with Different Operational Patterns for Hyperconnected Relay Transportation

Abstract: *Hyperconnected relay transportation enables using a relay system of short-haul drivers to deliver long-haul shipments collectively, which helps address root causes of trucker shortage issues by transforming working conditions with potentials of daily returning home, accessing consistent schedules, and facilitating load matching. This paper investigates hyperconnected relay transportation as a sustainable solution to trucker shortage issues through a logistics platform. We propose a two-stage programming model to optimize consistent working schedules for short-haul drivers while minimizing transportation costs. The first stage involves opening services and contracting truckers under demand uncertainty, where each service has a service route and approximate service schedules adhering to USA federal short-haul hour-of-service regulations. The second stage assigns hauling capacities to open services and manages commodity shipping or outsourcing given the demand realization. We extend the model formulation to account for various operational patterns (e.g., freight loading and unloading or hauler swapping) and schedule consistency requirements (e.g., weekly or daily consistency). A scenario-based approach is employed to solve the model for a case study of automotive delivery in the Southeast USA region. The experimental results validate the proposed approach, and further explore the impact of stochastic demands, operational patterns, consistent schedules, and hauling capacities on hyperconnected service network design. This research aims to offer practical guidance to practitioners in the trucking industry.*

Keywords: *Hyperconnected Relay Transportation; Logistics Platform; Stochastic Service Network Design; Short-Haul Truckers; Hour-of-Service Regulations; Demand Uncertainty; Operational Patterns; Consistent Schedules; Hauling Capacities; Physical Internet*

Conference Topic(s): *Interconnected Freight Transport*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper: ☐ PI Nodes, ☒ PI Networks, ☐ System of Logistics Networks, ☐ Access and Adoption, ☐ Governance.*

1 Introduction

2 Related Literature

3 Methodology

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J$_s$ 2$_s^c$

3.1 Two-Stage Stochastic Programming Formulation

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K$_s$

; 4 :

L$_k$#M' N$_{ka}$#M' O$_{su}$#M' L$_k$#M'

C M N$_{ka}$#M'

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A

; M

P(R S$_{s\in\mathcal{S}}$J$_s^f$K$_s$) T$_{w\in\mathcal{W}}$US$_{s\in\mathcal{S},u\in\mathcal{U}}J_{su}^vO_{su}$#M') S$_{k\in\mathcal{K}}J_k^oL_k$#M'V (1)

$s.t.$

$0 \le X_s \le q_s$ $\forall\, s \in \mathcal{S}$ (2)

S$_{u\in\mathcal{U}}Y_{su}$#w' $\le X_s$ $\forall\, s \in \mathcal{S}, w \in \mathcal{W}$ (3)

S$_{s\in\boldsymbol{S}_a,u\in\mathcal{U}}AO_{su}$#M' W S$_{k\in\mathcal{K}}N_{ka}$#M' X5 4 &^{M}M 4 Z #['

S$_{a\in\boldsymbol{A}:n_a^2=n}F_{ka}$#$w$' $-$ S$_{a\in\boldsymbol{A}:n_a^1=n}F_{ka}$#$w$' = \ v_k#w'#Z_k#w' $-$ 1', $if\ \ n =$ #o_k, t_k^e' ; v_k#w'6$1 - Z_k$#w'7, $if\ \ n =$ 6d_k, t_k^d7 ; $0, otherwise$

$\forall k \in \mathcal{K}, n \in \mathcal{N}, w \in \mathcal{W}$ (5)

3.2 Model variants

K$_s$ O$_{su}$#M' as integer

variables $L_k(M) \in \{0,1\}$ $N_{ka}(M)$
C 5 M

$$\sum_{s\in \boldsymbol{S}_a, u\in \boldsymbol{U}} u Y_{su}(w) \geq \sum_{k\in \boldsymbol{K}} v_k(w) F_{ka}(w) \quad \forall\, a \in \mathcal{A}^M, w \in \mathcal{W} \quad (4')$$

$$\sum_{a\in \boldsymbol{A}: n_a^2 = n} F_{ka}(w) - \sum_{a\in \boldsymbol{A}: n_a^1 = n} F_{ka}(w) = \begin{cases} Z_k(w) - 1, if\ \ n = (o_k, t_k^e) \\ 1 - Z_k(w), if\ \ n = (d_k, t_k^d) \\ 0, otherwise \end{cases}$$

$$\forall k \in \mathcal{K}, n \in \mathcal{N}, w \in \mathcal{W} \quad (5')$$

K_s $O_{ku}(M)$ $N_{ku}(M)$
K_s
; $O_{ku}(M)$ A C M
O ;
C $N_{ku}(M)$
C 5 M $L_k(M)$

$$\min \sum_{s\in\mathcal{S}} J_s^f K_s + T_{w\in\mathcal{W}} \left[\sum_{k\in \boldsymbol{K}, u\in \boldsymbol{U}} c_{ku}^v Y_{ku}(w) + \sum_{k\in \boldsymbol{K}} J_k^o L_k(M) \right] \quad (1'')$$

$s.t.$

$$0 \leq X_s \leq x_s^{max} \quad \forall\, s \in \mathcal{S} \quad (2'')$$

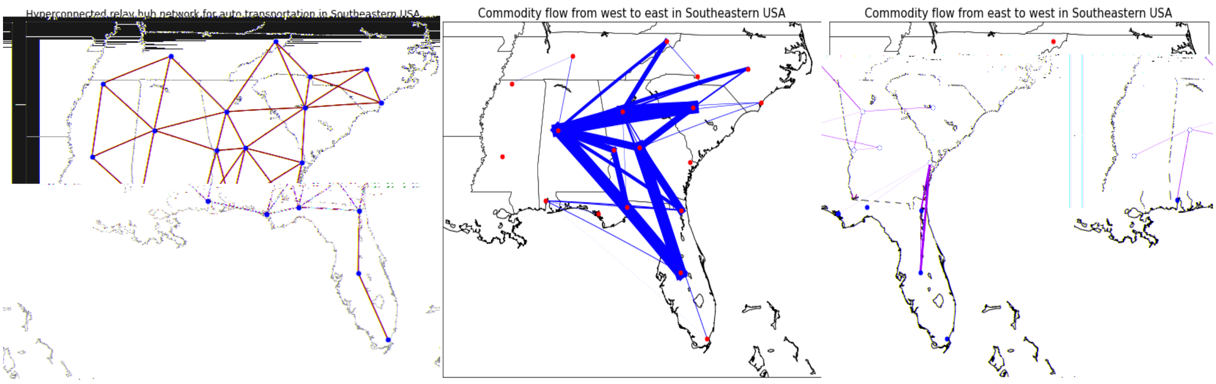
$$\sum_{k\in \boldsymbol{K}} F_{ka}(w) \leq \sum_{s\in \boldsymbol{S}_a} K_s \quad \forall\, a \in \mathcal{A}^M, w \in \mathcal{W} \quad (3'')$$

$$\sum_{u\in\mathcal{U}} A O_{ku}(M)\ W\ v_k(w)(1 - Z_k(w)) \quad \forall\, s \in \mathcal{S}, w \in \mathcal{W} \quad ([''')$$

$$\sum_{a\in \boldsymbol{A}: n_a^2 = n} F_{ka}(w) - \sum_{a\in \boldsymbol{A}: n_a^1 = n} F_{ka}(w) = \begin{cases} -\sum_{u\in\mathcal{K}} Y_{ku}(M), if\ \ n = (o_k, t_k^e) \\ \sum_{u\in\mathcal{K}} Y_{ku}(M), if\ \ n = (d_k, t_k^d) \\ 0, otherwise \end{cases}$$

$$\forall k \in \mathcal{K}, n \in \mathcal{N}, w \in \mathcal{W} \quad (5'')$$

4 Results and Discussion



F 1: H c c b , c a a (b) a (a)

Tab 1: T a a

H c ac ($)	29	*H -8 a a ($)*	10
H ac a ($)	18	*H -4 a a ($)*	5
O c c c ($)	0.93	*A a*	50
C ac c ca ac c	10	*C c c c ac*	0.8

Tab 2: C a c . c a c a c a c

KPIs \ Demand patterns	*D c*	*S c a c*
T a c ac [redacted] [redacted] *( )*	9,408	12,444
A a a ac ( )	8,023	9,285
A a a a ( )	8,023	9,285
A a c a c [redacted]	10.3%	0%
T a c [redacted] *a a c ($)*	556,494	422,985

Tab 3: C a c a c a a a

KPIs \ Operational patterns	*FLU-MCP*	*FLU-SCP*	*HS*
T a c ac [redacted] [redacted] *( )*	12,444	12,864	12,528
A a a ac ( )	9,285	9,312	12,528
A a a a ( )	9,285	9,312	955.2
A a c a c [redacted]	0%	0%	1.3%
T a c [redacted] *a a c ($)*	422,985	431,880	492,742

Tab 4: C a . a c c c a c

Consistent patterns	*W*		*Da*	
KPIs \ Hauling capacity	*F* [redacted]	*Va*	*F* [redacted]	*Va*
T a c ac [redacted] [redacted] *( )*	12,444	12,348	13,500	13,620
A a a ac ( )	9,286	10,562	9,456	11,045
A a a a ( )	9,286	10,562	9,456	110,45
A a c a c [redacted]	0%	0%	0%	0%
T a c [redacted] *a a c ($)*	422,985	418,253	357,840	355,152

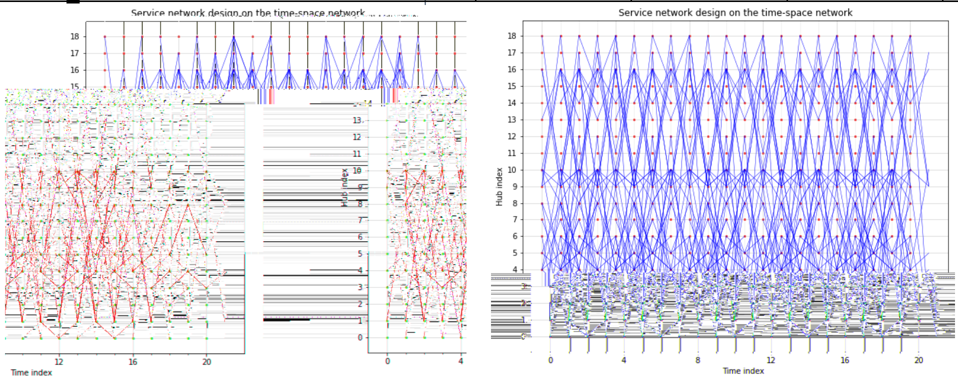
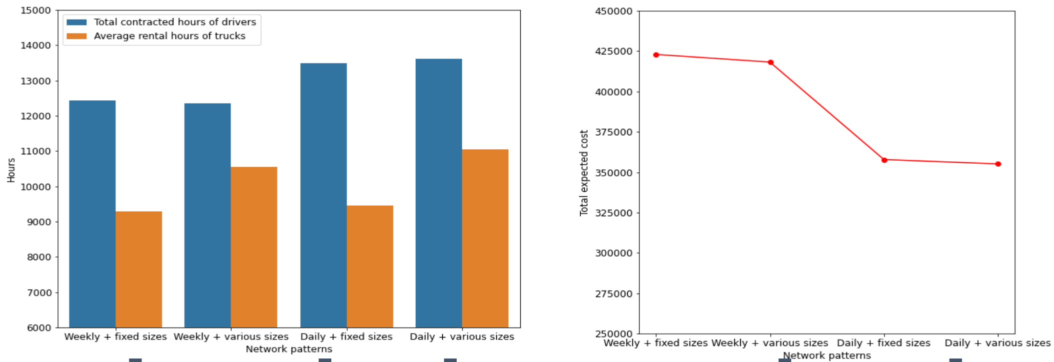


Figure 2: open services of model designs with weekly consistency (left) vs. daily consistency (right)



F 3: T a [redacted] *c ac* [redacted] *a* [redacted] *c a ( ) a* [redacted] *a c* [redacted] *c ( )*

5 Conclusion

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