

Competitive Performance Assessment of Dynamic Vehicle Routing Technologies Using Sequential Auctions

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Motivation ...

Developments in Information and Communication Technologies are:

- Transforming Supply Chain Operations
- Introducing **new ways of matching supply and demand**
 - Private Exchanges
 - Transportation Auctions
- Allowing carriers to implement more sophisticated Dynamic Vehicle Routing Technologies (DVR)
 - Real Time Operation
 - Improved scheduling decision systems

Dynamic Vehicle Routing Technologies have to increasingly deal with a new class of problems...

FROM

TO

- | | | |
|--|---|---|
| ■ Pre-negotiated Contracts | ➡ | ■ Dynamic Pricing |
| ■ Limited, standard services | ➡ | ■ Customized services, all the time, everywhere |
| ■ Static, Deterministic Conditions | ➡ | ■ Dynamic, Stochastic Environments |
| ■ Optimization for long term equilibrium | ➡ | ■ Optimization under Real Time Information |
| ■ Absence of competition in every day operations | ➡ | ■ Highly competitive environments |

Traditional Approaches to Evaluate the Performance of Vehicle Routing Technologies

■ Static

- complexity analysis
- worst case/average case

■ Dynamic

- Competitive Analysis
 - Competitive ratio against a powerful off-line adversary
 - Adversary determines the sequence of future tasks
 - Oblivious
 - Adaptive

■ Asymptotic performance

Traditional Approaches to Evaluate the Performance of Vehicle Routing Technologies

Issues in a Dynamic Competitive Environment:

- Does an optimal policy exist?
- Even if there is an optimal policy
 - Comparison is NOT in a level playing field (hind sight advantage)
 - Trivial results using competitive analysis
 - NO dynamic interaction among Carriers under relevant demand scenarios
 - Real Time Implementation

Proposed Approach to Evaluate the Performance of Dynamic Vehicle Routing Technologies (DVR)

1. Make 2 carriers compete under different demand scenarios in a Procurement Market for Transportation Services
2. Use Sequential 2nd price auctions
 - Allocate service requests among carriers
 - Determine the corresponding price
3. Use simulation to obtain the relevant pay-off information

Research Methodology

- Study the impact of:
 - fleet management technological asymmetries
- On carriers':
 - Costs
 - Revenue
 - Profits
 - Market share
- Under different market settings
 - Shipment Arrival Rates
 - Time Window Lengths

Auction Type: Second Price Auction (one shot)

■ DEFINITION (reverse auction)

- Carrier with lowest bid wins item
- Winner get paid second lowest bid
- Rest of bidders do not pay or receive anything

■ PROPERTIES (Vickrey 1961)

- Equilibrium strategies are truth-revealing and dominant strategies
- They do not require gathering or analysis of information about the competitors' situation
- Leads to complete economic efficiency, the bidder with the lowest cost wins

■ Equivalent Results with Ascending English Auction and Proxy Bidding

Problems with 2nd Price Sequential Auctions

- Complexity of equilibrium and strategy analysis increases substantially
- No known equilibrium for bidders with multi-unit demands and heterogeneous items
- Marginal Cost is a random variable and depends on the future sequence of arrivals

Behavioral Assumptions

ASSUMPTION: a carrier bids the “best” estimation of his marginal product produced by his technology

■ Obtained:

- Carriers rationality: preference over outcomes with higher expected profit
- Dropping common knowledge assumption
 - Minimum Information Revealed
 - Complexity of simulating competitors' future payoffs and actions

Experimental Factors

■ Different Carrier Technologies

- Naïve
- Optimal Static (OS)
- 1 Step Look-Ahead (1LA)

■ Different Arrival Rates (AR)

- $\lambda = 0.5$ arrivals/truck (Low)
- $\lambda = 1.0$ arrivals/truck (Med.)
- $\lambda = 1.5$ arrivals/truck (High)

■ Different Time Window Lengths (TWL)

- 1 * loaded distance + 1 * uniform (0,1) (Short)
- 2 * loaded distance + 2 * uniform (0,1) (Med.)
- 3 * loaded distance + 3 * uniform (0,1) (Long)

– Average Loaded Distance ≈ 0.52

– Average Empty Distance ≈ 0.25

Other Market Settings

- Geographic Area : 1 * 1 square space
- Shipment Origin and Destination \approx Uniformly distributed on space
- Earliest Pick Up Time = arrival time
- Fleet size: 2 to 6 vehicles serving the market
- The reservation price of the buyer is 1.5 units

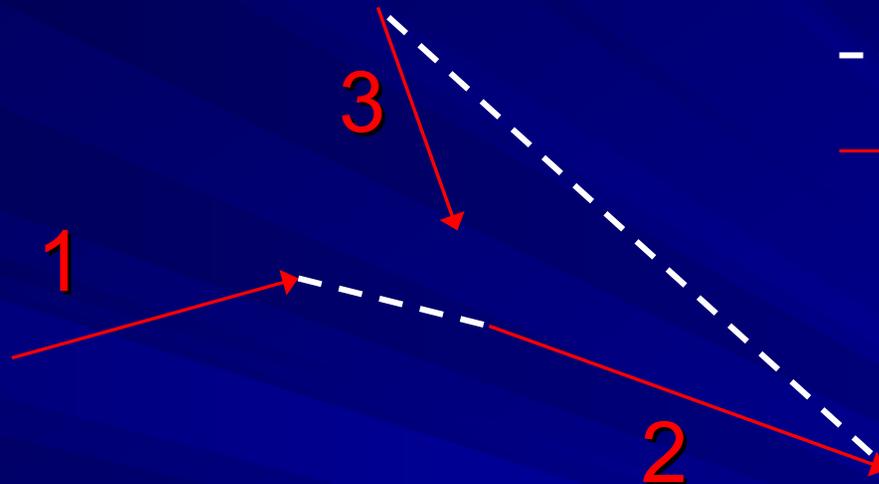
- Simulation Results: 10 iterations (1000 arrivals)

Carriers' Technologies

- **Naïve**: Insertion at the end of truck's list of assigned shipments
- **Tech OS** : “Optimal Static Assignment” at fleet level. Solve optimal assignment for ALL trucks at a time (MIP formulation)
 - MIP formulation objective:
 - Minimize empty distance

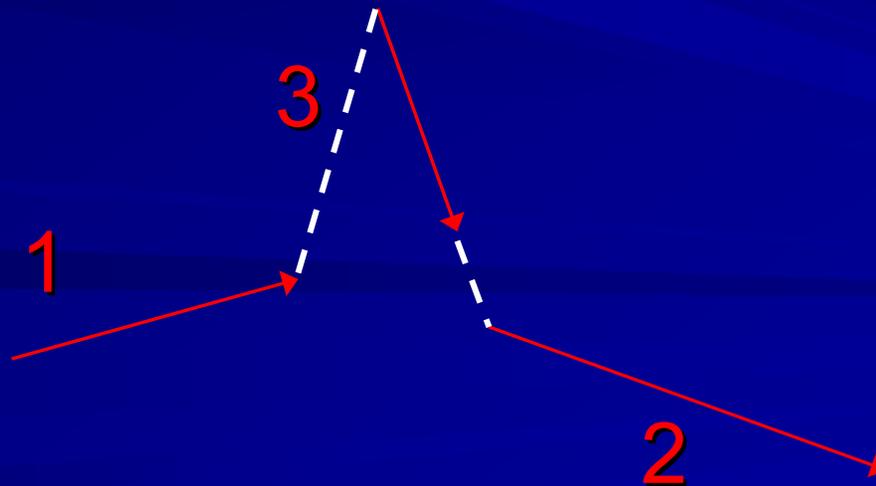
Carriers' Technologies

Naïve



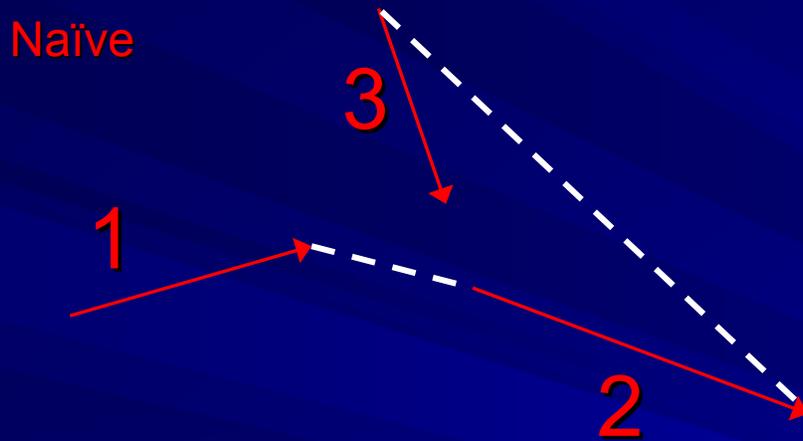
- 1, 2, 3 Arrival Order
- Empty Movement
- Loaded Movement

Tech OS

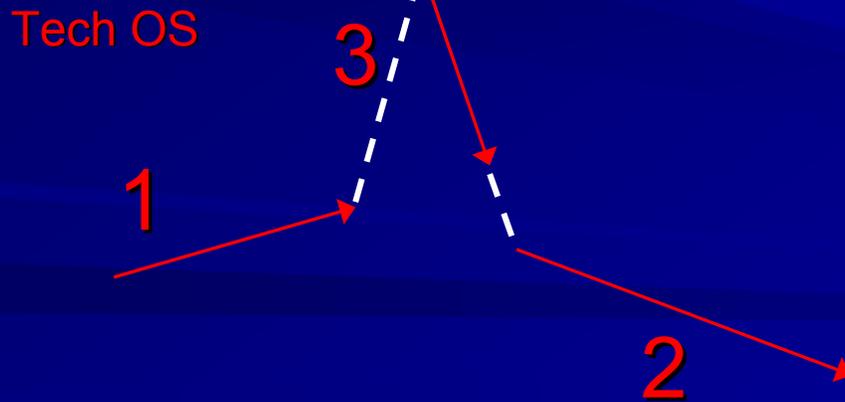


Carriers' Technologies Marginal Costs

- 1, 2, 3 Arrival Order
- Empty Movement
- Loaded Movement



Naïve Marginal Cost (Shipment 3)



OS Marginal Cost (Shipment 3)

----- (+) -----

(-) -----

= -----

Carriers' Technologies

- **Tech 1LA** : “Optimal Static Assignment” + 1 Step Look-Ahead
 - Elimination of Weakly Dominated Strategies
 - Backward Iteration

$$\text{Bid} = mc(\text{static}) + E(P_1 | \text{lose}) - E(P_1 | \text{win})$$

Where:

$E(P_1)$ = expected profit for the next arriving shipment

Intuition:

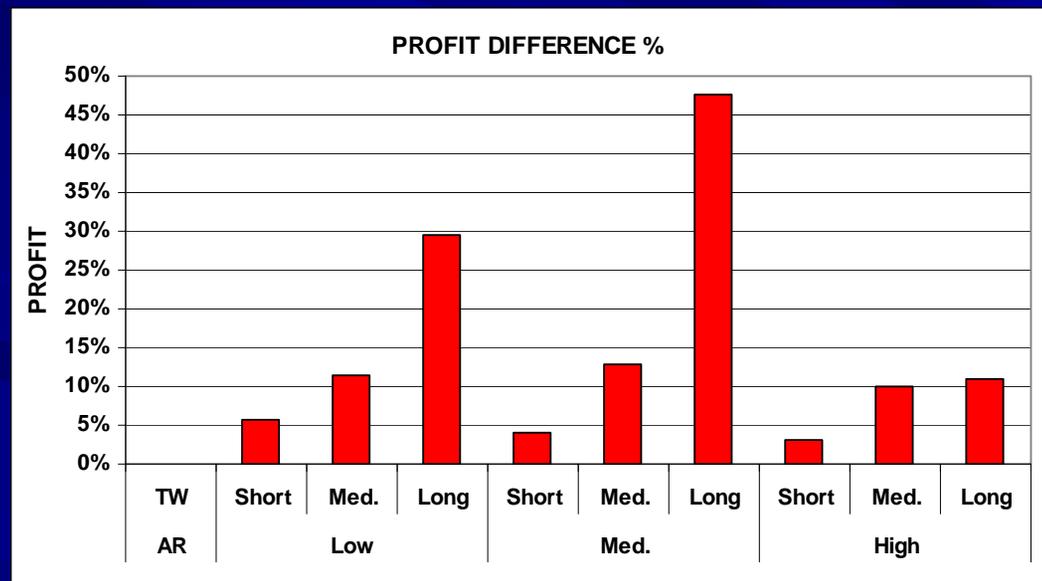
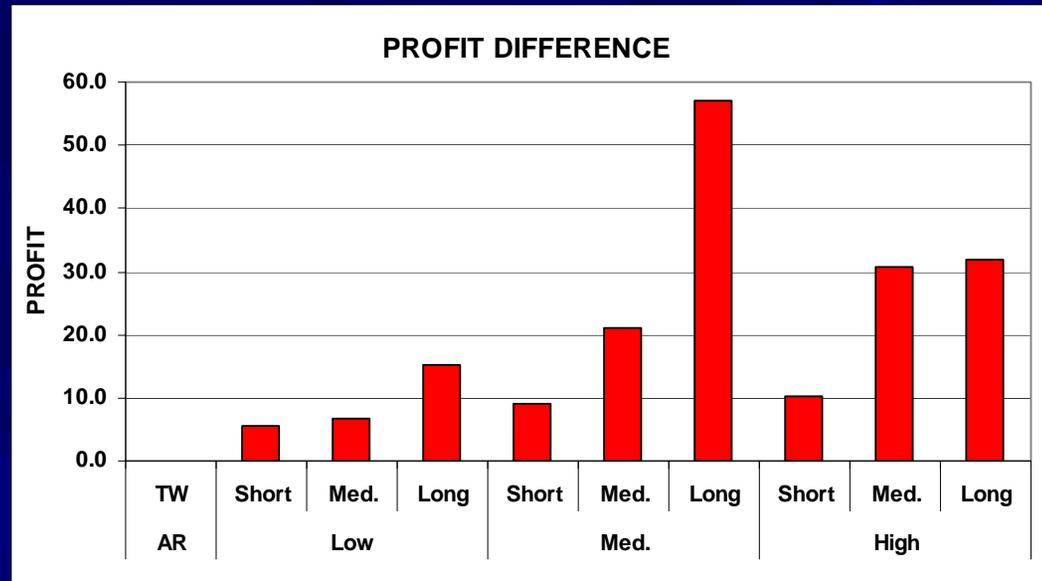
Better deployment, then future profits \uparrow , current $mc \downarrow$

Worse deployment, then future profits \downarrow , current $mc \uparrow$

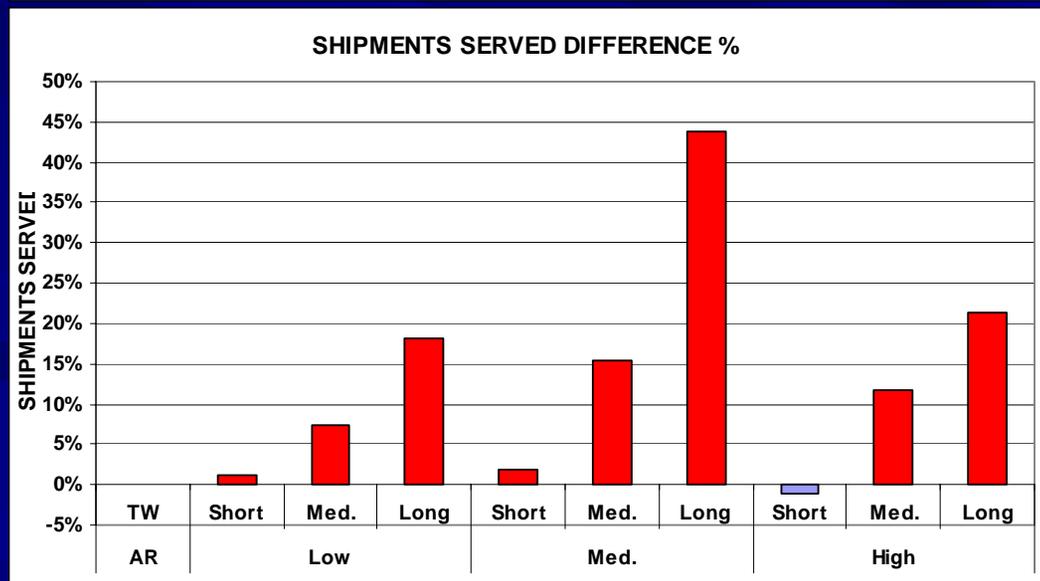
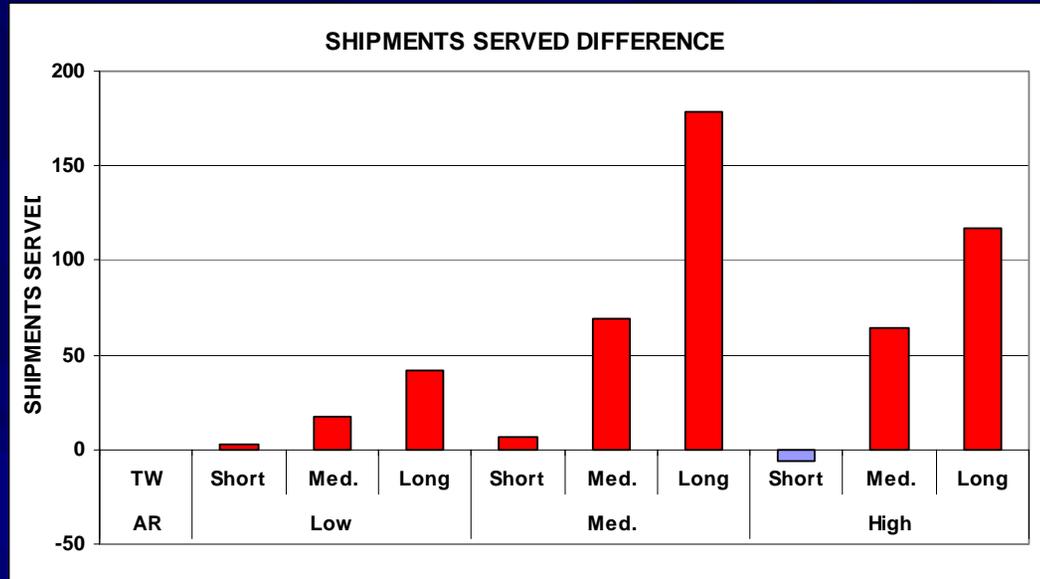
Carriers' Technologies

- **Tech 1LA** : “Optimal Static Assignment” + 1 Step Look-Ahead
 - Solve optimal assignment for all trucks at a time (MIP formulation)
 - Simulate future expected profits With and Without the shipment currently being bided on
 - Carrier learns revenue distribution online (assumed stationary stochastic process)
 - Adding opportunity cost to “static” estimation
 - Capacity to serve future shipments
 - Fleet deployment changes

Comparing Naïve and OS Technologies



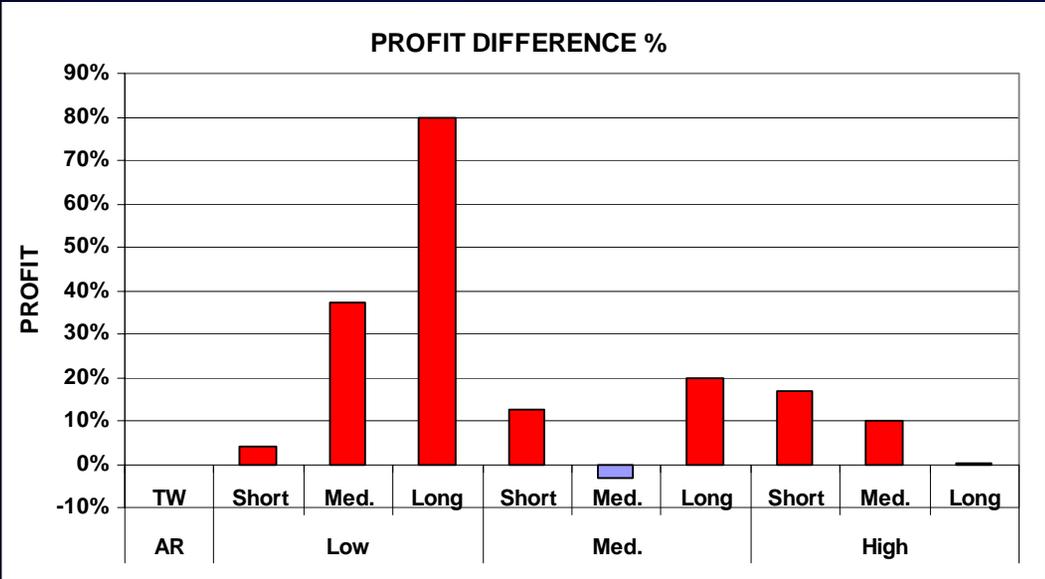
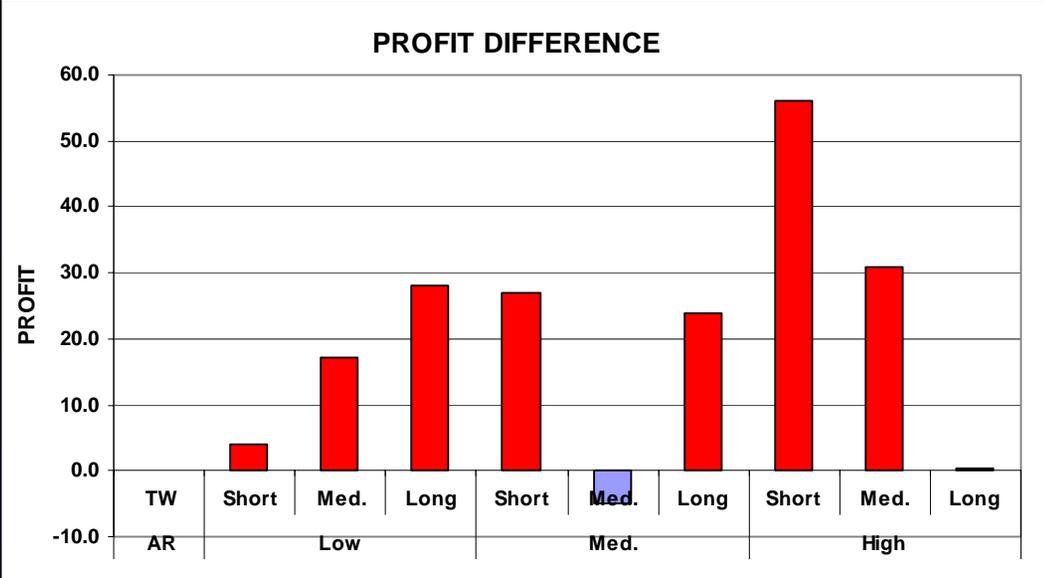
Comparing Naïve and OS Technologies



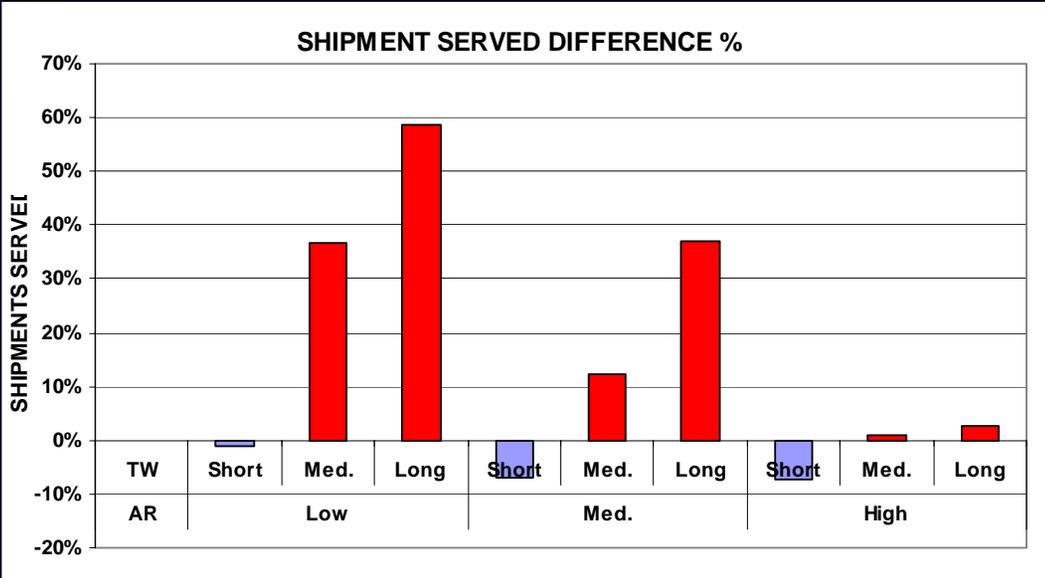
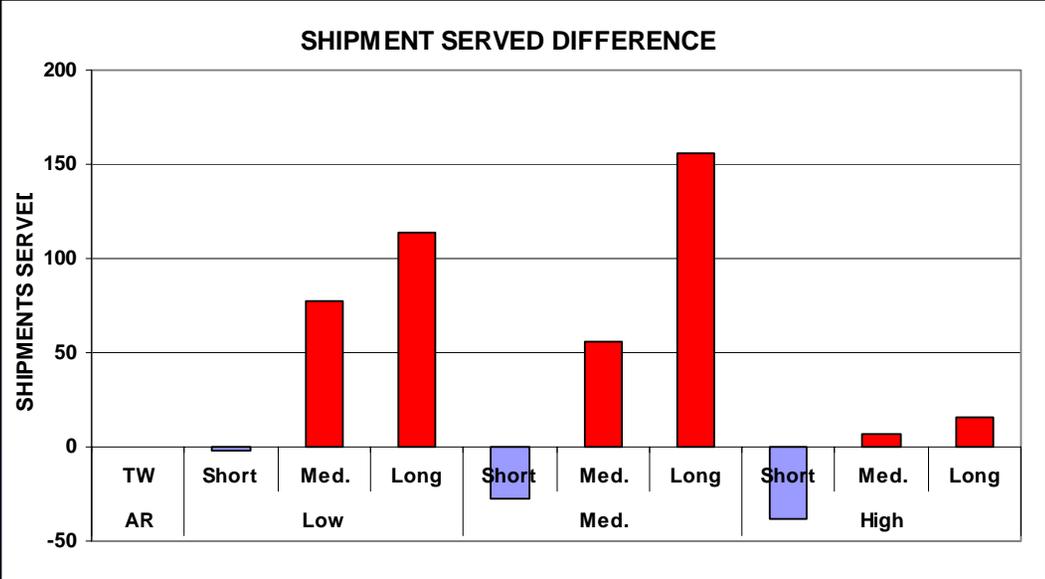
Analysis of Results

- More sophisticated technologies are more competitive
- OS significantly improves over Naïve:
 - Med. arrival rates (competitive environment)
 - Longer time Windows (more shipments)

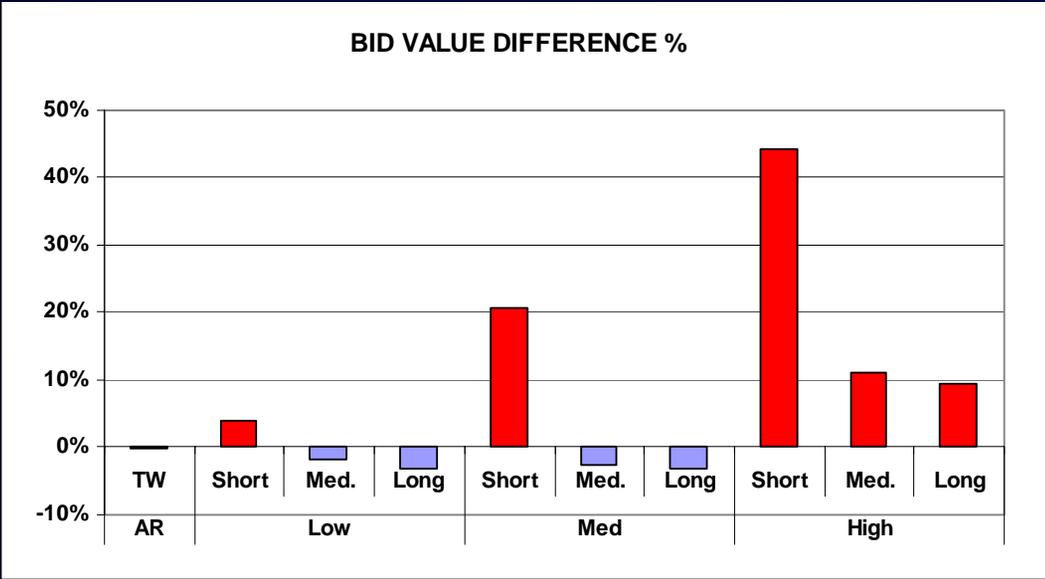
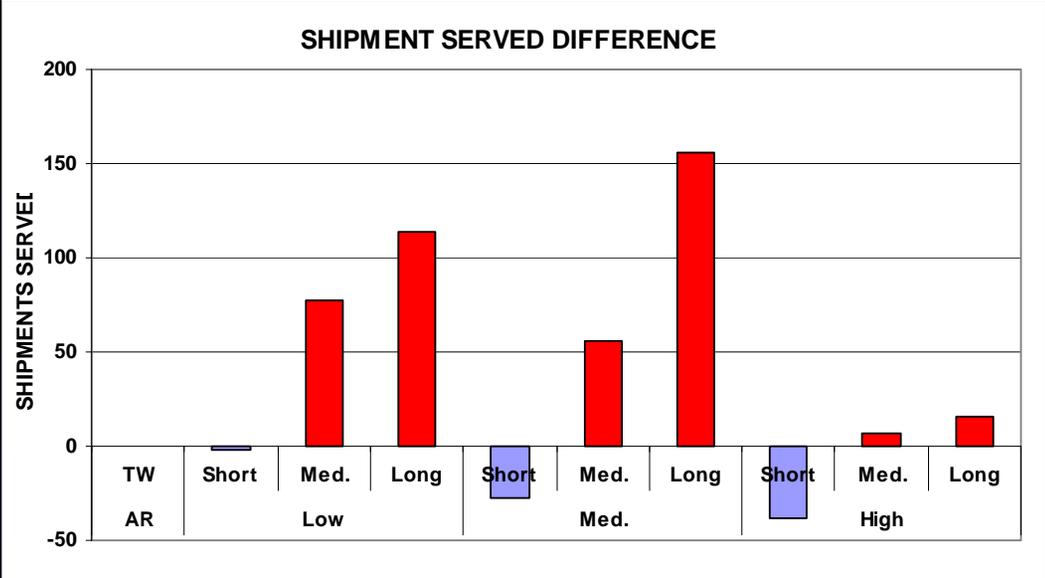
Comparing OS and 1LA Technologies



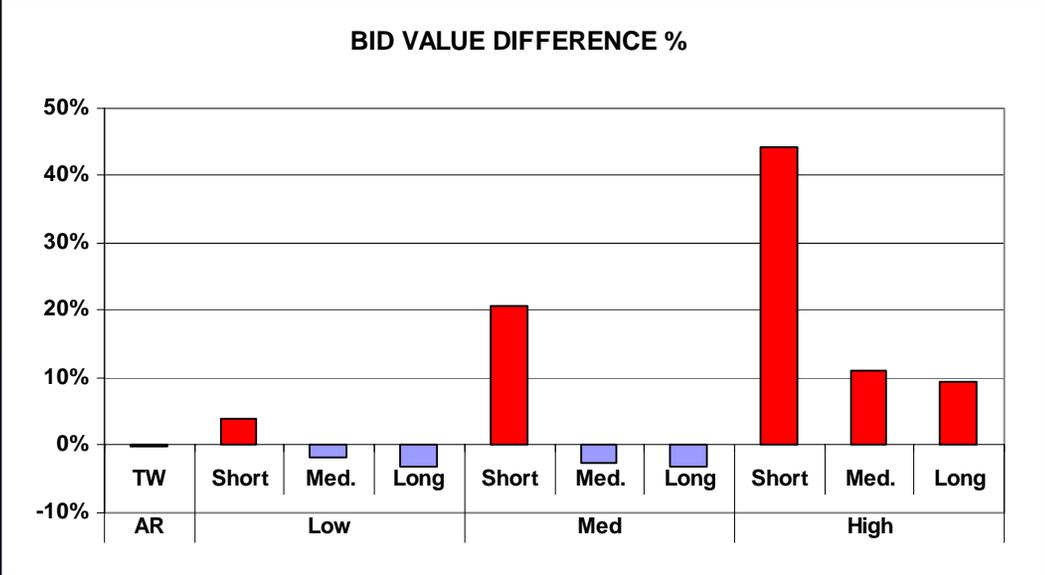
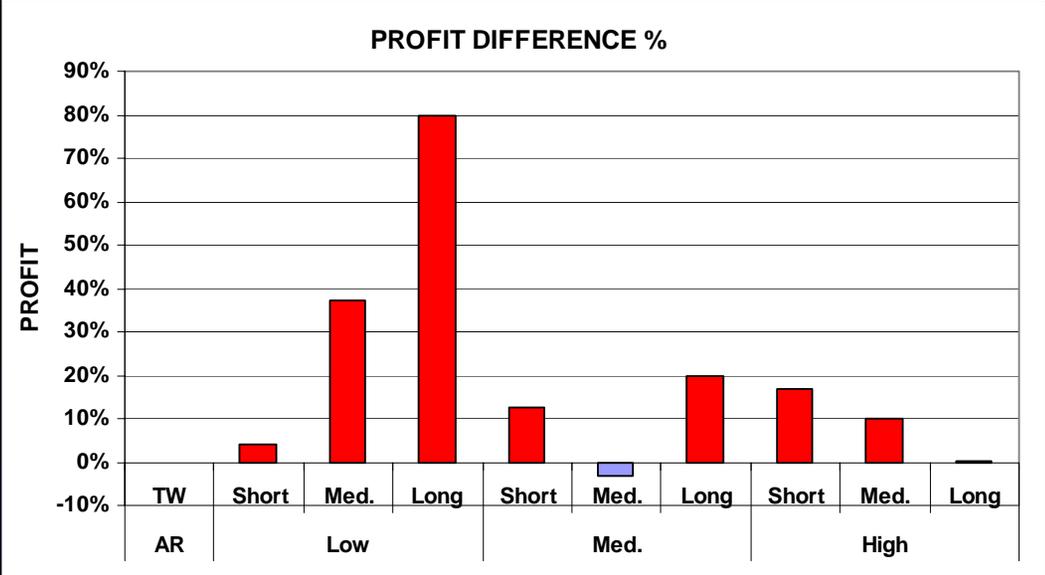
Comparing OS and 1LA Technologies



Comparing OS and 1LA Technologies



Comparing OS and 1LA Technologies



Analysis of Results

- 1LA significantly improves over OS:
 - Shorter time windows
 - Harder to accommodate new shipments
 - Higher prices → Less Shipments → Higher Profits
(static appraisal underestimates cost of a shipment)
 - Med. and Long time windows
(uncongested AR)
 - Easier to accommodate new shipments
 - Lower prices → More Shipments → Higher Profits
(static appraisal overestimates cost of a shipment)
 - Low arrival rate
 - Higher percentage wise profit increase

Conclusions

- Methodology to compare algorithms seems to capture the *competitiveness* of the different DVR technologies in relation to:
 - market parameters
 - characteristics of DVR algorithms
- 1SLA technology captures the “opportunity costs” of serving a shipment as function of
 - Arrival rate
 - Time window lengths