Optimization of Fleet Profile - Circulation Dispatch at *The Washington Post*

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SYST 798/OR 680

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The Washington Post

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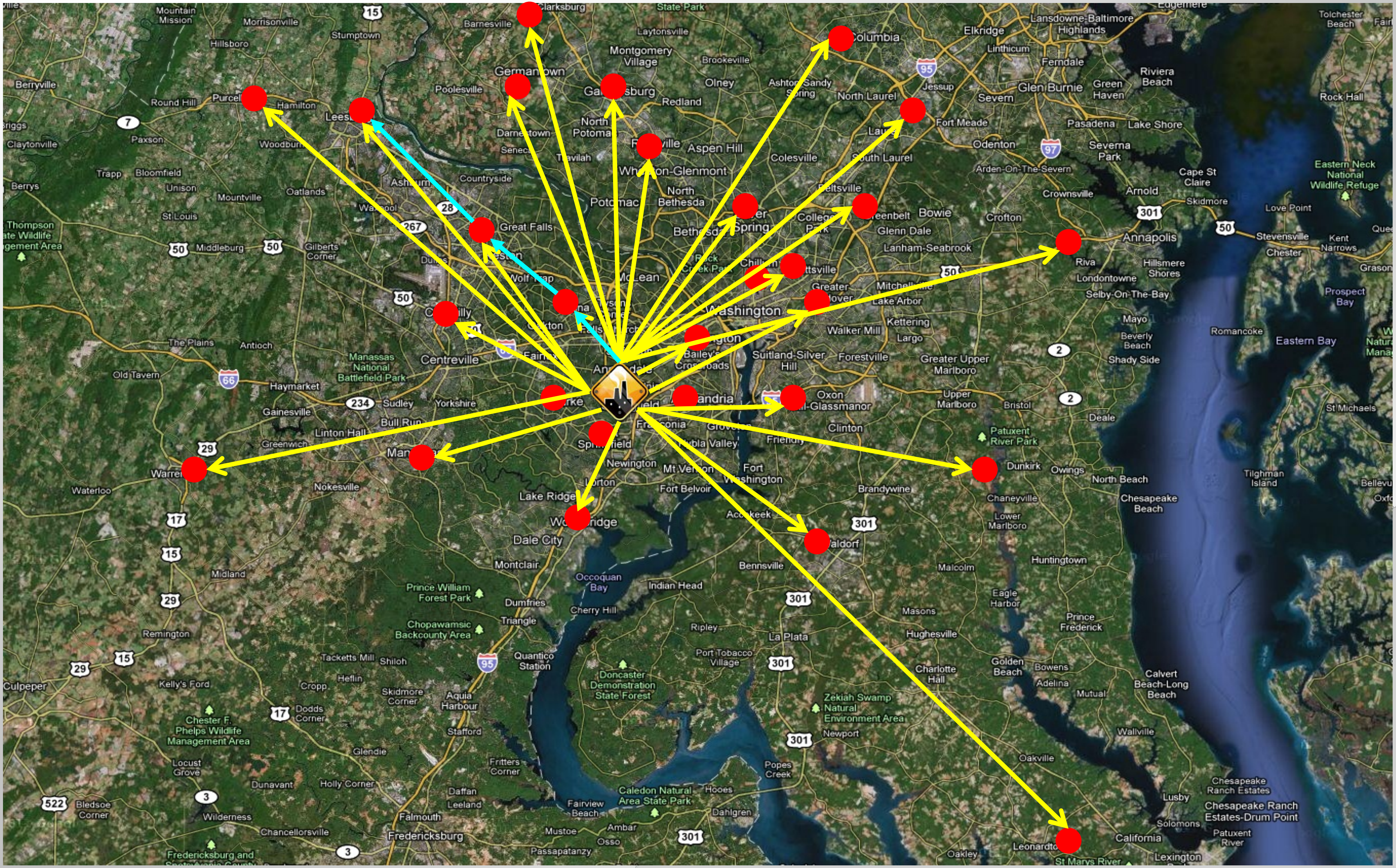
Agenda

- Problem Description
- Washington Post Distribution Process
    - CONOPS
    - System Structure
    - System Behavior
    - Data
- Modeling Approaches
    - Dynamic Truck Scheduling IP
    - Fleet Mix Prediction for Lease Analysis
    - Model Validation
- Results
    - Business Case for Truck Scheduling Model
    - Fleet Mix Recommendation
    - Washington Post Model Implementation
- Follow-on Work
- Questions

WPCD Descriptive Diagram



Problem Definition:

- Optimize Cost of Truck Scheduling and Routing
- Predict Necessary Fleet Composition
- Dynamically schedule drivers based on demand and production schedule

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- ~~Dynamically schedule drivers based on demand and production schedule~~

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Understand Existing System

- System and Process Analysis Goals
  - Document current WPCD system:
    - Structure
    - Behavior
    - Needs
    - Constraints
- Lack of existing WPCD system documentation

System Data Collection & Analysis

- Collected quantitative data for each system component
  - Washington Post has comprehensive data tracking system
  - WPCD provided two full months worth of shipping data
  - Received truck fleet mix, truck pallet capacity, and facility address list
- Elicited additional information from POC
  - Visited the WPCD Production Facility in Springfield, VA
  - Collected data that was not obvious through historical data analysis
    - Priorities, preferences, external influences, etc.
  - Questionnaires for process details

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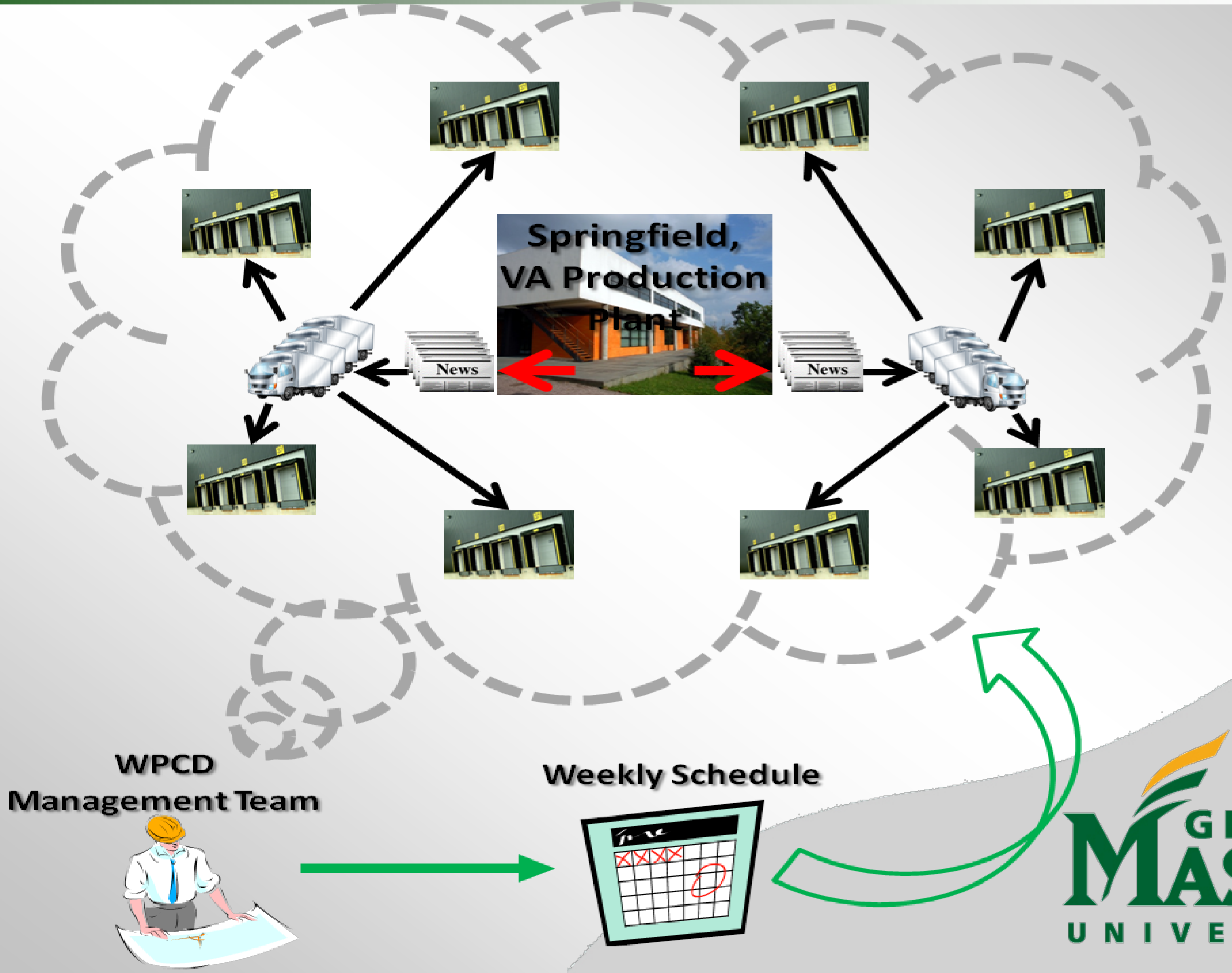
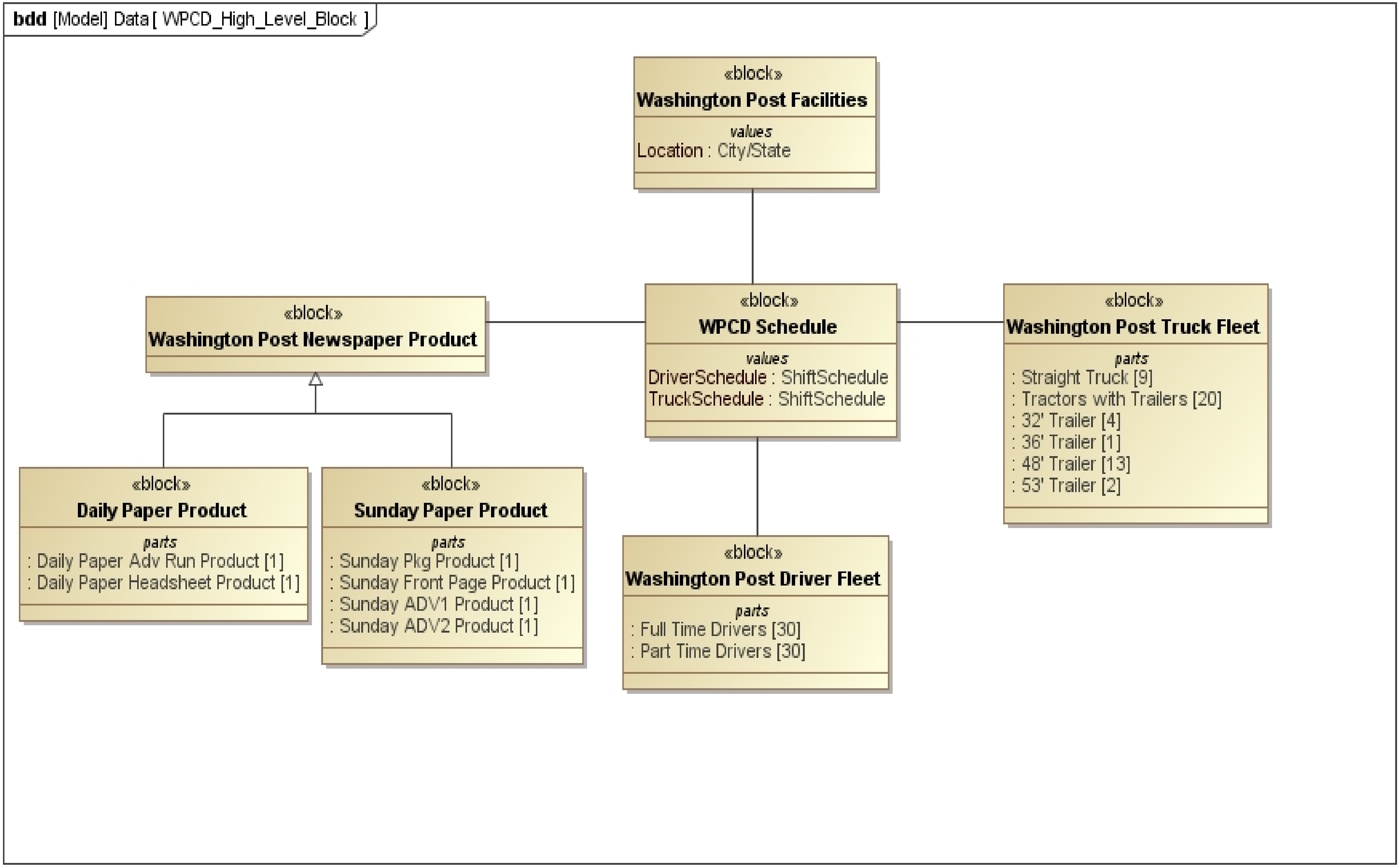
WPCD Operational Concept Diagram



WPCD System Structure



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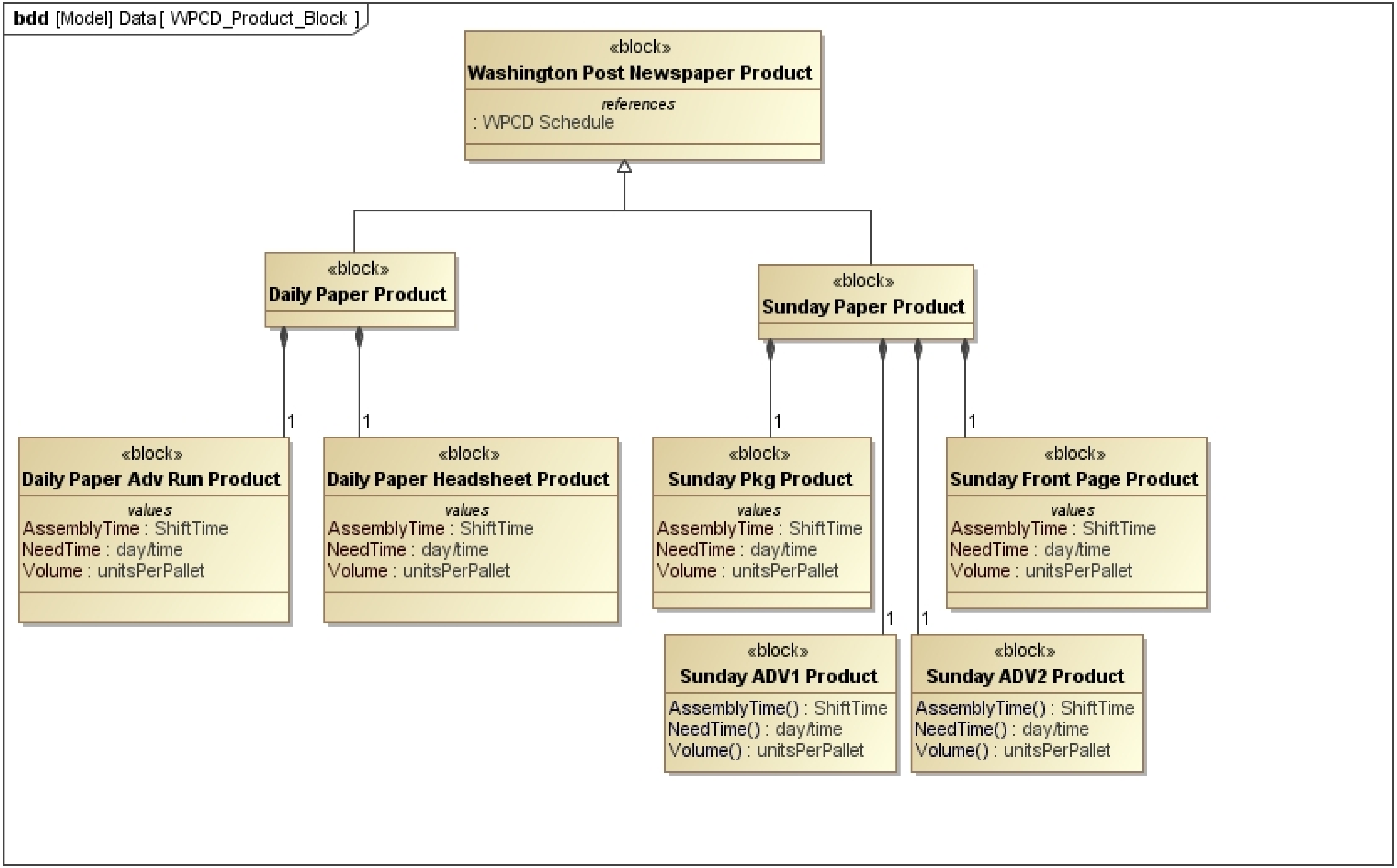

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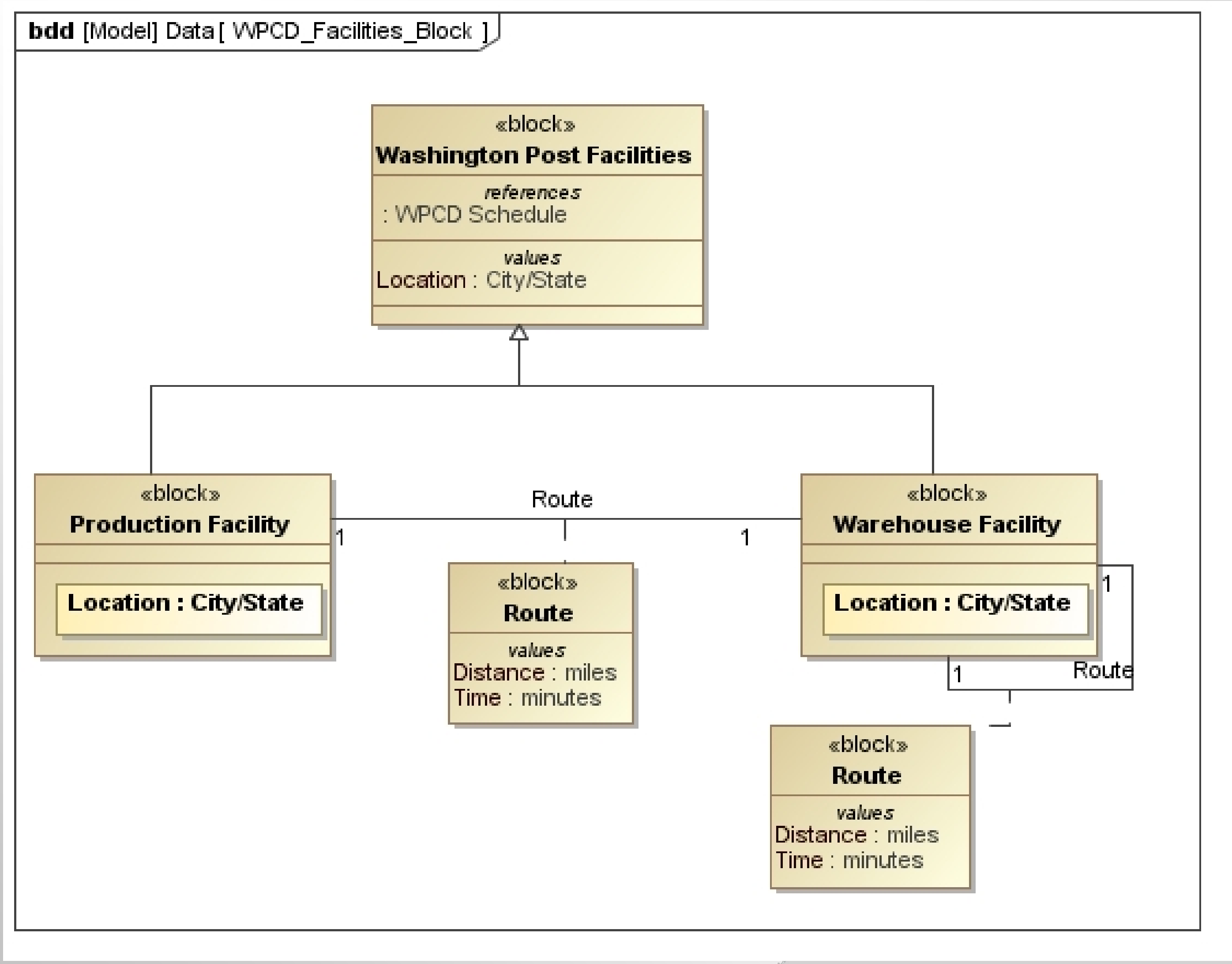

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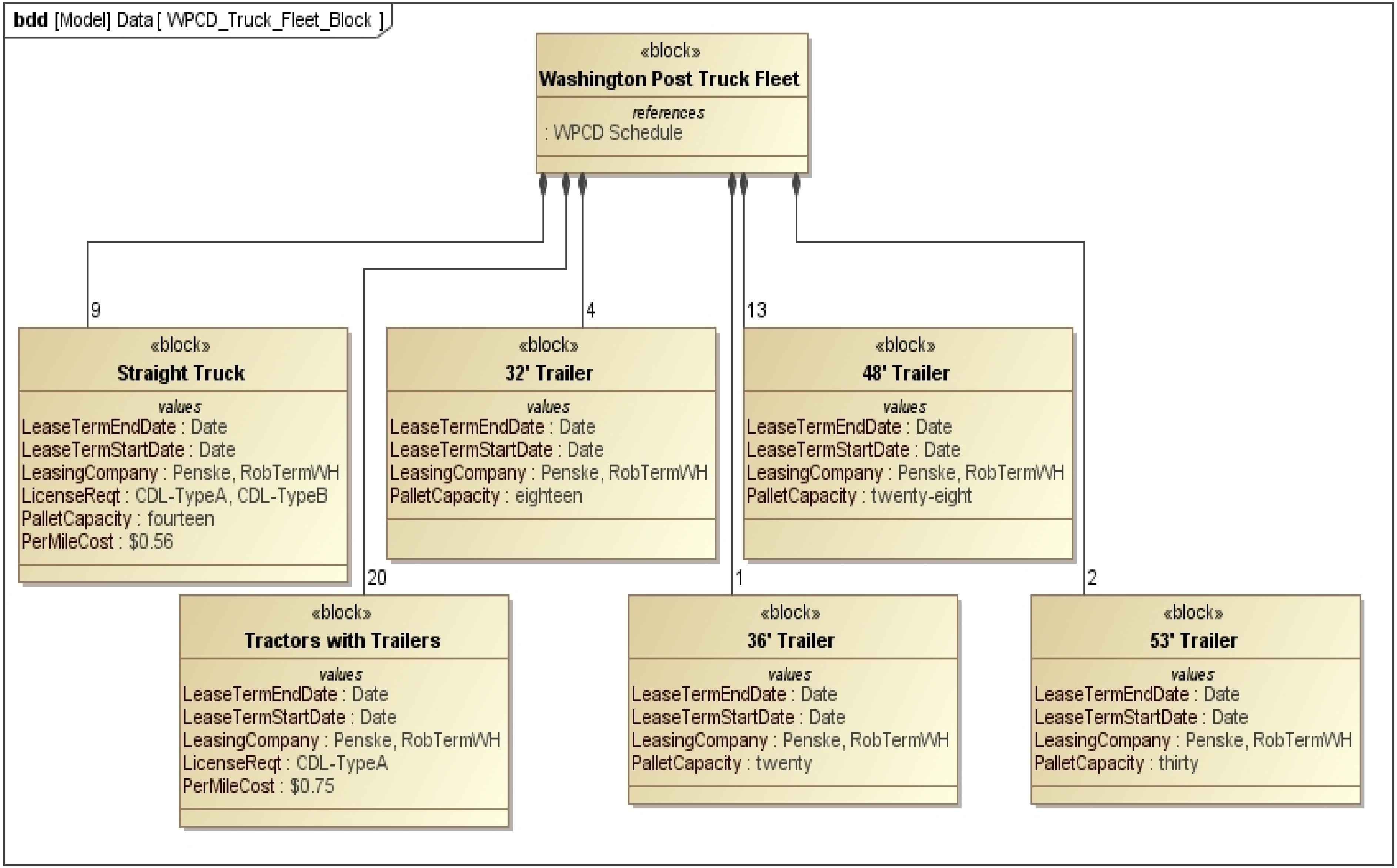

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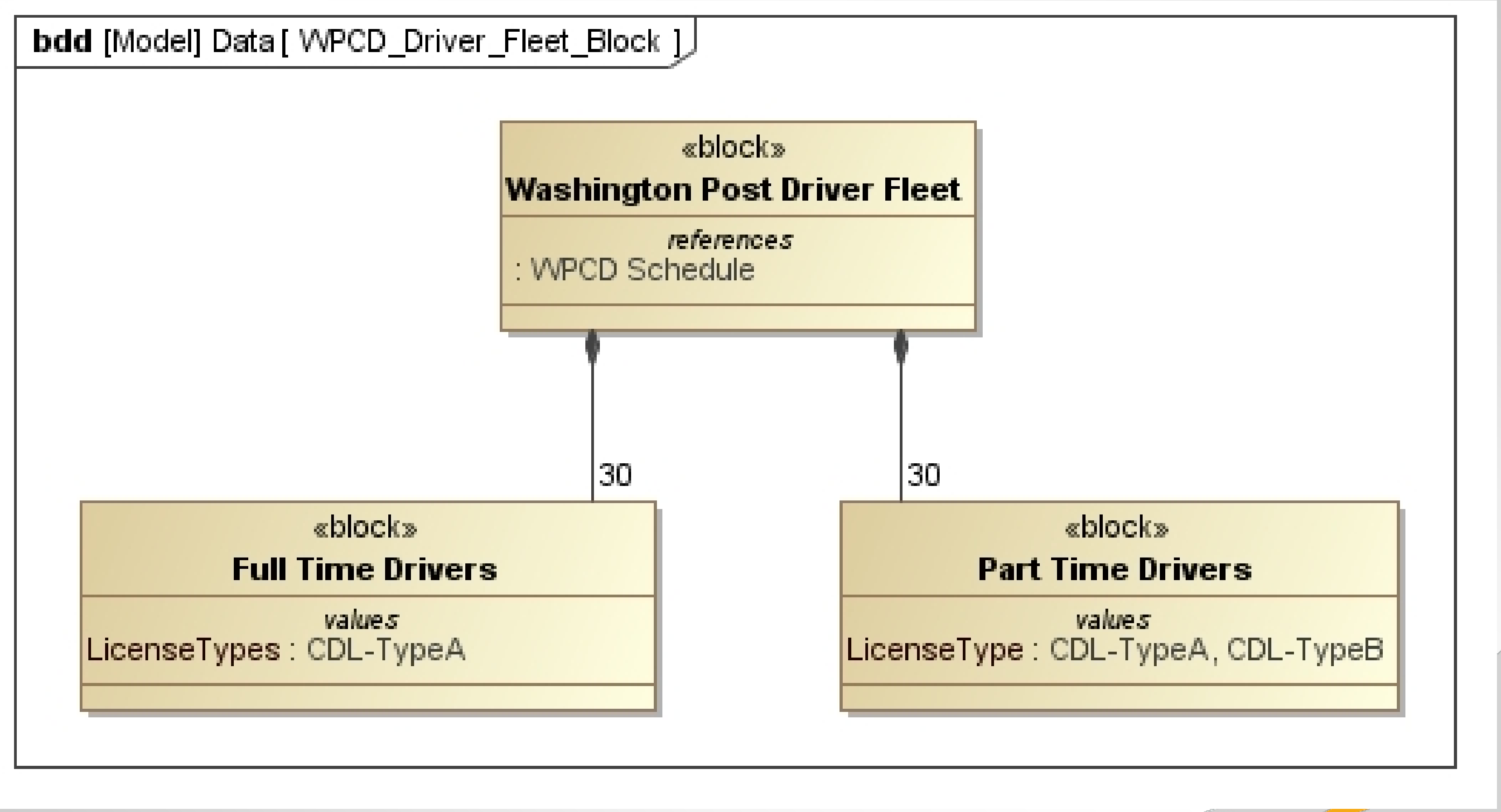

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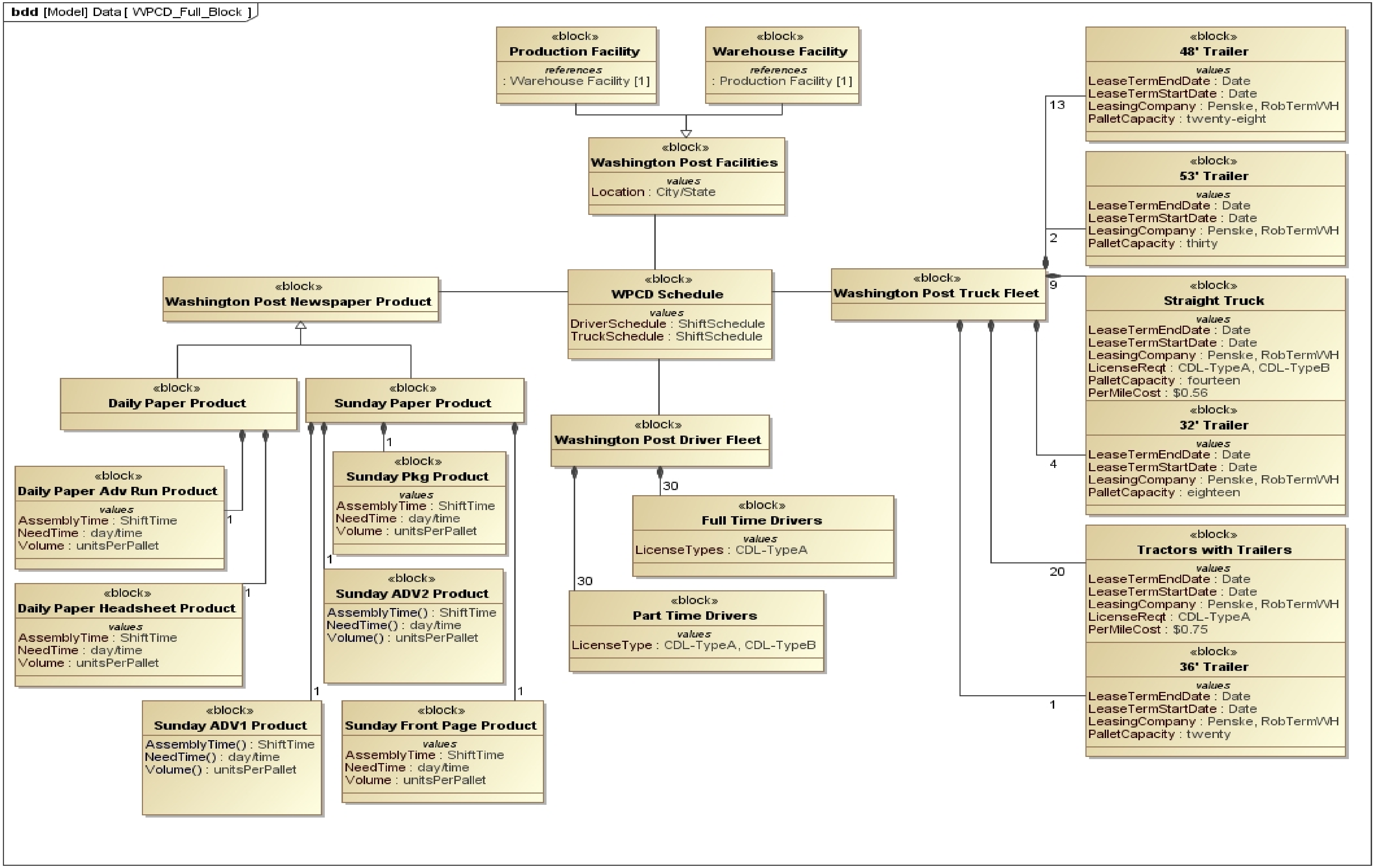
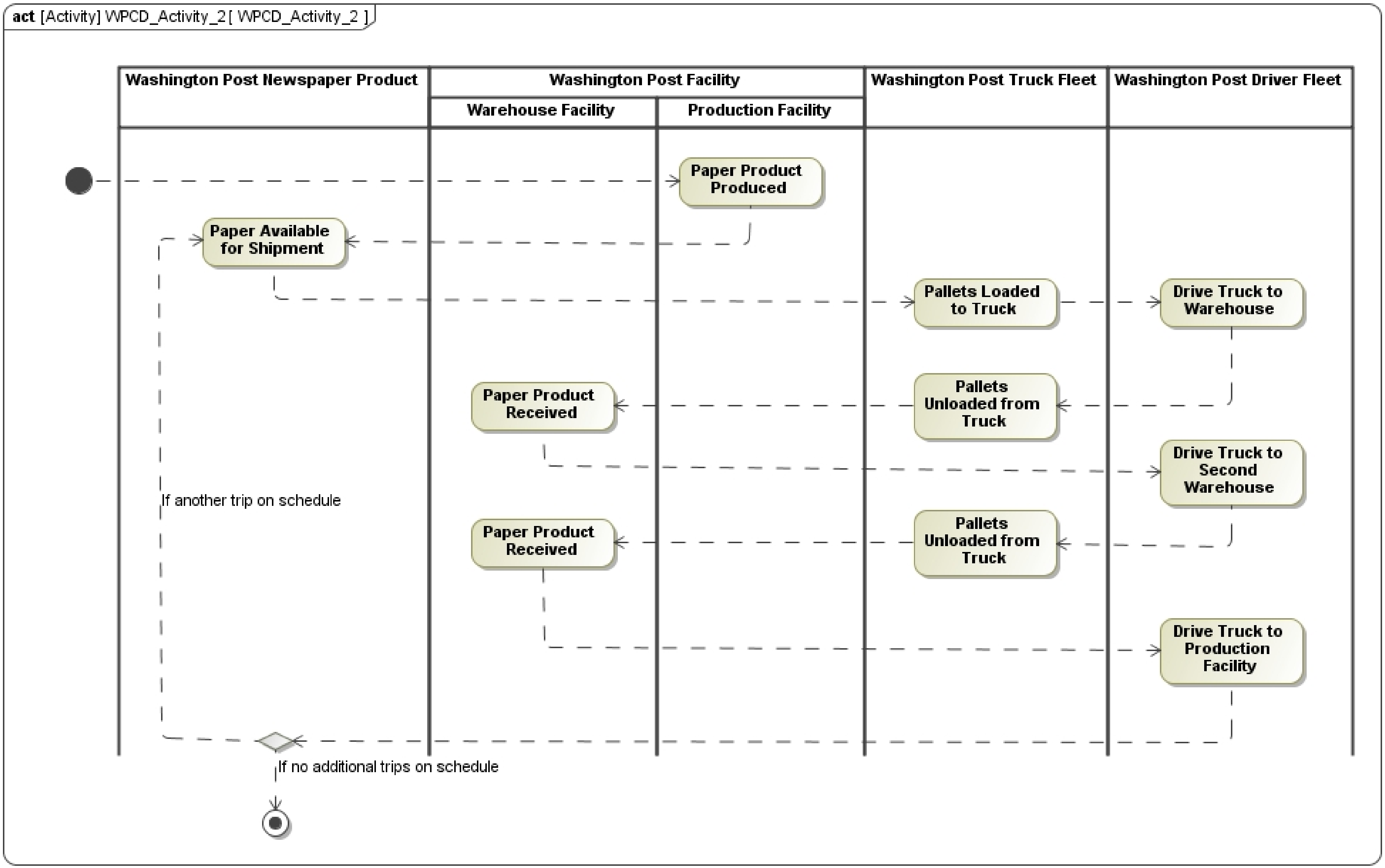
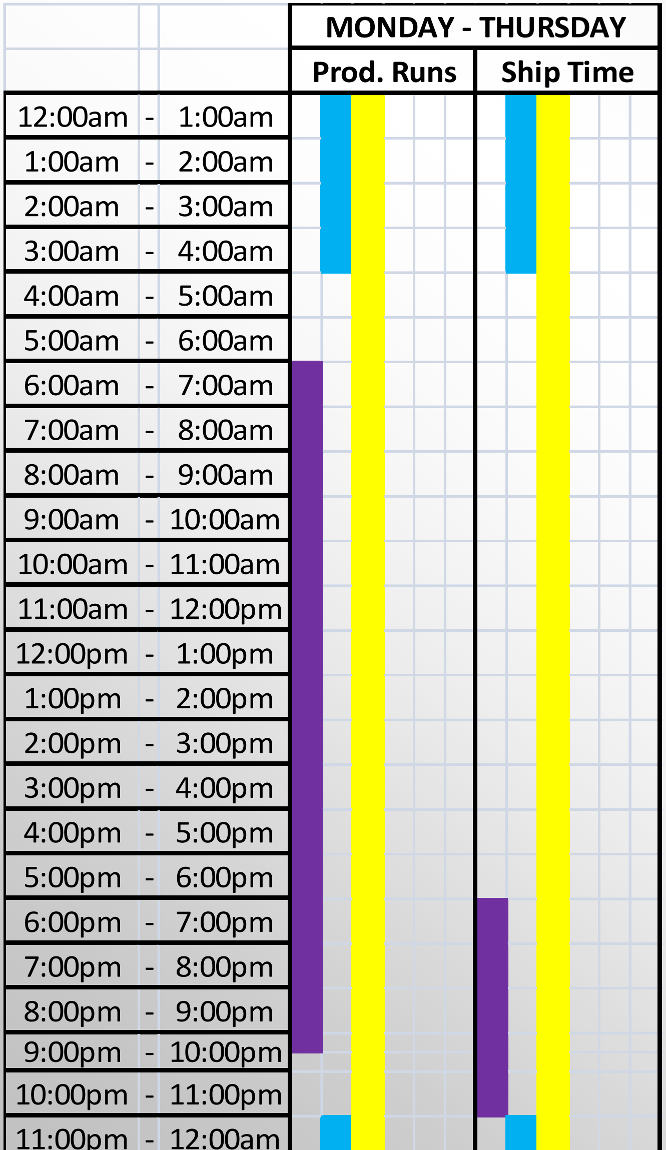
WPCD System Structure



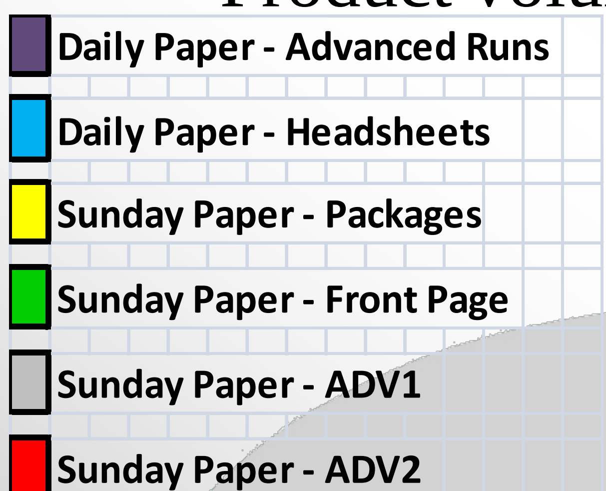
WPCD System Process



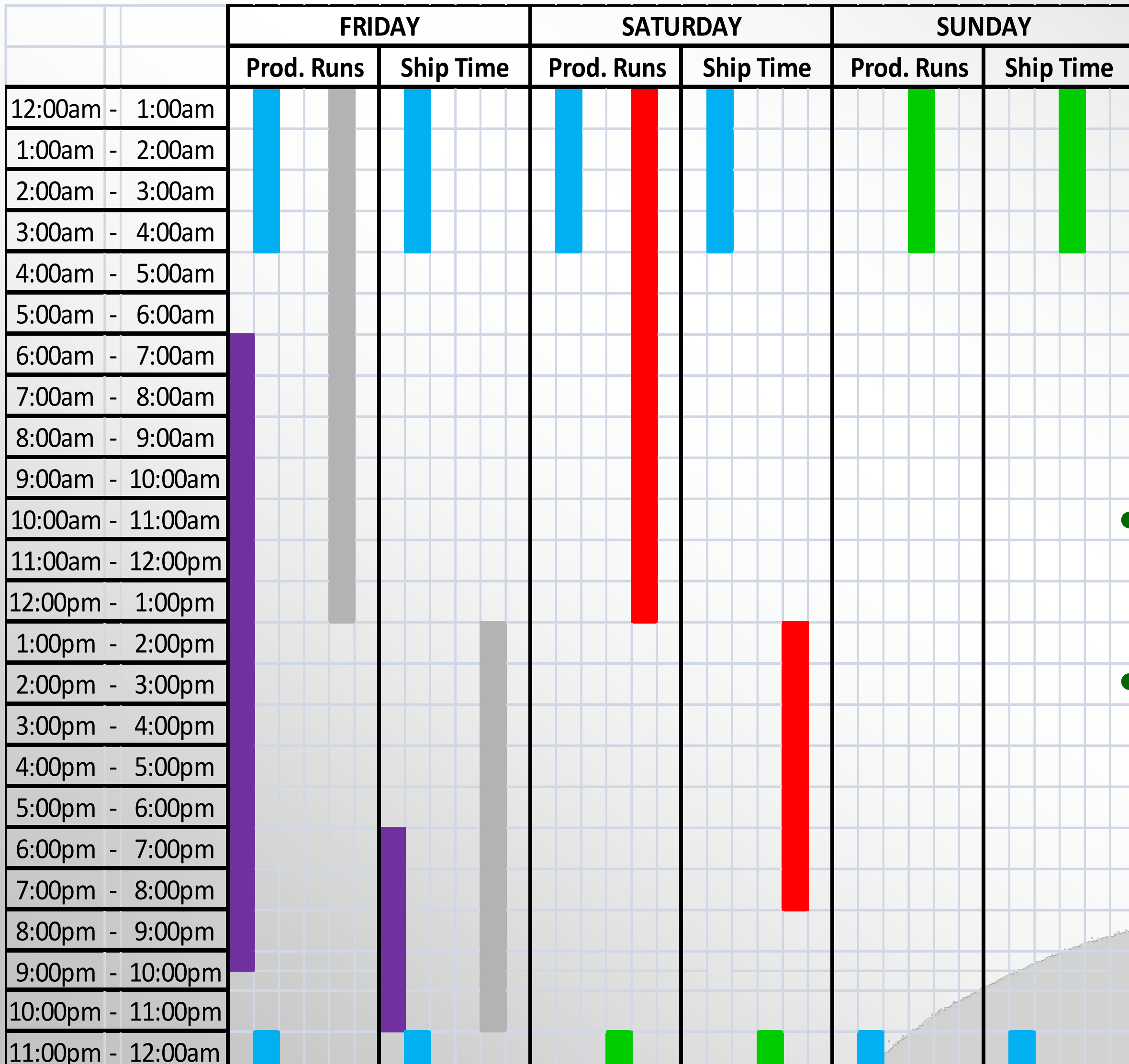
WPCD System Schedule: Mon-Thurs



- Monday – Thursday daily schedule is consistent from a shift perspective
- Daily details are variable
  - Product availability times for various warehouse locations
  - Product volume



WPCD System Schedule: Fri-Sun



- Daily Paper - Advanced Runs
- Daily Paper - Headsheets
- Sunday Paper - Packages
- Sunday Paper - Front Page
- Sunday Paper - ADV1
- Sunday Paper - ADV2

- Friday – Sunday daily schedule is unique
- Account for differing weekend products and deliveries

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Modeling Approaches

- VRP with multiple tours, multiple product types, a non-homogeneous fleet, and time windows
- Time-Space Network

Definitions

- Trucks: $x^k_{i,j} \in \{0, 1\}$
- Products: $y^p_{i,j} \in \mathbb{Z}^+$

MTMPMFVRP…

$$\min \sum_r \sum_k \sum_t \sum_{j=1}^{n} F_{k_t} X_{0,j}^{k_t^r} + \sum_r \sum_k \sum_t \sum_i \sum_j V_{ij}^k X_{ij}^{k_t^r} + \sum_r \sum_k \sum_t L_{k_t^r}$$

$$\sum_{i=0}^{n} X_{i,n+1}^{k_t^r} = 1 \qquad \forall r,k,t \qquad (1)$$

$$\sum_{j=1}^{n+1} X_{0,j}^{k_t^r} = 1 \qquad \forall r,k,t \qquad (2)$$

$$\sum_{i=1}^{n} X_{i,j}^{k_t^r} \leq 1 \qquad \forall j \in \{1 \ldots n\} | i \neq j,\ \forall r,k,t \qquad (3)$$

$$\sum_{j=1}^{n} X_{i,j}^{k_t^r} \leq 1 \qquad \forall i \in \{1 \ldots n\} | i \neq j,\ \forall r,k,t \qquad (4)$$

$$\sum_p Y_{i,j}^{k_t^r} \leq \bar{D} X_{i,j}^{k_t^r} \qquad \forall i,j | i \neq j,\ \forall r,k,t \qquad (5)$$

$$\sum_r \sum_k \sum_t \sum_i Y_{i,j}^{k_t^r} = D_j^p \qquad \forall j,p \qquad (6)$$

$$\sum_i \sum_j \sum_p Y_{i,j}^{k_t^r} \leq Q_k \qquad \forall i \neq j, r, k, t \qquad (7)$$

$$\sum_i \sum_j l_{i,j} X_{i,j}^{k_t^r} = L_{k_t^r} \qquad \forall i \neq j, r, k, t \qquad (8)$$

$$S_{k_t^{r+1}} \geq S_{k_t^r} + L_{k_t^r} \qquad \forall r \in \{1 \ldots R-1\},\ \forall k,t \qquad (9)$$

$$\sum_j Y_{0,j}^{k_t^r,p} \leq \bar{D}(1 - z_{k_t^r}) \qquad \forall r,k,t,p \qquad (10)$$

$$-S_{k_t^r} + m_p \leq \bar{D} z_{k_t^r} \qquad \forall r,k,t,p \qquad (11)$$

$$X_{i,j}^{k_t^r} \in \{0,1\},\ Y_{i,j}^{k_t^r,p}, S_{k_t^r} \in \mathbb{Z}_+ \qquad \forall i,j,k,t,r,p \qquad (12)$$

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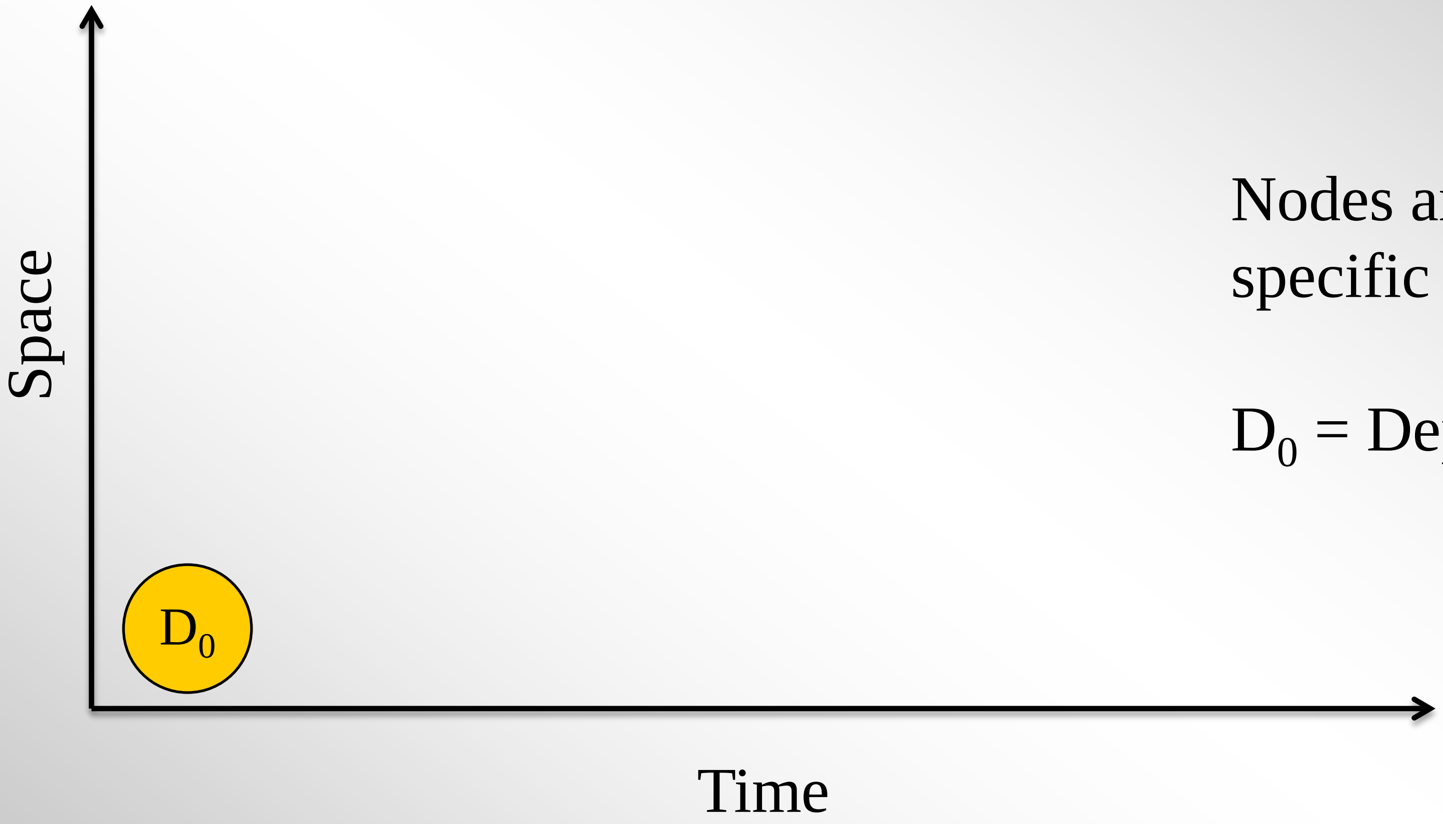
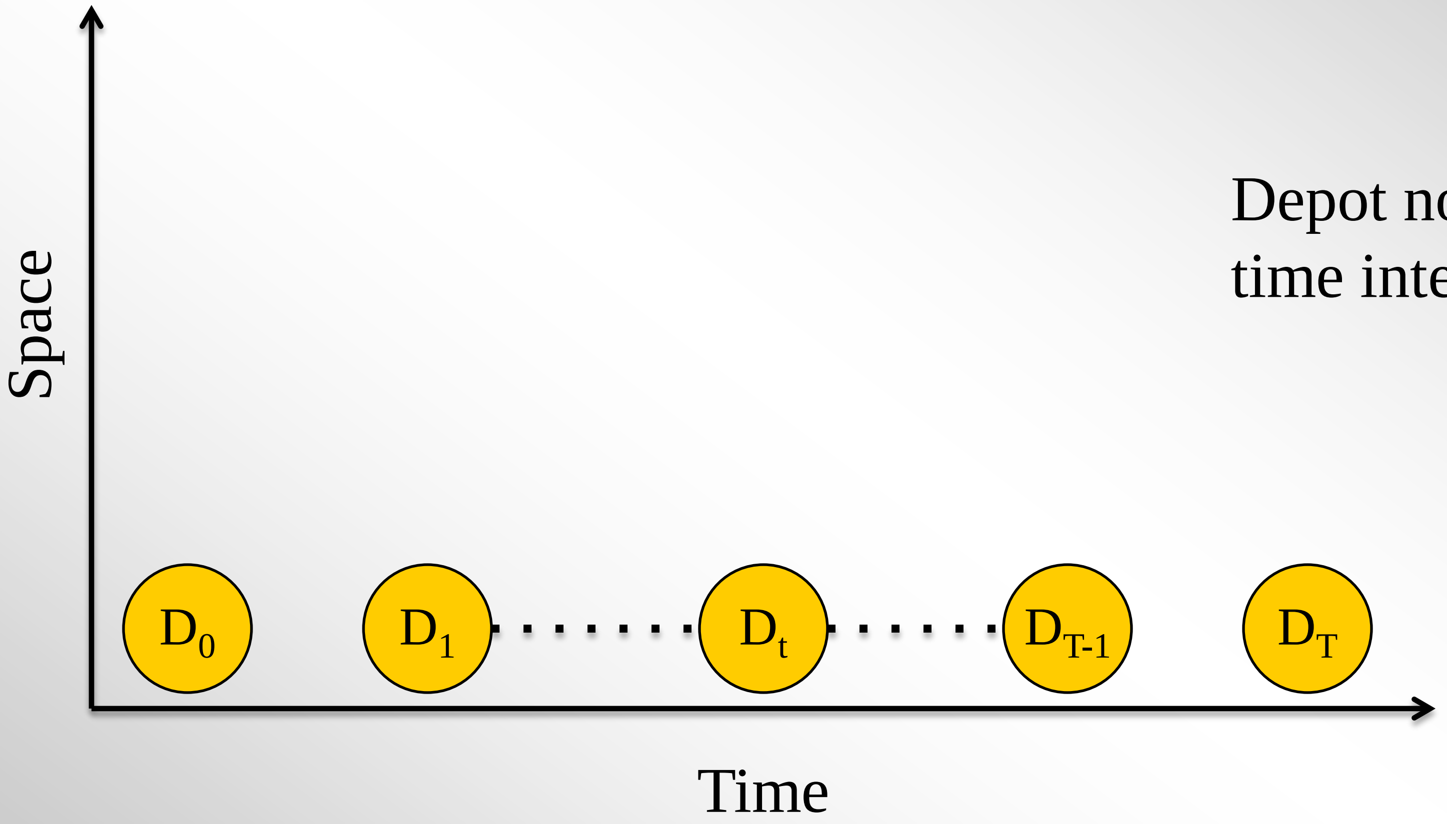
Time-Space Networks



Nodes are locations at specific times.

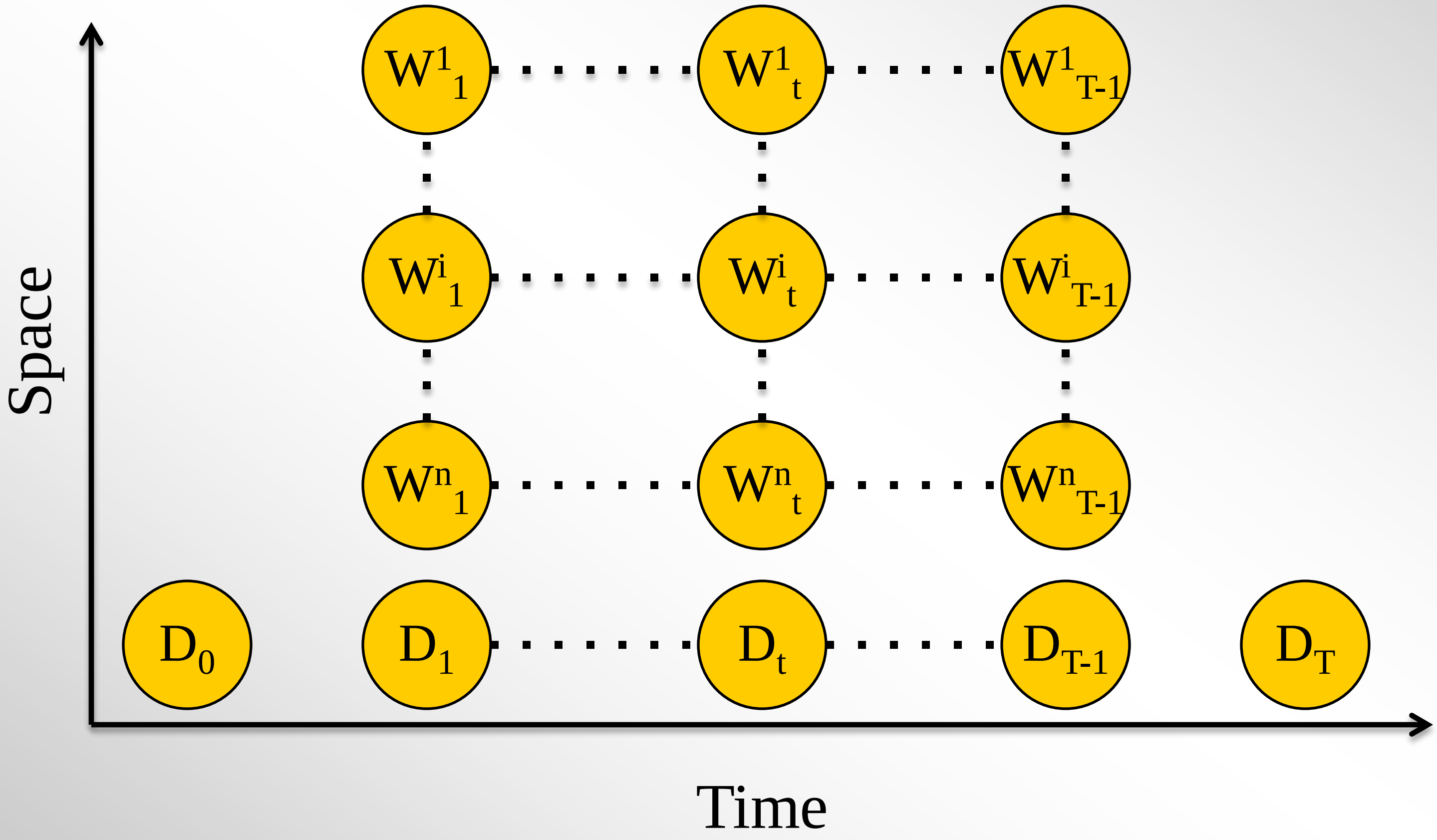
D_0 = Depot at time 0

Time-Space Networks

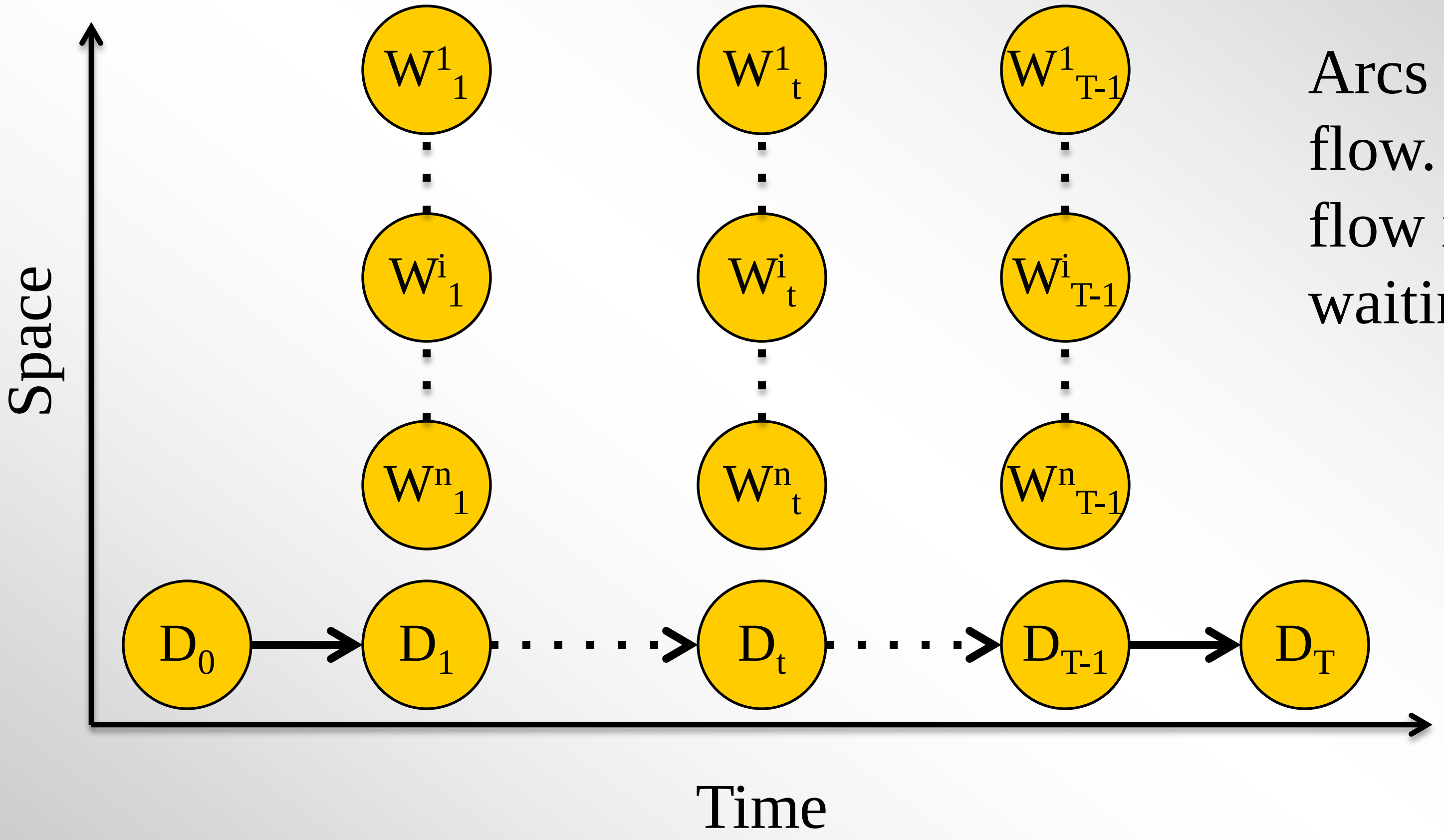


Depot nodes over all time intervals

Time-Space Networks

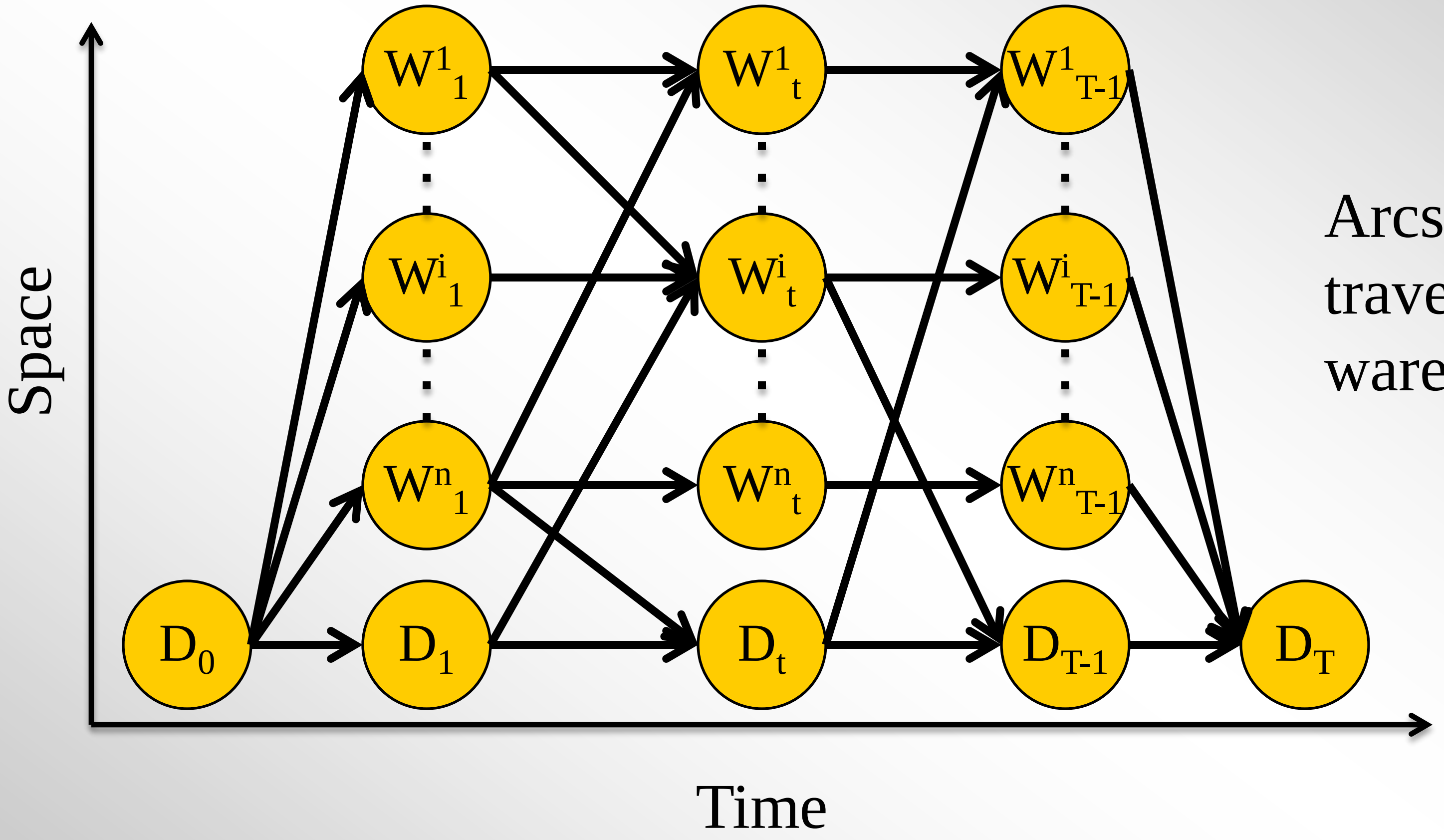


Time-Space Networks



Arcs are feasible flow. Here product flow is restricted to waiting at the depot.

Time-Space Networks



Arcs determined by travel times between warehouses

Time-Space Networks

- Multi-commodity min-cost flow problem*
- Input: network, production schedule, truck availability
- Output: How much of each product on each truck type as well as the route schedules for all trucks
- Solves fleet mix problem

Time-Space Networks

- Multi-commodity min-cost flow problem*
- Input: network, production schedule, truck availability
- Output: How much of each product on each truck type as well as the route schedules for all trucks
- Solves fleet mix problem
- Much more compact than initial vehicle routing formulation

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Time-Space Networks

- Objective: Minimize costs of driving the trucks
- Constraints: Product flow across arc is capacitated by truck type. (Arcs between the same location are uncapacitated)
- Flow in = Flow out

MCMCF Formulation

$$\min \sum_{(i,j)\in A,p} V^p_{i,j} y^p_{i,j}$$

$$\sum_p y^p_{i,j} \leq C_{i,j} \qquad \forall (i,j) \in A \tag{1}$$

$$\sum_{i,p} y^p_{i,k} - \sum_{j,p} y^p_{k,j} = b_k \qquad \forall k \in N \tag{2}$$

$$y^p_{i,j} \in \mathbb{Z}^+ \tag{3}$$

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Single Unit Flow*

$$\min \sum_{(i,j)\in A,k} D_{i,j} V^k x^k_{i,j}$$

$$\sum_p y^p_{i,j} \le C^k x^k_{i,j} \qquad \forall (i,j) \in A$$

$$\sum_{i,p} y^p_{i,l} - \sum_{j,p} y^p_{l,j} = b_l \qquad \forall l \in N$$

$$\sum_{i,k} x^k_{i,l} - \sum_{j,k} x^k_{l,j} = b'_l \qquad \forall l \in N$$

$$y^p_{i,j} \in \mathbb{Z}^+,\ x^k_{i,j} \in \{0,1\}$$

Single Unit Flow*

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$$\sum_{i,k} x_{i,l}^k - \sum_{j,k} x_{l,j}^k = b_l' \qquad \forall l \in N$$

$$y_{i,j}^p \in \mathbb{Z}^+, \; x_{i,j}^k \in \{0,1\}$$

Depot causes problems

Single Unit Flow*

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$$y^p_{i,j} \in \mathbb{Z}^+,\ x^k_{i,j} \in \{0,1\}$$

DCs cause problems

Batch Flow*

$$\min \sum_{(i,j)\in A,k} D_{i,j} V^k x^k_{i,j}$$

$$\sum_o P^o y^o_{i,j} \le C^k x_{i,j} \qquad \forall (i,j) \in A \qquad (1)$$

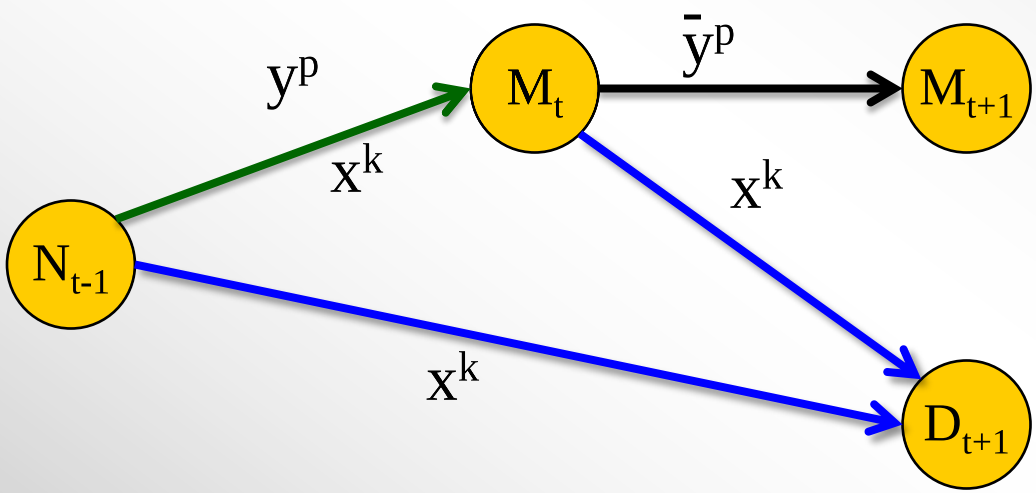
$$\sum_{i,o} P^o y^o_{i,l} - \sum_{j,o} P^o y^o_{l,j} = b_l \qquad \forall l \in N \qquad (2)$$

$$\sum_{i,k} x^k_{i,l} - \sum_{j,k} x^k_{l,j} = b'_l \qquad \forall l \in N \qquad (3)$$

$$y^o_{i,j},\ x^k_{i,j} \in \{0,1\} \qquad (4)$$

Defining Arc Sets

- How do we force trucks back to the depot?



x^k Binary

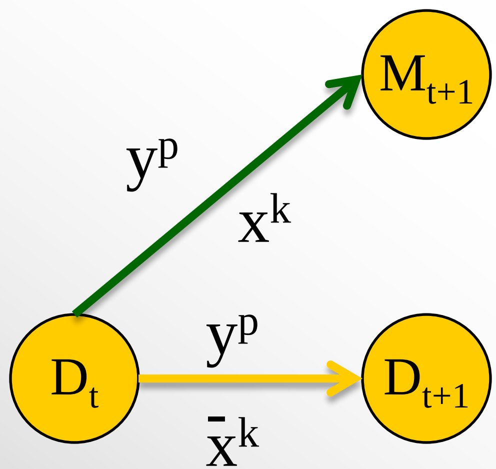
in X

in X and Y

in $\bar{Y}$

Defining Arc Sets

- How do we force trucks back to the depot?
- How do we manage truck flow out of depot?



$\bar{x}^k$ Integer!

in X and Y

in $\bar{X}$ and Y

Correct Formulation (SU)

$$\min \sum_{(i,j)\in A,k} D_{i,j} V^k x_{i,j}^k$$

$$\sum_p y_{i,j}^p \le C^k x_{i,j}^k \qquad \forall (i,j) \in Y$$

$$\sum_{i,p} (y_{i,l}^p + \bar{y}_{i,l}^p) - \sum_{j,p} (y_{l,j}^p + \bar{y}_{l,j}^p) = b_l \qquad \forall l \in N$$

$$\sum_{i,k} (x_{i,l}^k + \bar{x}_{i,l}^k) - \sum_{j,k} (x_{l,j}^k + \bar{x}_{l,j}^k) = b_l' \qquad \forall l \in N$$

$$y_{i,j}^p,\ \bar{y}_{i,j}^p,\ \bar{x}_{i,j}^k \in \mathbb{Z}^+,\ x_{i,j}^k \in \{0,1\}$$

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0-1 Flow

- Same formulation as Batch Flow
- Truck Type replaced by Truck
- Truck availability = 1
- Increases the number of variables substantially
- All variables are now binary

Model Parameters

- How do we manage the size of the network?
- Time Interval: Larger TI => Smaller Network
  Larger TI => More Conservative
- Time Bound: Larger TB => Larger Network
- Max Hold: Larger MH => Larger Network

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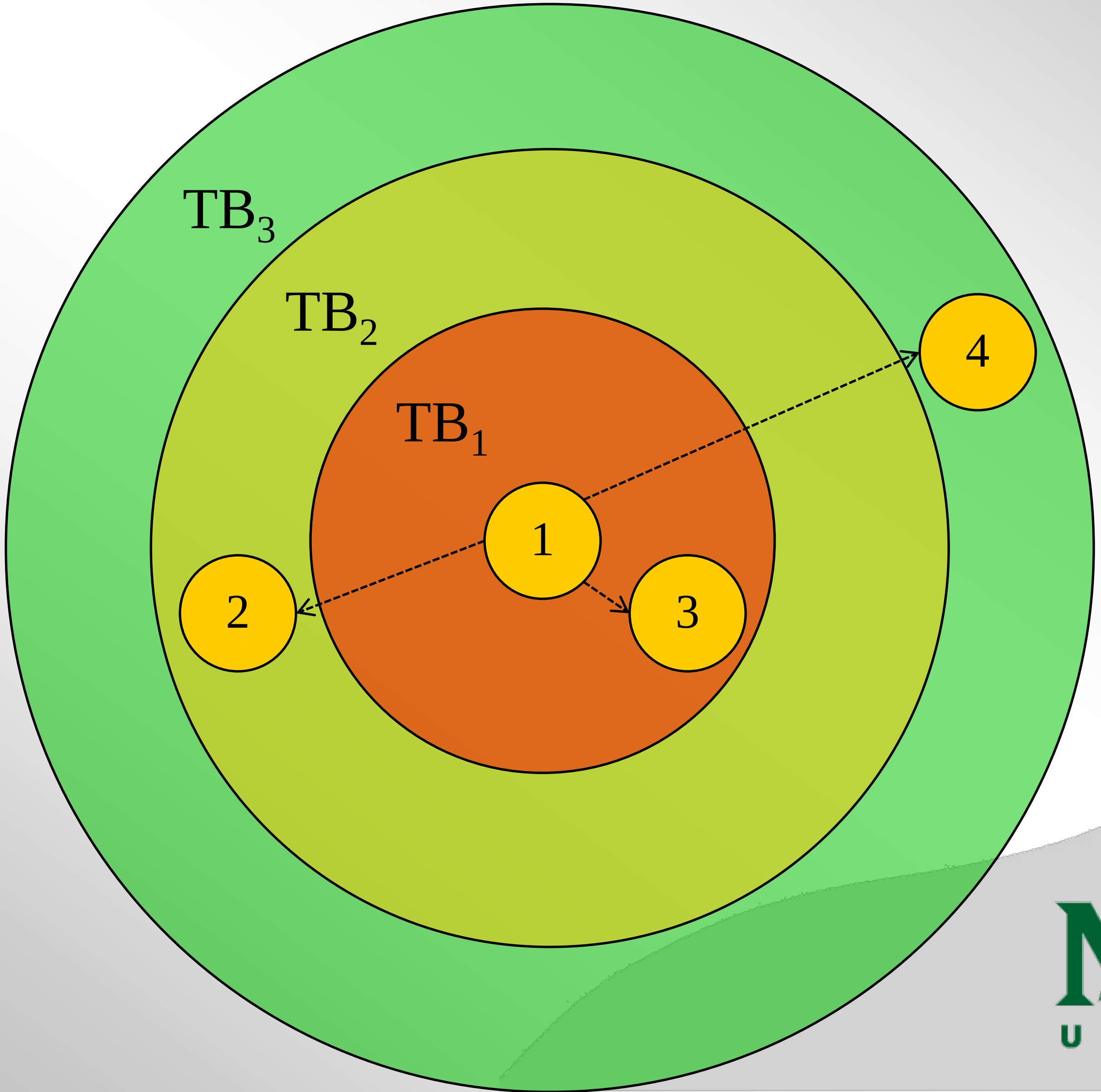
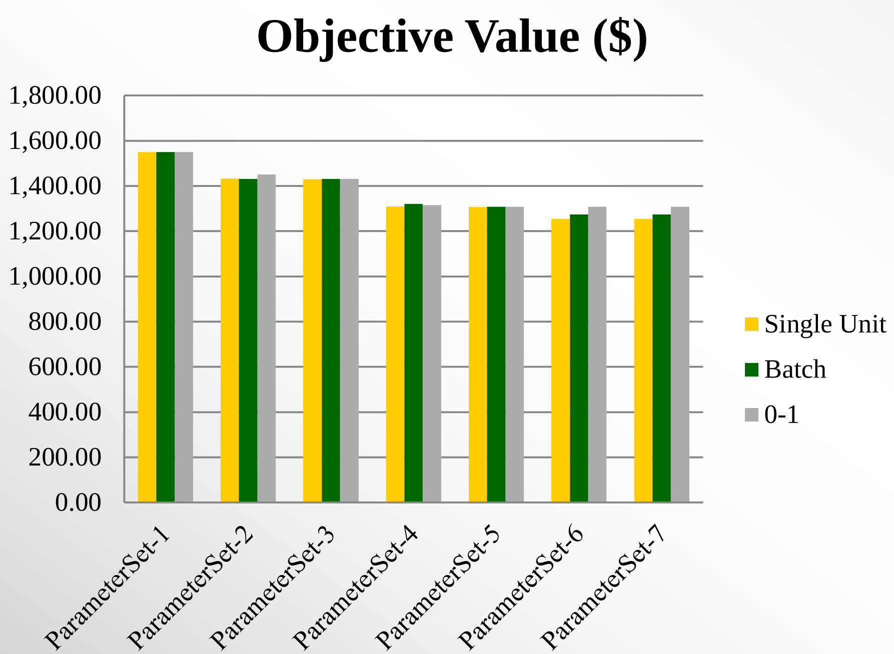
Time Bound

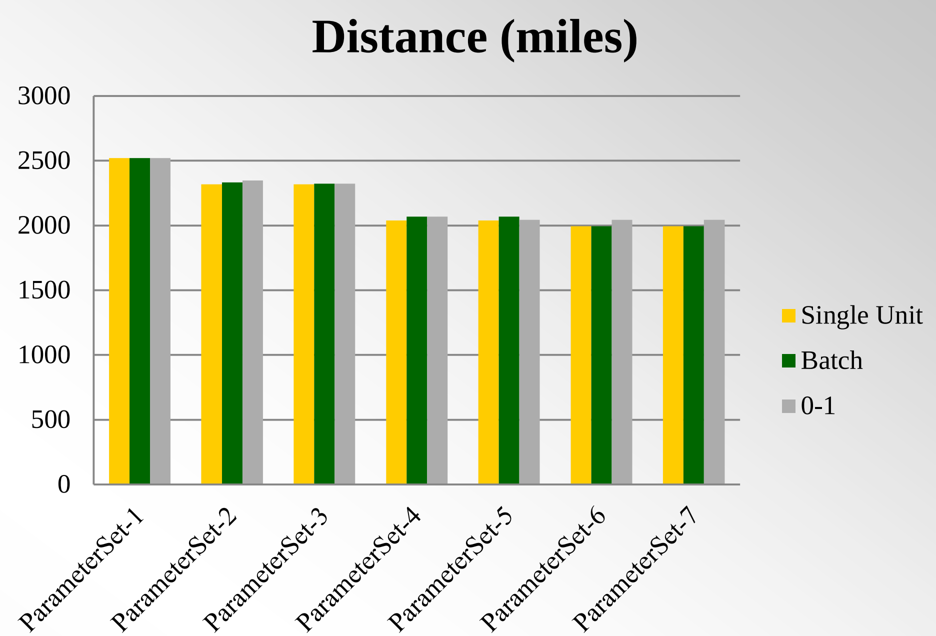


Solving Strategy

- Iterative network expansion
- Initialize with small network (TB = 0)
- Add arcs and resolve using previous solution as initial basis

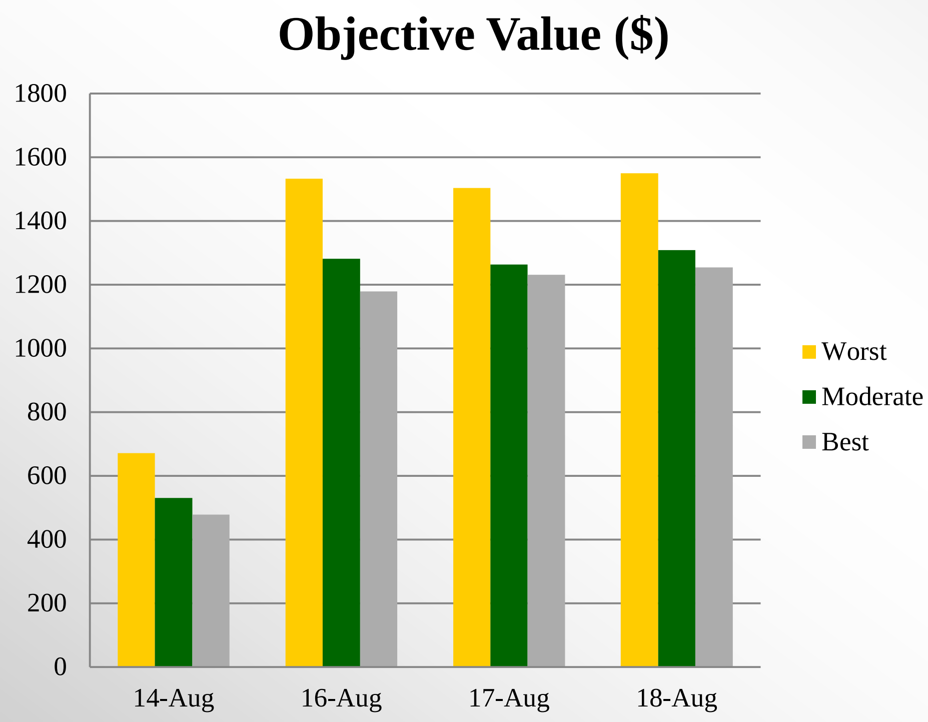
Parameter Tuning (8/18/11-8/19/11)

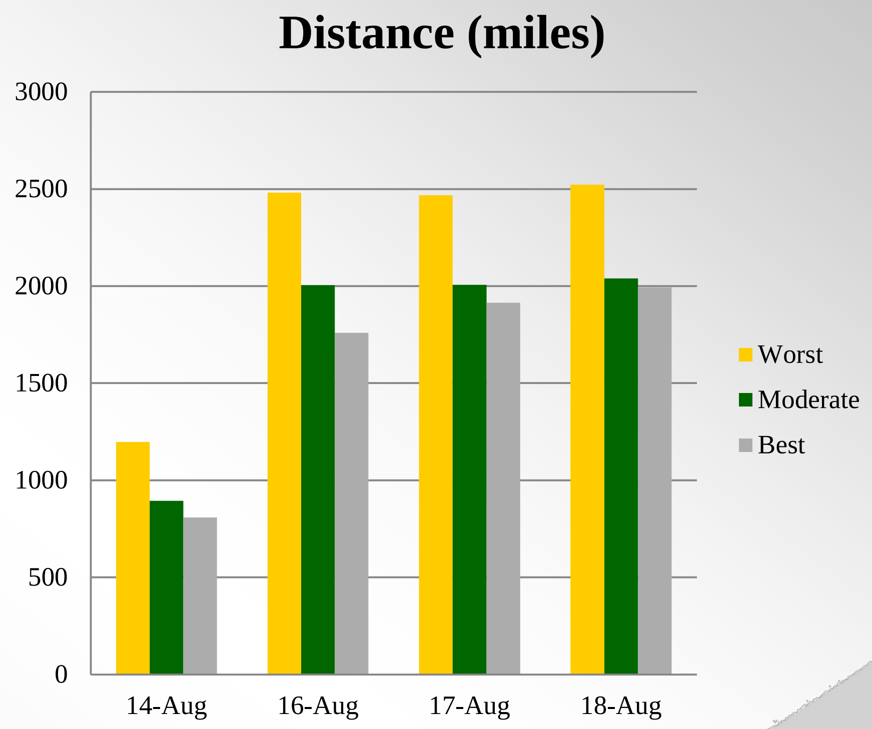




	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
ParameterSet-1	0	30	60
ParameterSet-2	30	30	60
ParameterSet-3	45	30	60
ParameterSet-4	60	30	60
ParameterSet-5	90	30	60
ParameterSet-6	60	30	120
ParameterSet-7	60	30	180

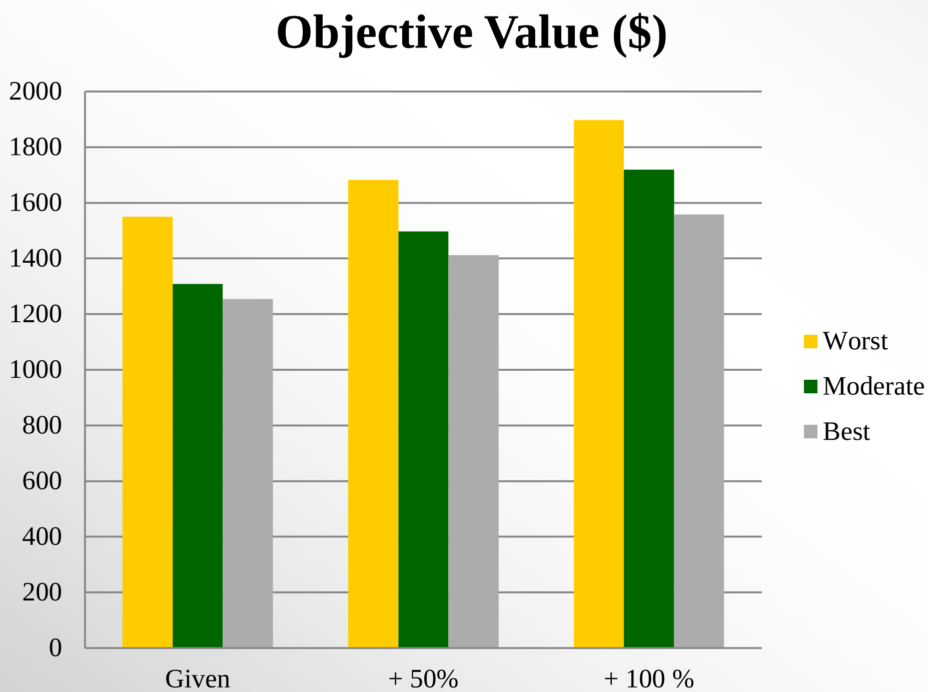
4 Day Compare

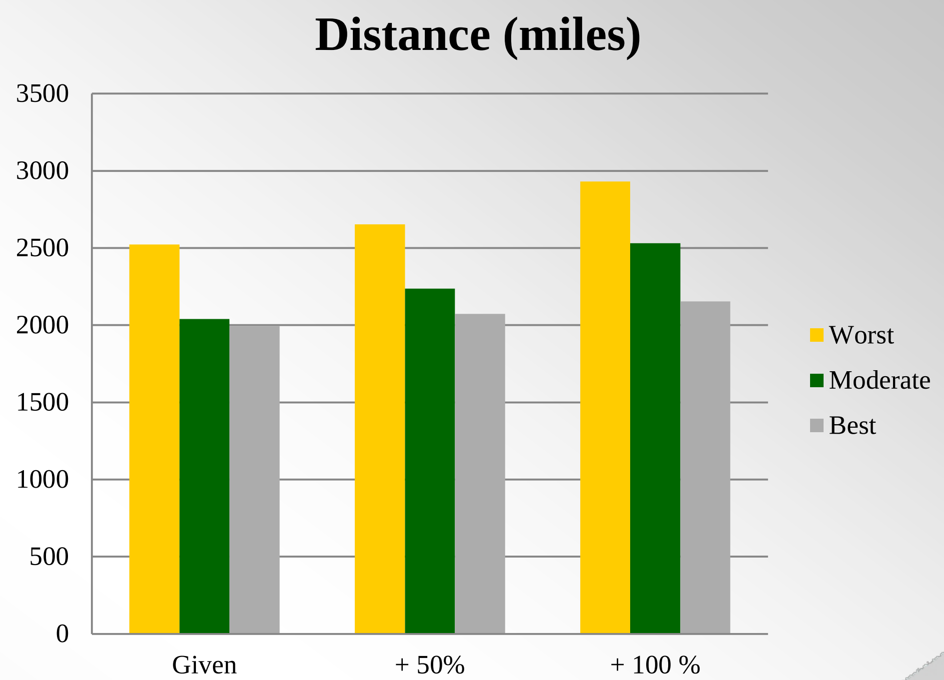




	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
Worst	0	30	60
Moderate	60	30	60
Best	60	30	120

Volume Increase Compare





	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
Worst	0	30	60
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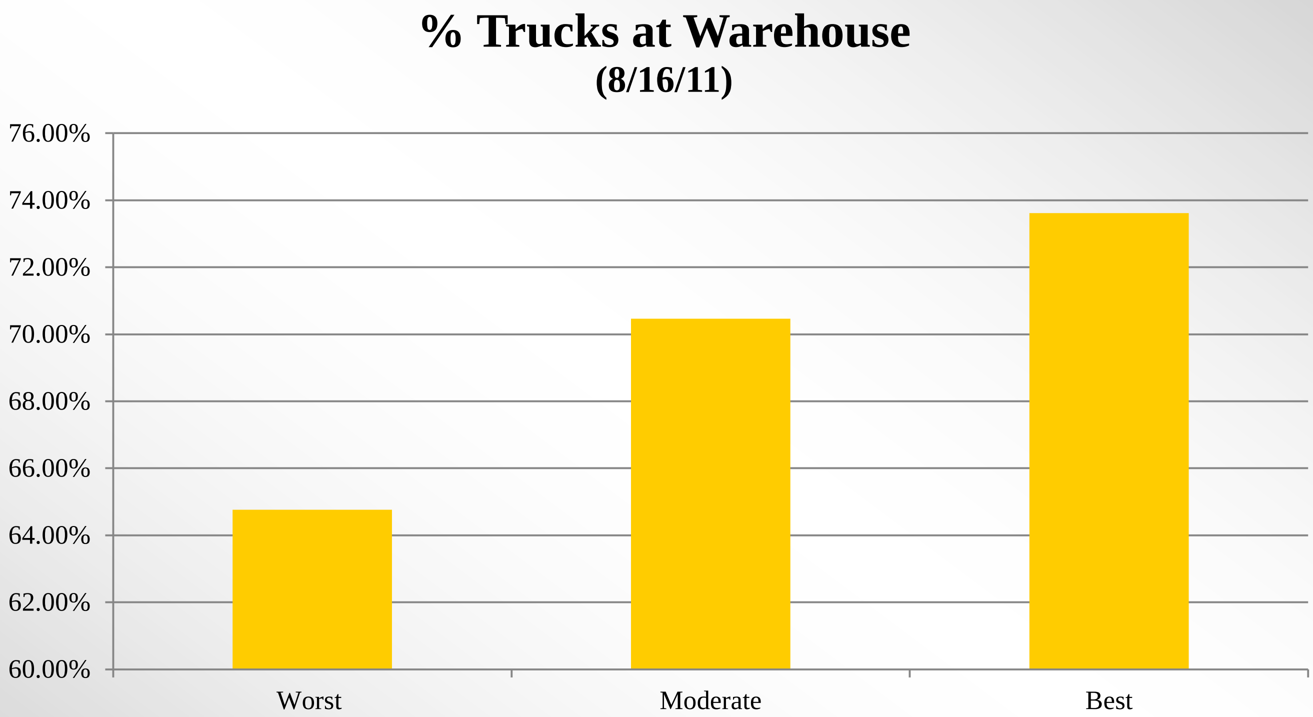
Truck Utilization Compare



	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
Worst	0	30	60
Moderate	60	30	60
Best	60	30	120

Tours

- No Repeats!
- Max: 4 Distribution Center tour
  - D – Hyattsville – South Dakota – Seat Pleasant – Annapolis – D
- No obvious pattern, highly dependent on demand
- Tours even when demand is doubled

What Didn't Work For Us

- VRP
- Full Network
- Holding Costs
- Batching
- 0-1
- Modifying Variable Costs

Fleet Mix Model

- A Truck sitting at the Depot idle is a wasted resource – Why pay for something you don't use?

- The Fleet should change over time:
  - Decline in Subscriptions
  - More Efficient Truck Routing
  - Increase in Advertisement Bulk
  - Total Market Coverage
  - Changing Lease Terms

Fleet Mix Modeling Approach

- Use Truck Routing Model

- Assess Future Pallet Demand at each Distribution Center
  - Linear Regression
  - Worst Case Demand?
  - Better Projection Methods?

- Unconstrained Fleet
  - Sufficiently large number of trucks that won't bound a solution

- The Trucks used by the model represent the optimal fleet to meet the predicted demand

Linear Regression of Demand

- Linear Regression Performed using all data for each of 27 Distribution Centers

Destination	60 day Pallet Projection
ALEXANDRIA	11
ANNAPOLIS	16
ARLINGTON	9
ANNAPOLIS JUNCTION	8
BOWIE	16
BURKE	18
CHANTILLY	20
COLUMBIA	25
DERWOOD	30
DUNKIRK	3
FREDERICK	9
GERMANTOWN	17
HOLLYWOOD	4
HYATTSVILLE	20
LEESBURG	0
MANASSAS	14
OXON HILL	9
PURCELLVILLE	6
ROCKVILLE	45
SEAT PLEASANT	8
SOUTH DAKOTA	27
SPRINGFIELD	12
STERLING	19
VIENNA	22
WALDORF	12
WARRENTON	2
WHITE OAK	13
WOODBRIDGE	9

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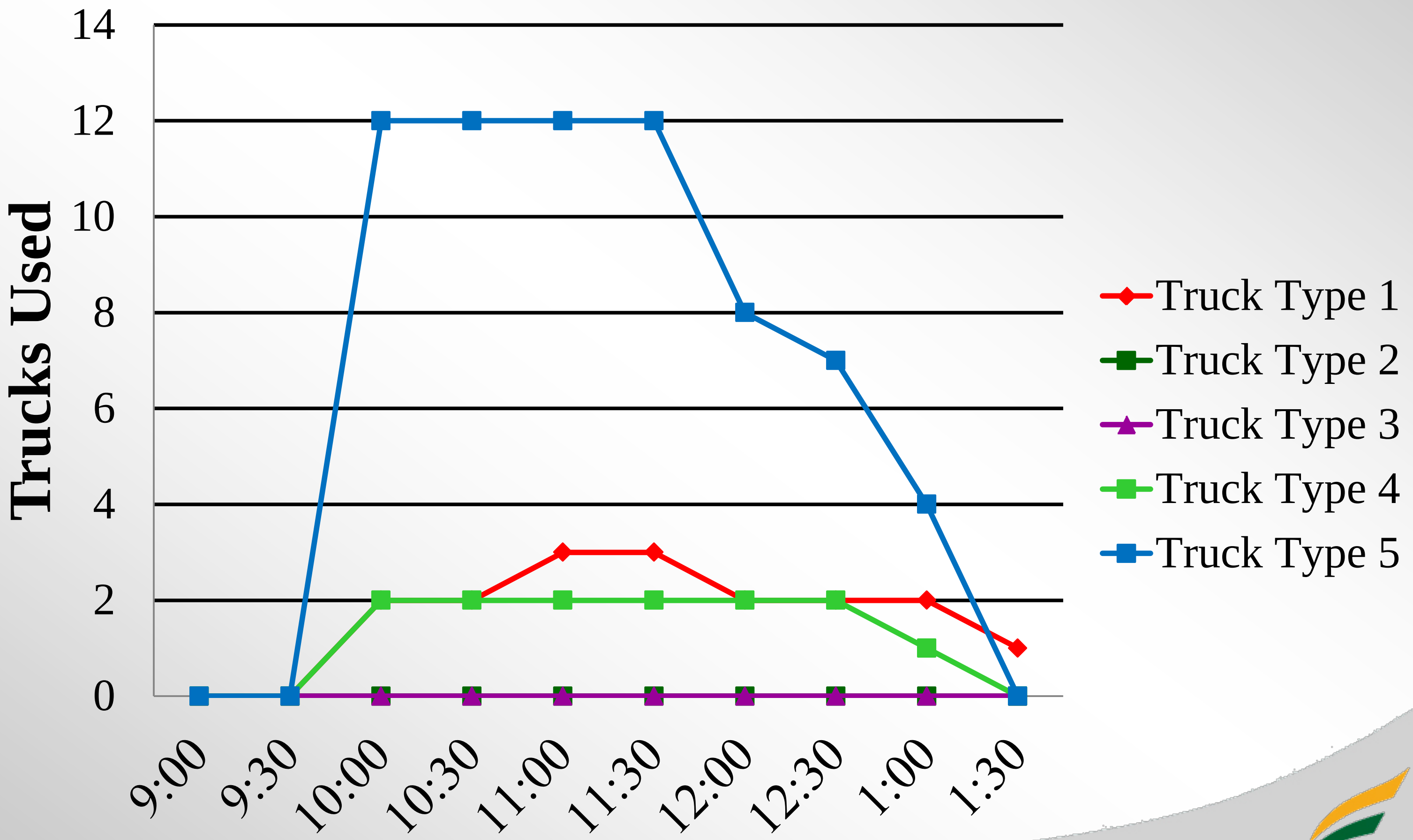
Projection Limitations

- Not enough Data: 2 Months of Data August-October
  - Projections show increases likely due to Holiday Ads
  - Need Data over a longer time period for better projections
- Projections are of Average Demand
  - Because of Variability need worst case projections to assess fleet

Unconstrained Fleet Mix



Conclusions

- Bundling orders into multi-distribution center tours generates significant savings.
- Efficient tour routing is not obvious and requires optimization software.
- Given that cost/mile is roughly the same for all tractor trailers, fleet should move towards a mix of straight trucks and 53’ trailers.
- Efficiently scheduling truck routes reduces the number of trucks (drivers) needed.

Follow on Work

- Fleet Mix Assessment
  - Collect More Data
  - Establish Better Projections
  - Assess Fleet Mix by performing Trade of long/short lease

- Predictive Driver Scheduling model
  - Predict Weekly Demand
  - Feed demand into truck schedule
  - Generate driver assignments based on schedule
  - Propose process to account for difference between schedule and need for drivers

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Acknowledgements

- Dr. Loerch
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Questions?