Inventory Planning in Engineer-to-Order (ETO) Steel Industry

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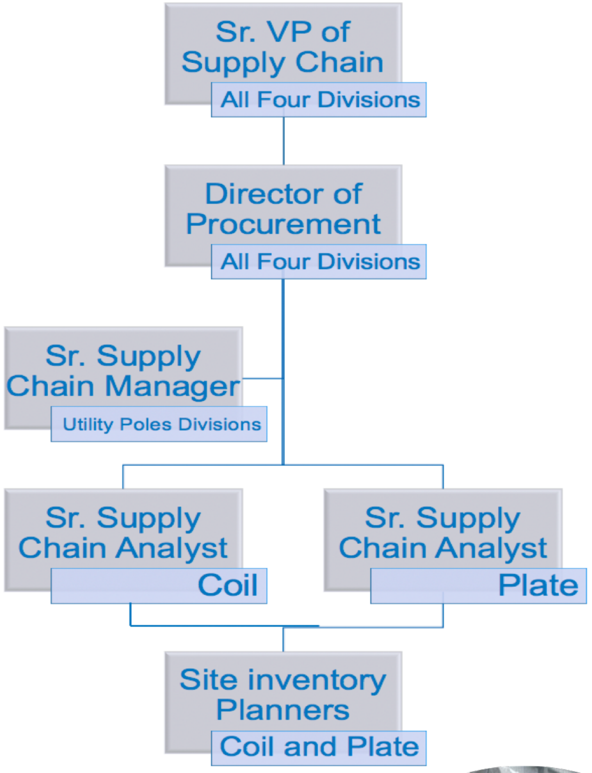
MIT | Supply Chain MANAGEMENT

Agenda

1. ETO Industry & Case Company Supply Chain
2. Motivation & Research Question
3. Data Analysis and Methodology
4. Model Formulation & Model Validation
5. Sensitivity & Scenarios Analysis
6. Conclusion and Future Research

ETO Industry, Case Company & its Supply Chain

- ETO Characteristics:
  - Decoupling Point
  - Modification & Customizations
  - High Uncertainty Demand
  - Long Lead Time
  - Low Volume



- Focus On: Safety Stock, Lead Time, ETO Order Pattern

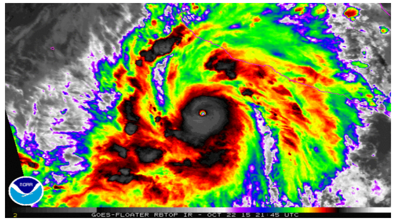
- Case Company:
  - Engineer-To-Order (**ETO**)
  - **Project Tender-for-Bid** Based Business
  - Uncertain Demand
  - Consume **STEEL** as Raw Material:
    Steel Coil and Plate

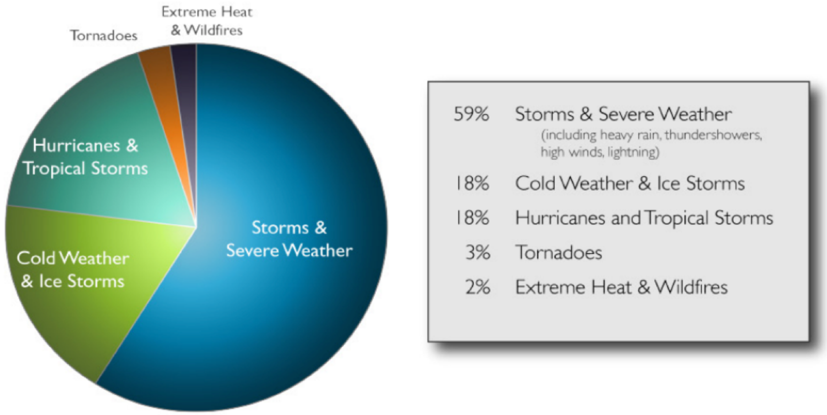
Motivation

- Initial Motivation
  - In 2008, $420 billion spent valued at $2 trillion inventory.

(Wilson, R. 2009. 20th Annual State of Logistics Report. Council of Supply Chain Management Professionals)

  - In 2017, hurricane damage rescue.
  - 6-9 months to replace the destroyed utility poles





Severe weathers, storms, hurricanes, and tornados caused nearly **90%** of all weather-related power outage

(Data Source: the U.S. Department of Energy's (DOE) Office of Electricity Delivery & Energy Reliability-Form OE-417 report)

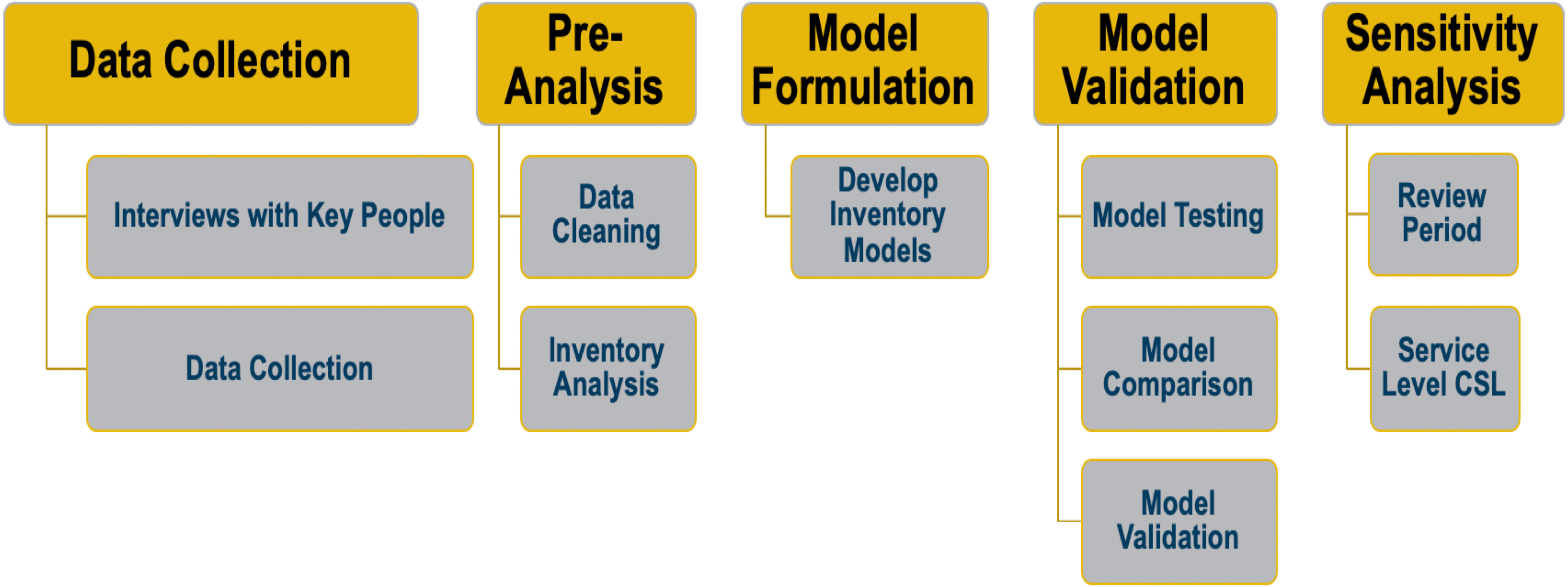
- Motivation in Scope
  - Outdated inventory policy
  - Scientific approach to replace the inventory management system

Research Question

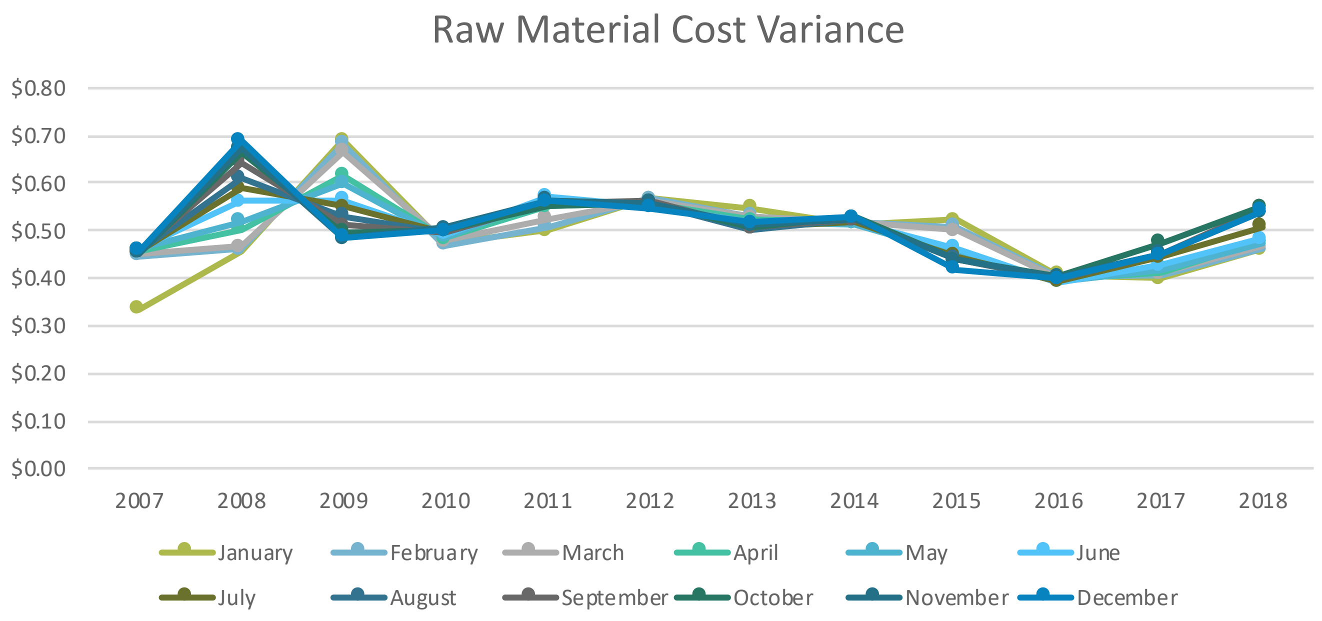
What is the optimal inventory policy of the company under regular business process?

What is the optimal review period, safety stock level, and order quantity for each site?

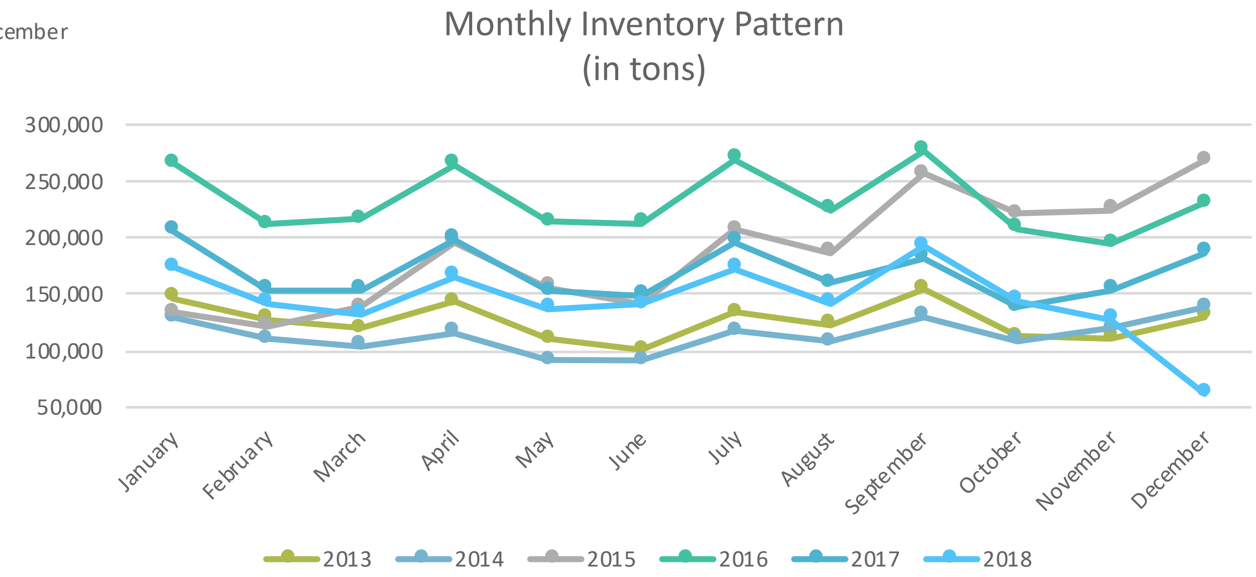
Methodology



Data Analysis



Raw Material Cost: $ per lbs



Model Assumptions and Notation

- Model Assumptions
  - Demand
    - variable and continuous
  - Lead time
    - constant and deterministic

      (4 weeks avg)
  - Raw material
    - independent items

      (total tonnage of steel coil and plate)
  - Holding Cost
    - 12.5%
  - Service Level
    - 90% (Management Decided)

Table 1: Notation

c	Cost of raw material (dollar per ton)
i	Index for review period (review period per week)
h	Inventory holding rate – annual (% of inventory cost)
C_s	Shortage Cost (dollar per ton)
C_t	Ordering cost (dollar per order)
C_e	Inventory holding cost (dollar per ton) $C_e = c * h$
s	Reorder point (weight - tonnage)
μ_{DL}	Mean demand over lead time (weight - tonnage)
σ_{DL}	Standard deviation of demand over lead time (weight - tonnage)
CSL	Service level: 90% -- management decided
	$CSL = 1 - \text{Prob [Stockout]} = 1 - \text{Prob [X} > \text{s]} = \text{Prob[X} <= \text{s]}$
k	Safety stock factor
	$k = norm.s.inv\ (1 - \text{P X} > \text{s})$ or $k = norm.s.inv(CSL)$
$g(k)$	Unit short factor
	$g(k) = norm.dist(k, 0,1,0) - k \times (1 - norm.s.dist\ (k, 1))$
S	Order up-to point (weight - tonnage)
R	Review time period - 1 week in this case
μ_{DL+R}	Mean demand over lead time and review period (weight - tonnage)
σ_{DL+R}	Standard deviation of demand over lead time and review period (weight - tonnage)
Q	Order quantity (weight - tonnage)
TRC	Total relevant cost (dollar of total tonnage)

Model Formulation

Continuous Review Inventory model

(s,Q) Model
Order Point, Order Quantity

VS

Periodic Review Inventory model

(R,S) Model
Review Period, Order Up-To

$$s = \mu_{DL} + k \times \sigma_{DL}$$

$$S = \mu_{DL+R} + k \times \sigma_{DL+R}$$

Total Relevant Costs

VS

$$TRC(Q) = \sum_{i=1}^{52}(C_t * \left(\frac{D}{Q}\right) + C_e * \left(\frac{Q}{2} + k * \sigma_{DL}\right) + C_s * Prob[Stock\ Out])$$

or $$TRC(Q) = \sum_{i=1}^{52}(C_t * \left(\frac{D}{Q}\right) + C_e * \left(\frac{Q}{2} + k * \sigma_{DL}\right) + C_s * \sigma_{DL} * g(k) * \left(\frac{D}{Q}\right))$$

Total Relevant Costs

$$TRC(Q) = \sum_{i=1}^{52}(C_t \left(\frac{D}{Q}\right) + C_e \left(\frac{Q}{2} + k * \sigma_{DL+R}\right) + C_s * Prob[Stock\ Out])$$

or $$TRC(Q) = \sum_{i=1}^{52}(C_t \left(\frac{D}{Q}\right) + C_e \left(\frac{Q}{2} + k * \sigma_{DL+R}\right) + C_s * \sigma_{DL+R} * g(k) * \left(\frac{D}{Q}\right))$$

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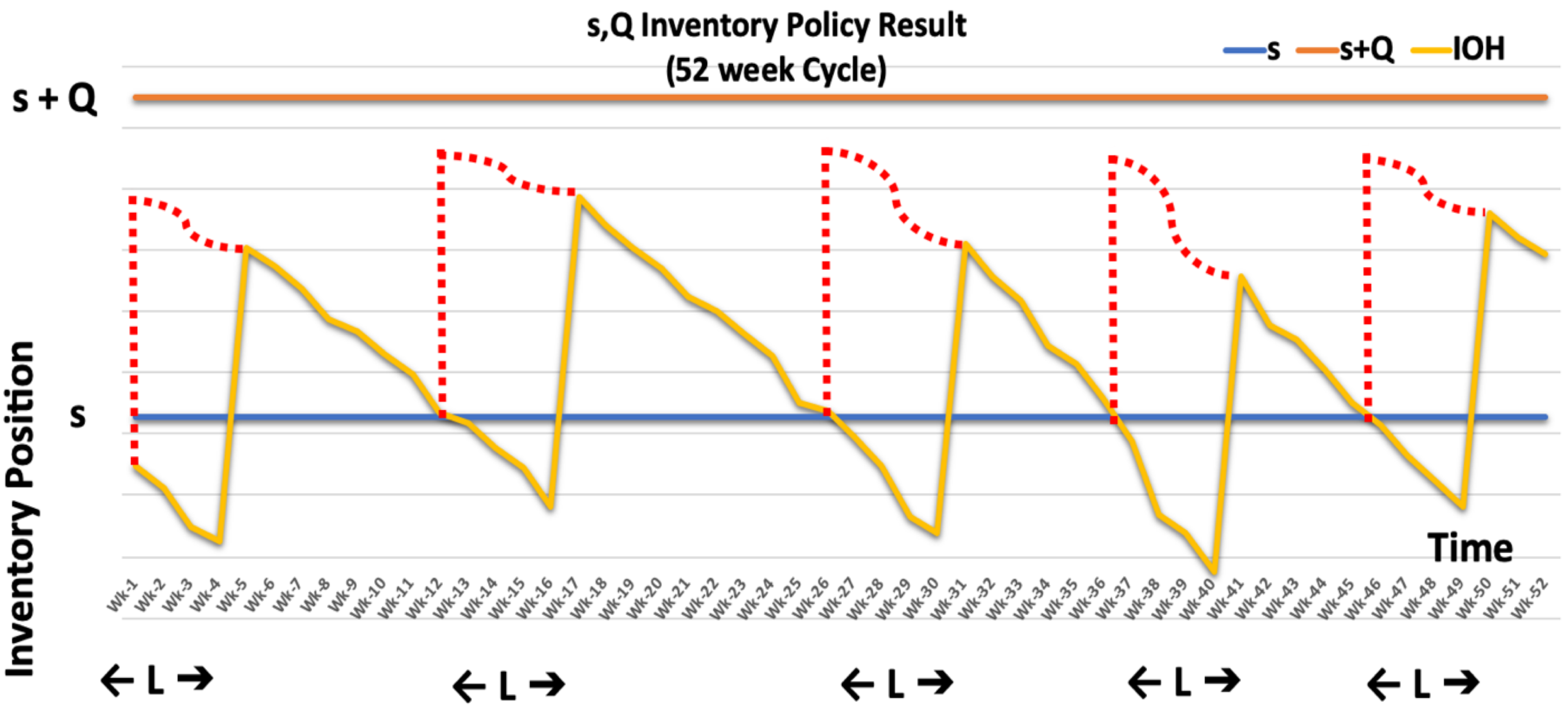
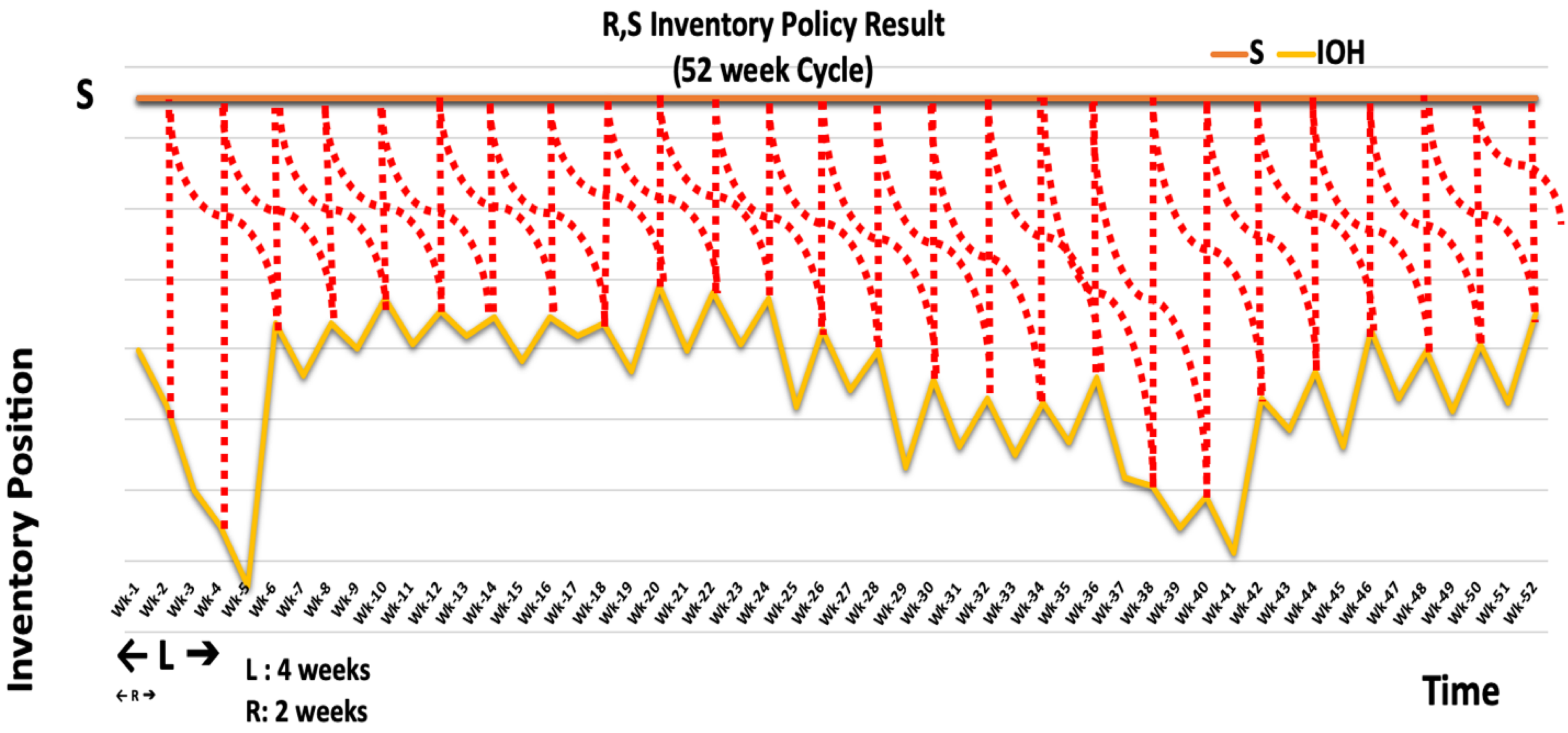
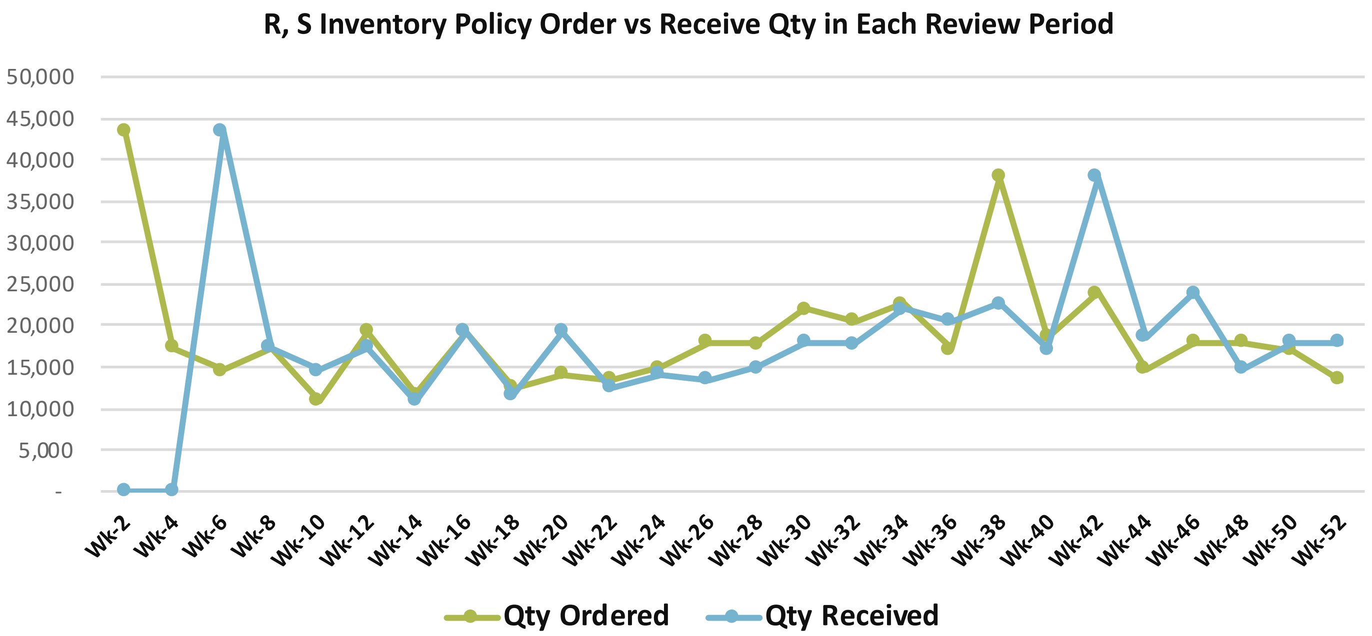
Model Result – (s,Q) Policy



Model Result – (R,S) Policy



Model Result – (R,S) Policy



Week Ordered	Qty Ordered	Week Received
Wk-2	43,362	Wk-6
Wk-4	17,334	Wk-8
Wk-6	14,562	Wk-10
Wk-8	17,406	Wk-12
Wk-10	10,890	Wk-14
Wk-12	19,242	Wk-16
Wk-14	11,664	Wk-18
Wk-16	19,278	Wk-20
Wk-18	12,582	Wk-22
Wk-20	14,076	Wk-24
Wk-22	13,536	Wk-26
Wk-24	14,922	Wk-28
Wk-26	18,000	Wk-30
Wk-28	17,748	Wk-32
Wk-30	22,032	Wk-34
Wk-32	20,538	Wk-36
Wk-34	22,644	Wk-38
Wk-36	17,100	Wk-40
Wk-38	37,926	Wk-42
Wk-40	18,594	Wk-44
Wk-42	23,850	Wk-46
Wk-44	14,832	Wk-48
Wk-46	17,910	Wk-50
Wk-48	18,000	Wk-52
Wk-50	16,974	Wk-2 Following Year
Wk-52	13,536	Wk-4 Following Year

Model Validation

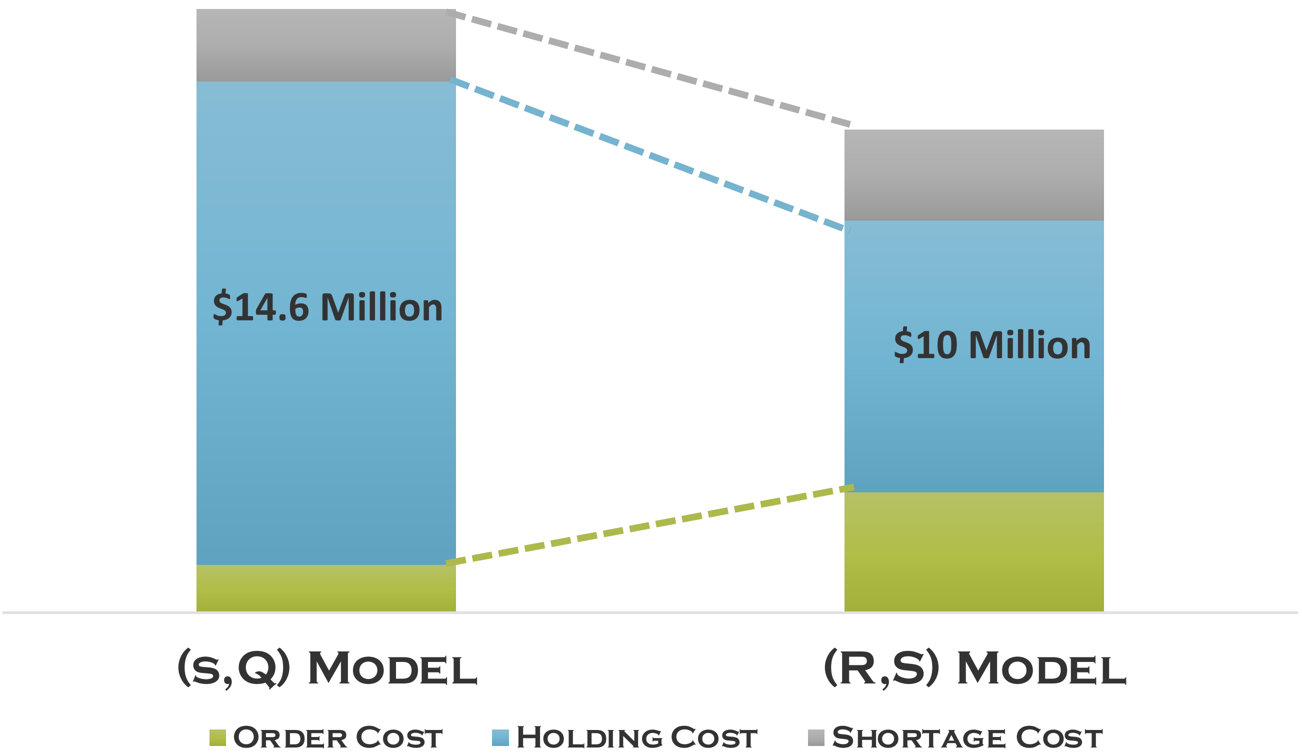
Total Relevant Cost

- (R,S) Policy is better
- $4.6 million dollars less spend

s,Q Inventory Policy				
Quantity				
s - Reorder Point	Q in ton	Safety Stock	Shortage	Ttl Order Count
45,685	104,346	10,794	399	5

R,S Inventory Policy				
Quantity				
S - Order upto	Q in ton	Safety Stock	Shortage	Ttl Order Count
65,556	* below chart	13,220	488	24

(s,Q) Model vs (R,S) Model



(Chart is not scaled based on cost)

Sensitivity Analysis

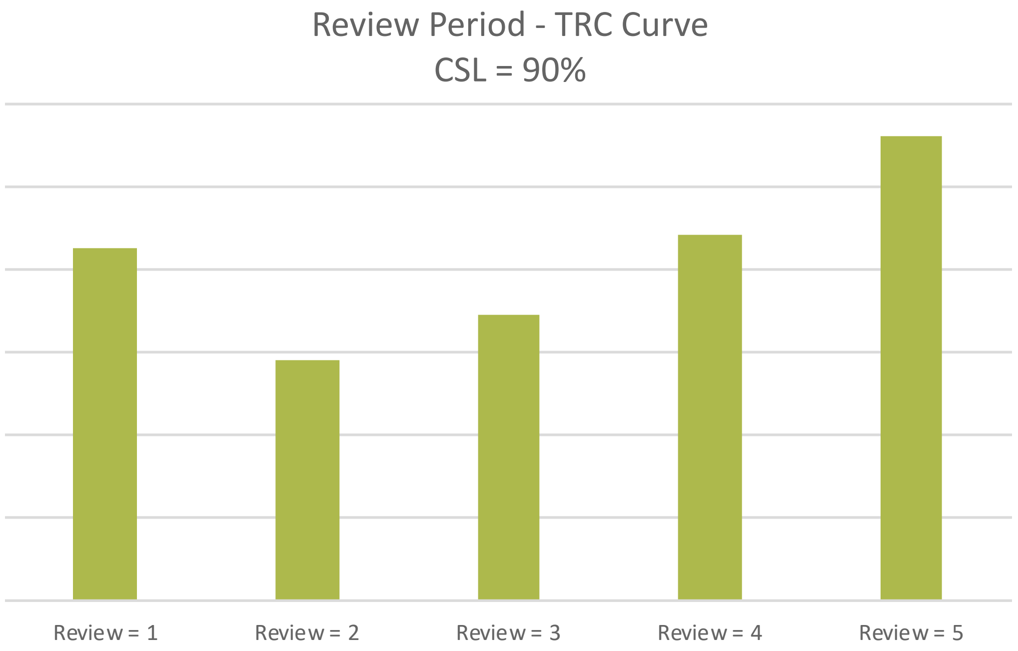
Optimal

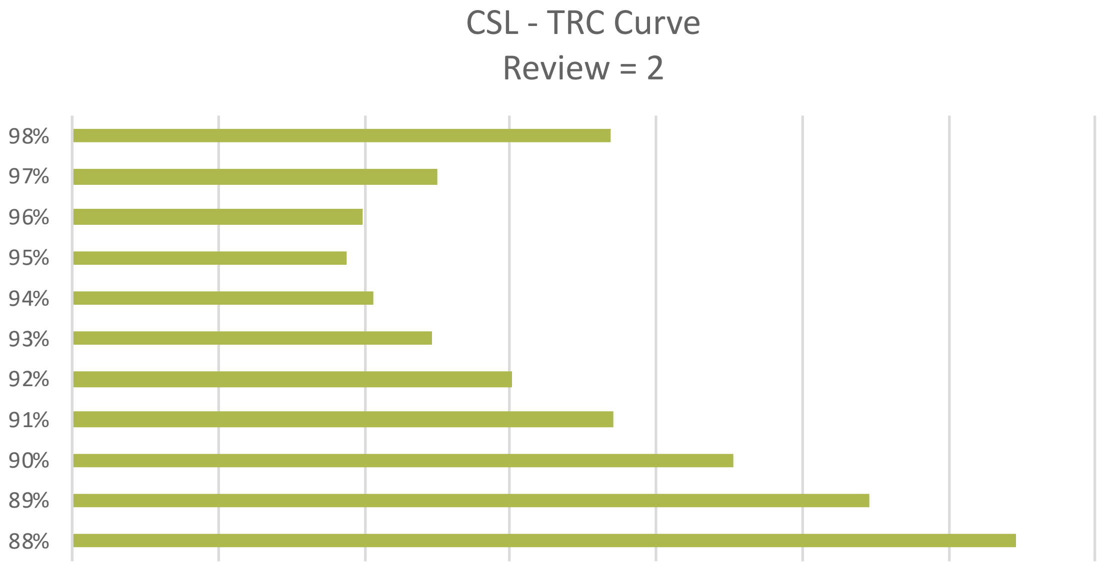
- Review Period: 2 weeks
- CSL: 95%

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($675,984)	$0	($4,719,743)	($5,216,229)	($5,799,050)

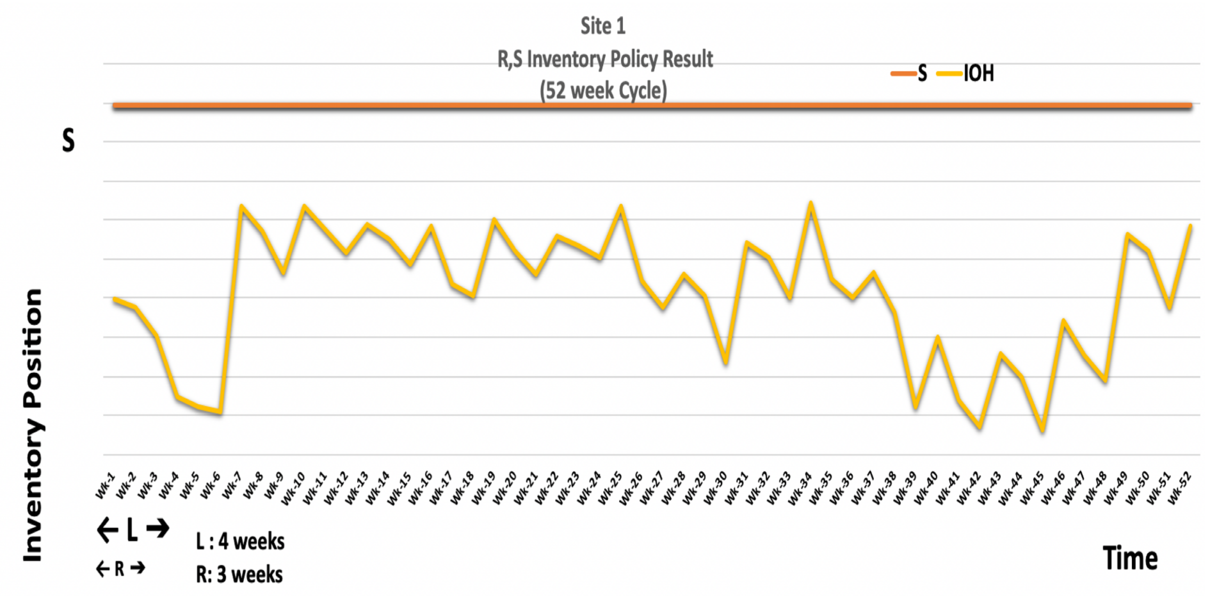
CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($940,379)	($264,395)	($531,359)	($1,027,845)	($1,610,66

Review Period = 2 Weeks	93%	94%	95%	96%	97%	98
TRC	($57,032)	($17,957)	$0	($10,193)	($61,259)	($180,56





Scenarios Analysis – Site 1



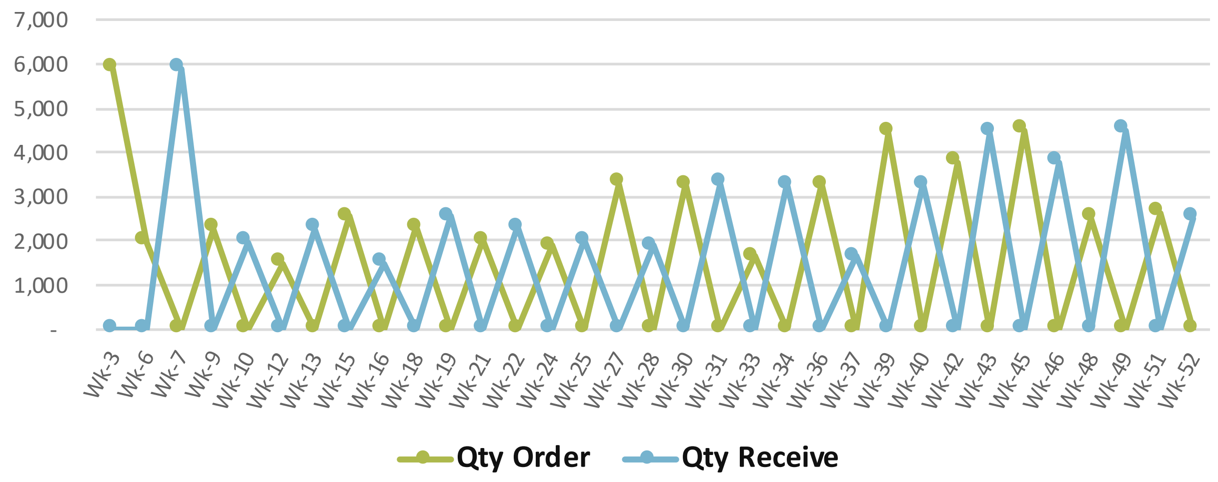
Site 1 Optimal

- Review Period: 3 weeks
- CSL: 93%

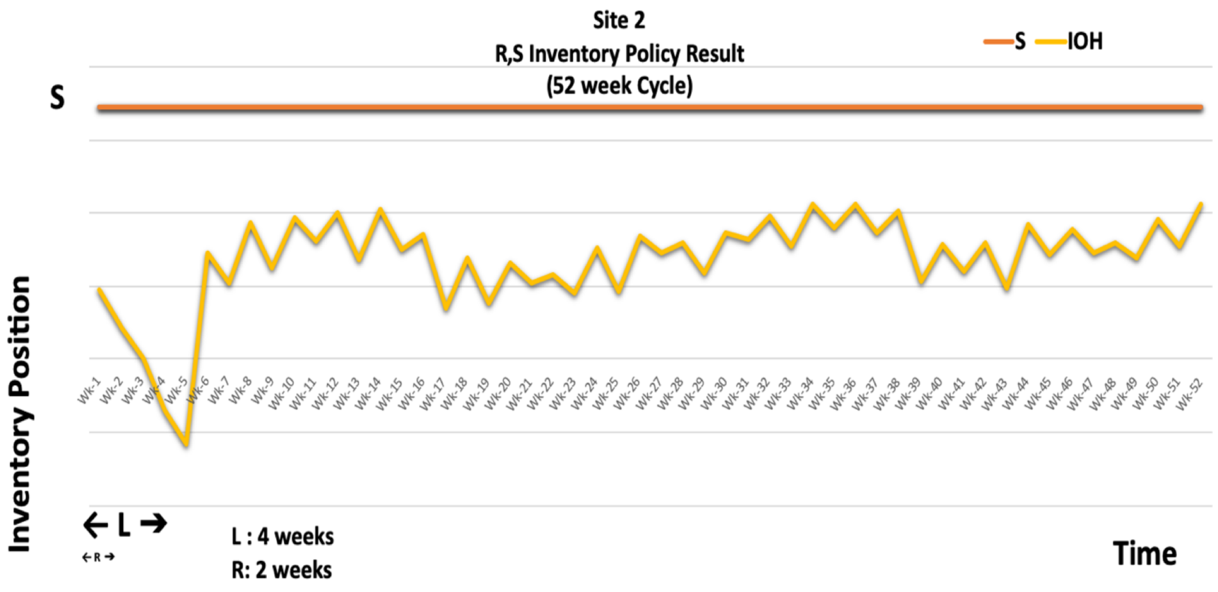
Site 1 (R,S) Result

- Safety Stock Level: 2,948 tons
- No stock out

Site 1 R, S Inventory Policy Order vs Receive Qty in Each Review period

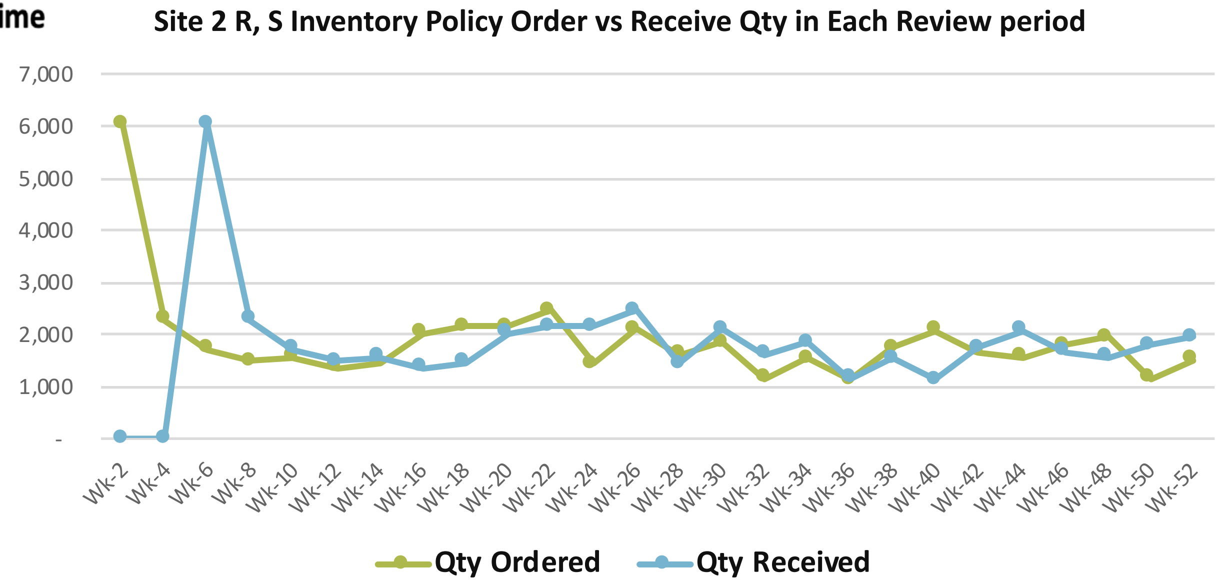


Scenarios Analysis – Site 2



Site 2 Optimal

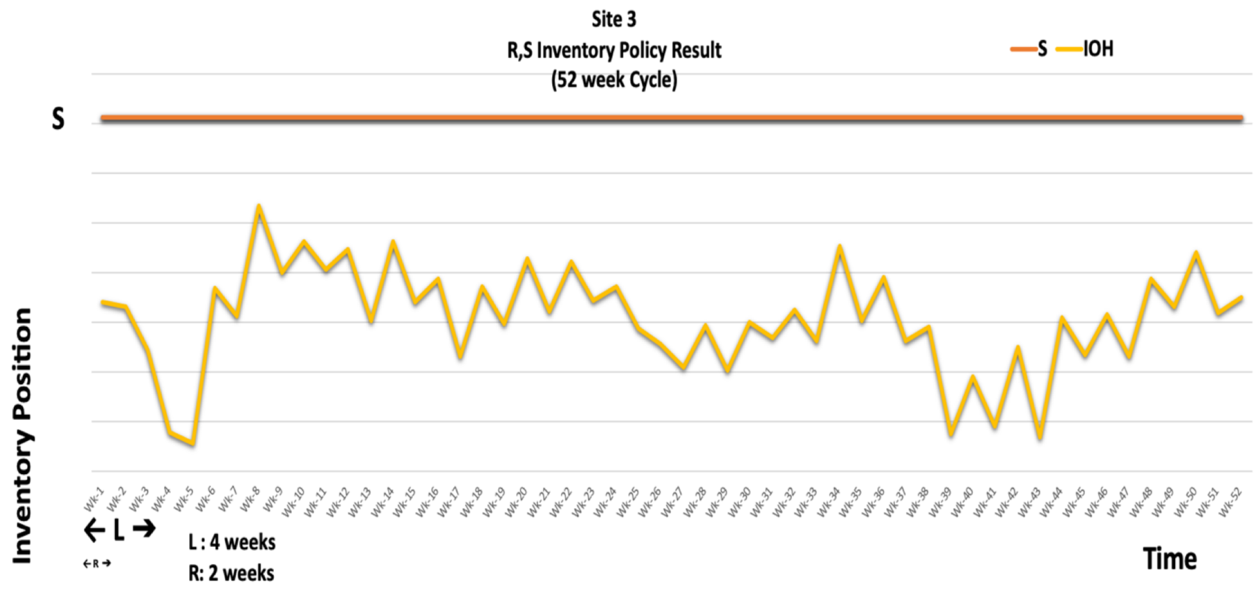
- Review Period: 2 weeks
- CSL: 95%



Site 2 (R,S) Result

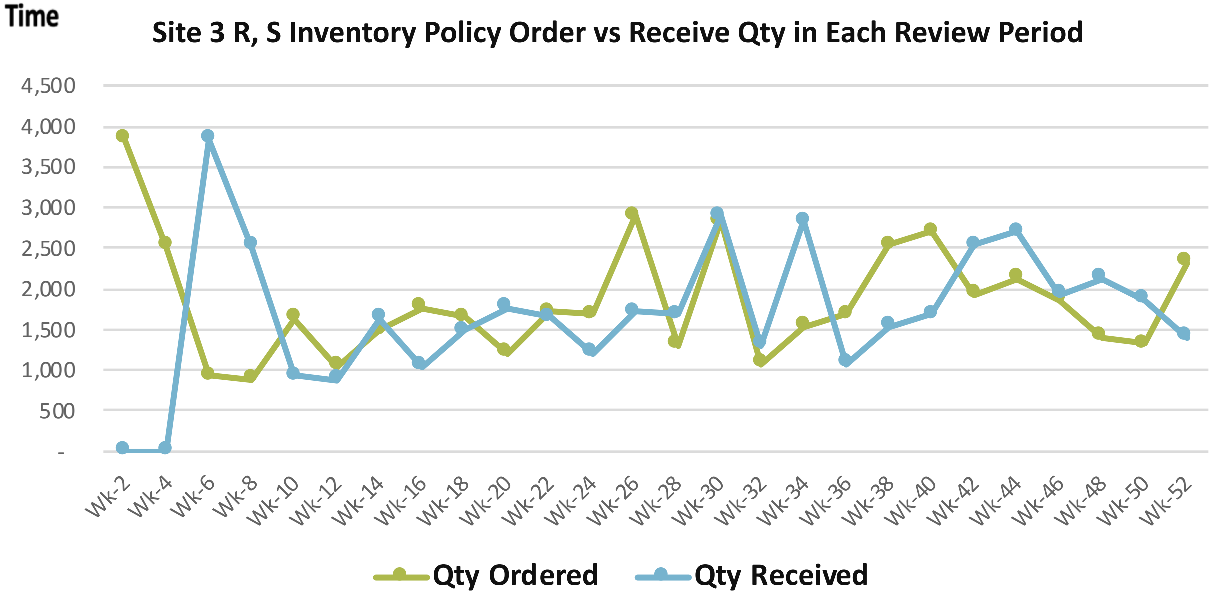
- Safety Stock Level: 1,757 tons
- Two Stock Out: week 4 and 5

Scenarios Analysis – Site 3



Site 3 Optimal
- Review Period: 2 weeks
- CSL: 95%

Site 3 (R,S) Result
- Safety Stock Level: 2,020 tons
- No Stock Out



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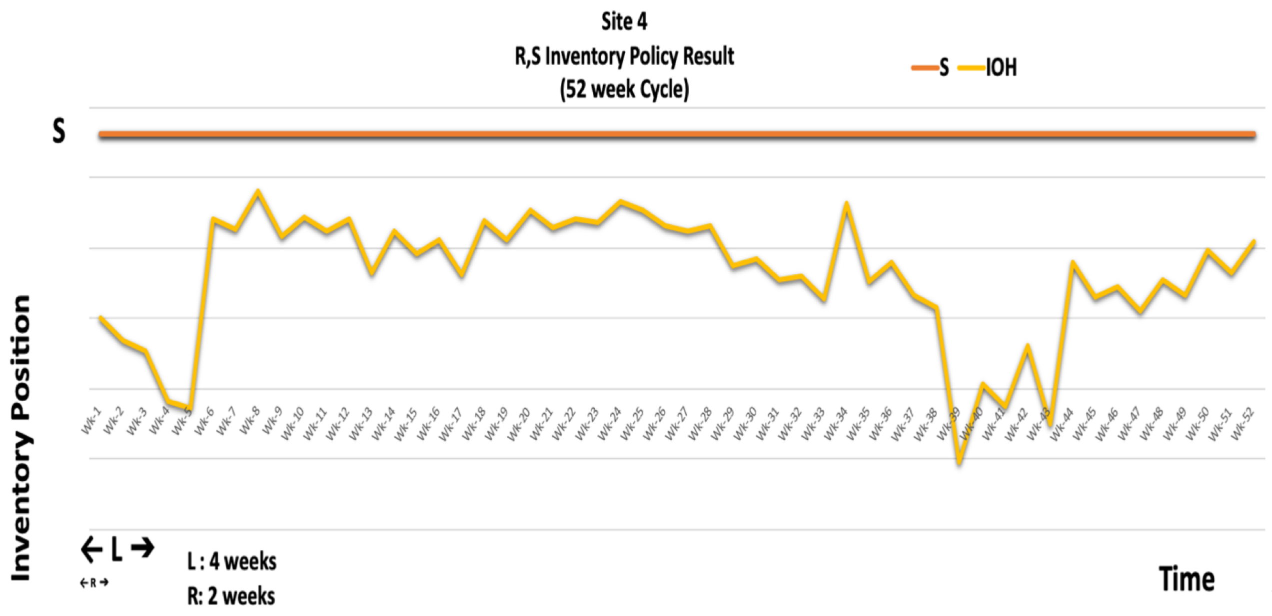
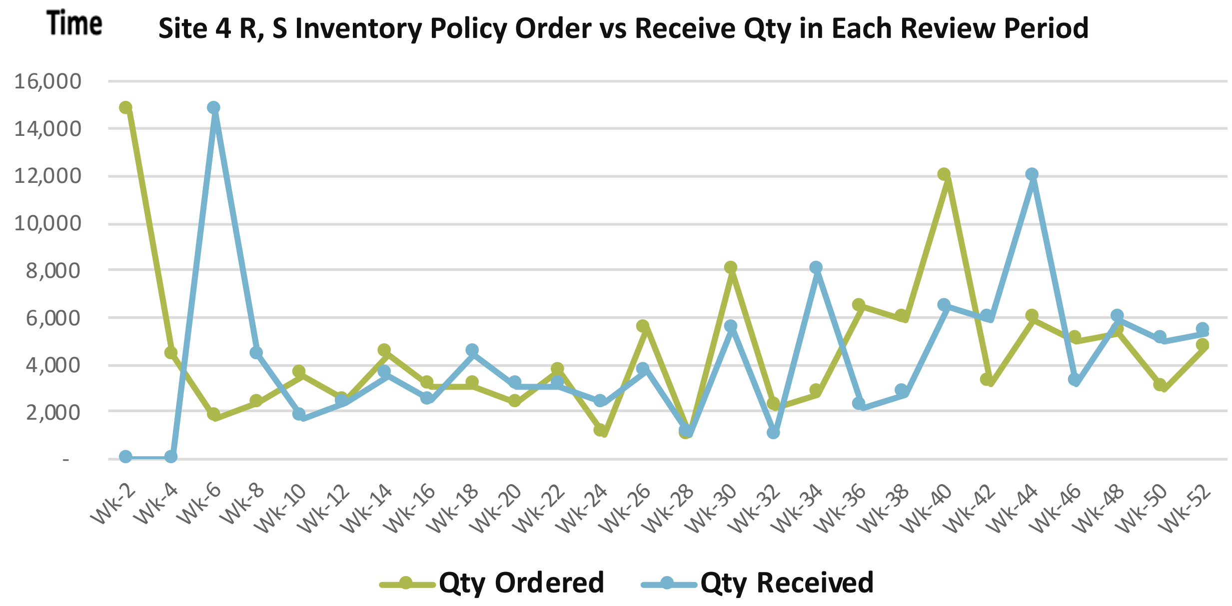
Scenarios Analysis – Site 4



Site 4 Optimal

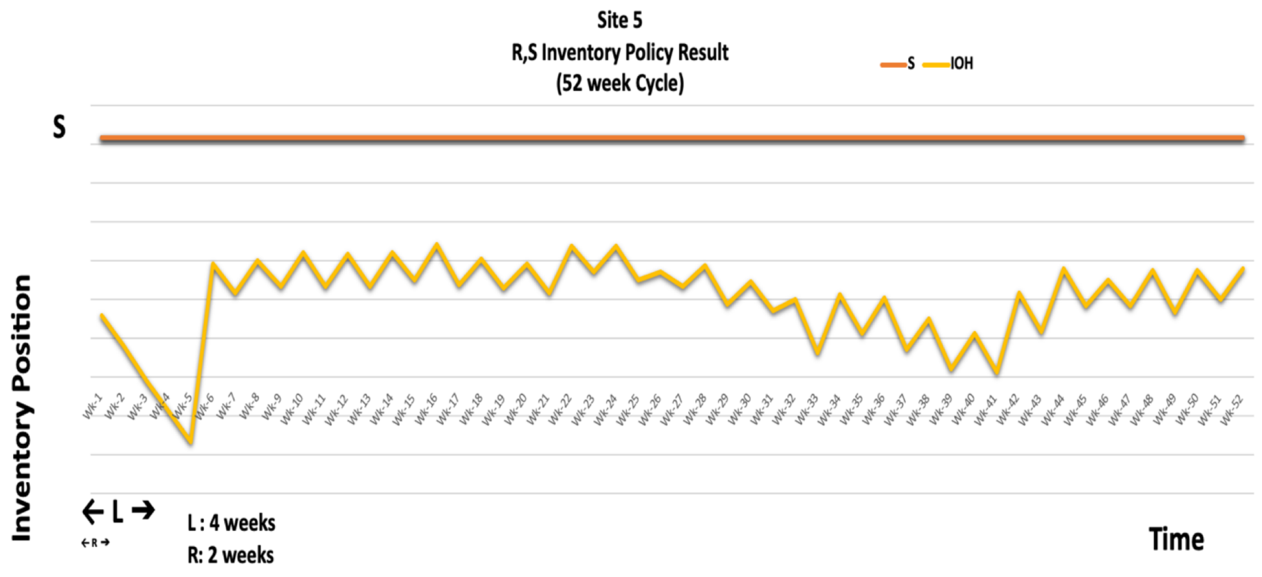
- Review Period: 2 weeks
- CSL: 95%



Site 4 (R,S) Result

- Safety Stock Level: 6,198 tons
- Stock Out: weeks 4, 5, 39, 41 and 43

Scenarios Analysis – Site 5

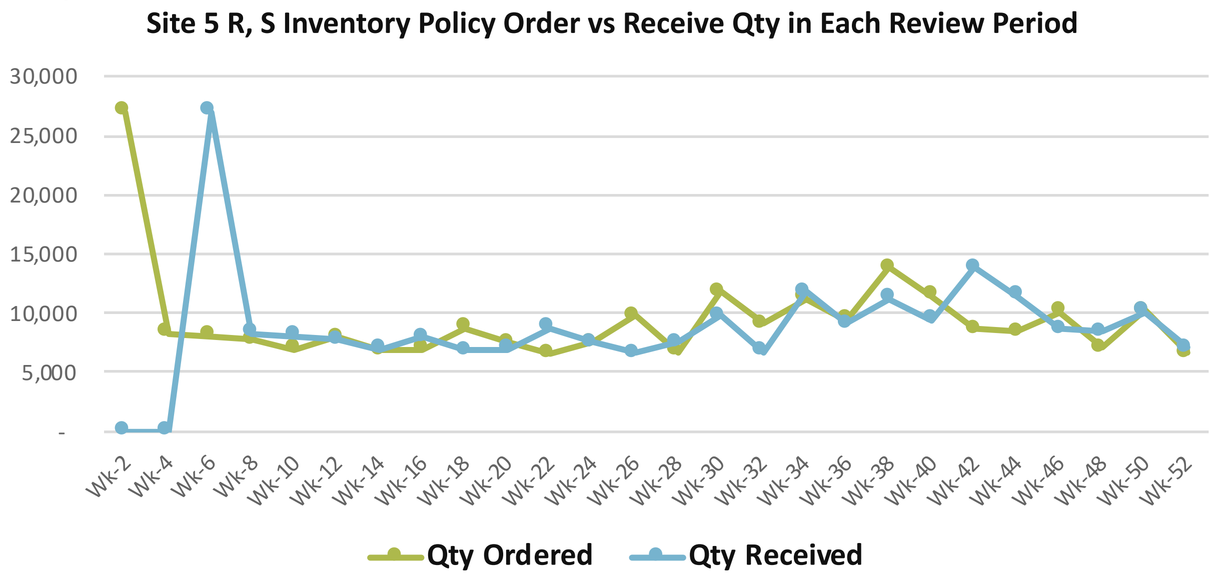


Site 5 Optimal

- Review Period: 2 weeks
- CSL: 95%

Site 5 (R,S) Result

- Safety Stock Level: 5,190 tons
- Stock Out: weeks 3, 4 and 5



Conclusion and Future Research

Research Question

Model

Result & Sensitivity

Modeling Order Uncertainly

Sporadic Extreme Weather

Safety Stock

Order Period

Order Quantity

(s,Q) Model

(R,S) Model

(R,S) Model Selected

Optimal: CSL 95%

R=2 weeks

Project bid Win/Loss possibility in modeling

Capture the weather condition in the modeling

Conclusion

Future Research

MIT Center for
Transportation & Logistics
EXECUTIVE EDUCATION