Hospital Inventory Management

New Trends in Healthcare

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Problem Motivation

- Supplies management – significant costs involved 30-40% of the average hospital's budget (Neil, 2005)
- Many different supplies
- Many different locations
- Little or no visibility of inventory at point-of-use
- Stock rotation is critical
- Focus on patient care

Traditional Hospital Inventory Practices

Service Centers

Nurse Servers

Central Warehouse

Literature Review

Inventory management at hospitals

- Bijvank and Vis (2012)
- Little and Coughlan (2008)
- Lapierre and Ruiz (2007)
- Opolon, et al. (2009)
- Landry and Beaulieu (2009)

Impact of technology adoption

- Delen (2007)
- Lee and Ozer (2007)
- Gaukler et al. (2008)
- Cakici et al. (2010)

Dealing with inventory complexities

- Automated Dispensing Machines (ADMs)
  - Computerized cabinet allows inventory visibility at point-of-use
  - 90% of large hospitals (> 300 beds) have ADMs (*)
- Hospital Substituted nurse servers for Pyxis Supply Stations

(*)Pedersen et al., 2006

Benefits of ADMs

- Improve the dispensing and control of medical supplies
- Allows continuous time tracking of inventory
- Improve billing accuracy
- Enabled the use of new/improved inventory replenishment practices
- Hospital management unsure how to take advantage of new technology

New Inventory Practices

Using ADMs

- Inventory is tracked continuously
  - A par value
  - Refill level
  - Critical level
  - Stockout level

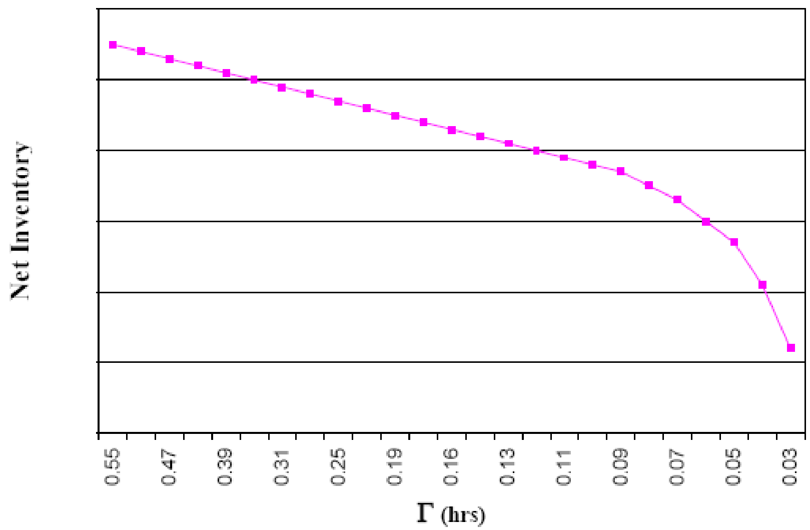
Replenish at start of every shift - (*S*,*s*) [A par value, Refill level]

Replenish between shifts – (*Q*,*R*) [Critical level, Stockout level]

- Between shifts if inventory hits critical level - item is replenished
  - Should we replenish if close to periodic replenishment?
  - What are the benefits of allowing the replenishment of a critical item?
  - How much improvement do we get versus traditional periodic replenishment?

What Makes this Problem Challenging?

- Hybrid Inventory Policy
  - Periodic (*s*,*S*) replenishment – Beginning of shift
  - Continuous (*Q*,*R*) replenishment – out of cycle – whenever needed
- Optimal policy – likely non-stationary



Behavior of non-stationary R

What Makes this Problem Challenging?

- There is a "fixed cost" of performing a replenishment - the out-of-cycle replenishment is considered more costly

  out of cycle fixed cost (k_o) > periodic fixed cost (k_p)

- There is no restriction to the number of out-of-cycle replenishments

- Holding costs associated with limited space available

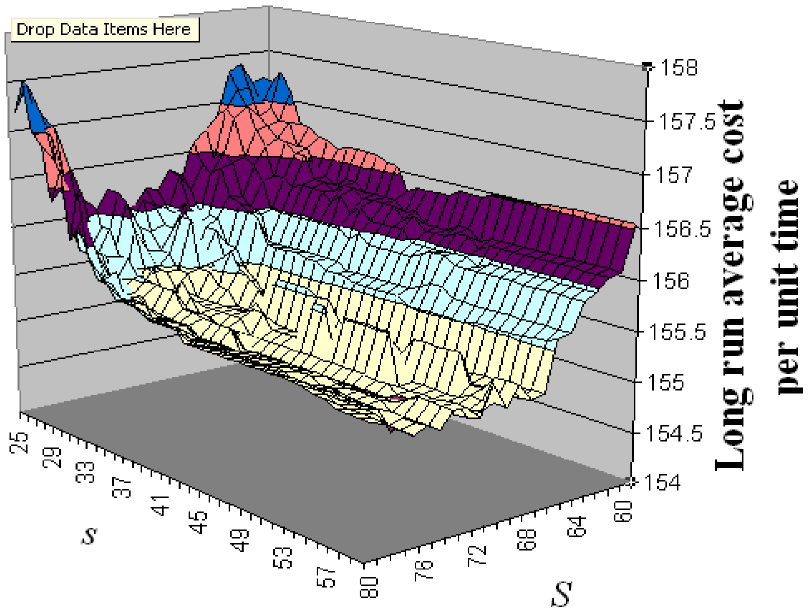
- Penalty cost when stock-outs occur wasting valuable nurse time

- Many items (> 100)

Single Item Hybrid Policy Solution Approach

- No simple closed form expression for average cost given *s*,*S*,*R*,*Q*
- Cost function – not convex

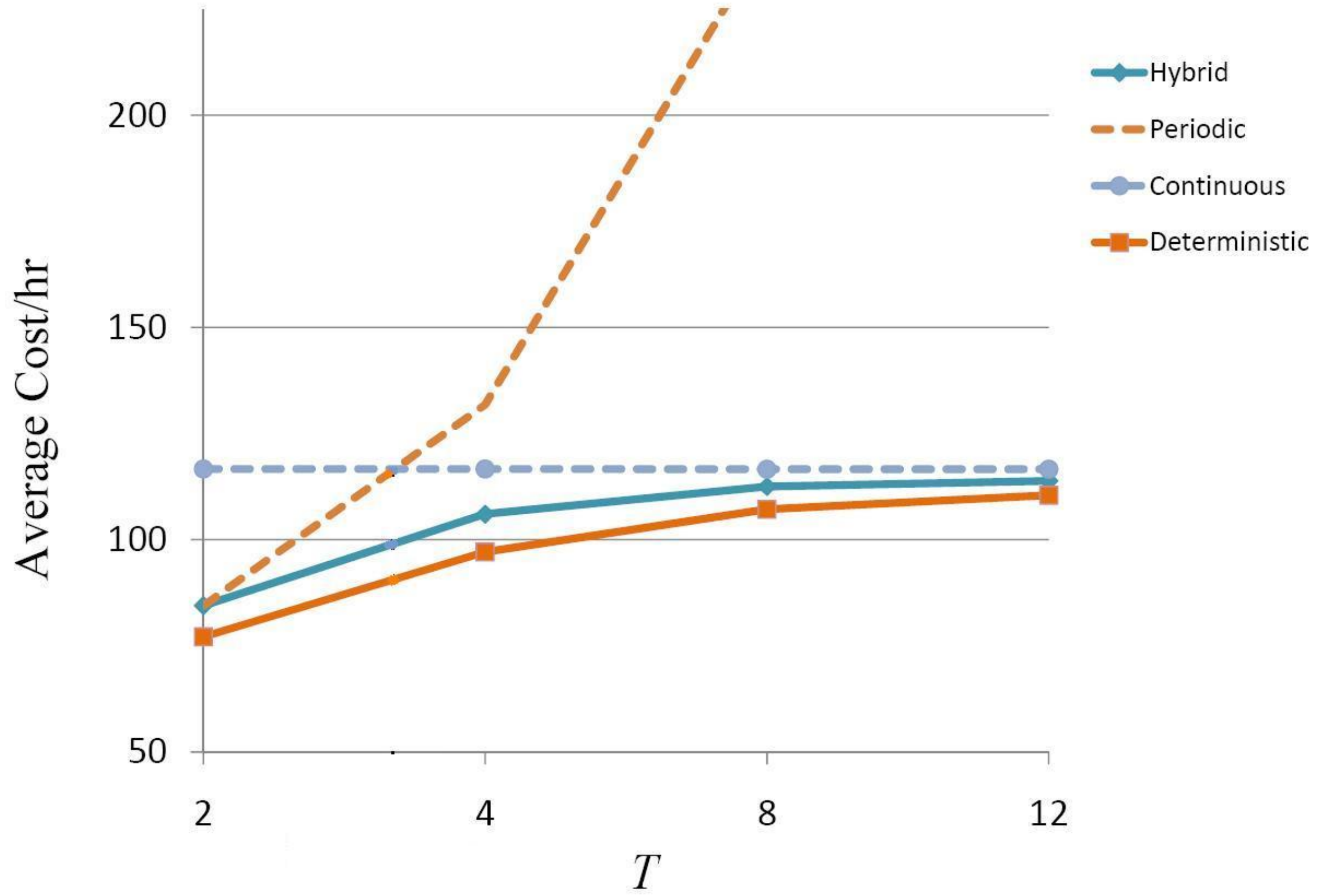
1. Develop a stochastic optimization heuristic using simulation
2. Obtain approximate parameter expressions using the optimal solution to deterministic Hybrid policy



Optimization Heuristic

- Search heuristic
  - Coded in C++
  - Iteratively searches for (*R*,*Q*) and (*s*,*S*) values until convergence is reached
  - Heuristic is re-started with different starting points looking for better local optima
  - Simulation is used to evaluate long run average cost
- Cost within 1% of optimal vs. exhaustive grid search
- Heuristic used to test different scenarios

Hybrid Cost Function



Single Item - Insights Obtained

- High economic benefits possible for hybrid - up to 18% improvement
- Significant differences observed in parameter values – $S \ll S_{periodic}$
- Hybrid – flexible, can behave as periodic policy, or approach continuous policy
- Hybrid provides maximum benefit when cost of periodic and continuous policy is equal

Approximate Solution From Deterministic Hybrid

- Estimates for the stochastic hybrid policy parameters

$$(S - s) = (S_d^* - s_d^*) \qquad Q = Q_d^*$$

$$s = s_d^* + \text{safety stock} \text{ (periodic replenishment interval + order lead time)}$$

$$R = R_d^* + \text{safety stock} \text{ (order lead time)}$$

  - Estimated parameters performed well for hospital conditions tested
  - Parsimonious solution for large number of items still needed

Dealing with Multiple Items
The Two-Bin System

- Motivated by lean principles
- Each item's inventory stored in two bins – primary and secondary
- Stock from primary bin is consumed first - secondary bin becomes the new primary
- No manual counting necessary / No need to track individual item consumption
- Number of items per bin usually selected to provide a pre-specified number of inventory turns.

Two Bin System - Advantages

- No need to track individual item inventory continuously
- Fewer parameters to be defined for inventory control
- Replenishment can be triggered periodically or by accumulation of empty bins
- Can be used for all types of products (drugs, supplies, office, etc)

Two-Bin Replenishment System with RFID

- Each bin carries one RFID tag
- When a bin is emptied, the RFID tag is placed on the board and read
- Information is downloaded to MM information system
- Depending on system conditions, a replenishment is triggered
  - If order triggered – stock delivered after some time
  - While replenishment is processed – more bins may become empty

Two Bin-RFID System in Hospitals

- Hospitals used to periodic replenishment –

- With RFID – hospitals don't always take advantage of additional information
  - system conditions that should trigger replenishment are not defined

- Several factors may trigger an order
  - When a predetermined number of tags appear on the board
  - When a tag of a primary bin has been on the board for a predetermined period of time
  - When the tag of a secondary bin appears on the board

Hospital Data

- Access to over one year of data
- Data for two different hospitals

P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	1/3/11 11:23 AM	1/4/11 7:33 AM	1/4/11 10:29 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	1/21/11 10:31 AM	1/22/11 8:03 AM	1/22/11 11:08 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	1/26/11 3:20 PM	1/27/11 7:37 AM	1/27/11 10:31 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	2/6/11 1:22 PM	2/7/11 7:34 AM	2/7/11 10:37 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	2/9/11 1:55 PM	2/10/11 7:32 AM	2/10/11 10:24 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	4/4/11 4:03 PM	4/5/11 7:31 AM	4/5/11 10:29 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	4/20/11 10:10 AM	4/21/11 7:29 AM	4/21/11 10:26 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	5/9/11 8:50 AM	5/10/11 7:30 AM	5/10/11 10:36 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	6/5/11 3:54 PM	6/6/11 7:30 AM	6/6/11 10:24 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	6/16/11 9:23 AM	6/17/11 7:28 AM	6/17/11 10:40 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	6/24/11 3:55 PM	6/25/11 7:50 AM	6/25/11 11:10 AM
P2124C	P2124C	1002720	Bandage rayonne extensib	N	9	5	P	1	PQT (12/UN	7/10/11 8:21 AM	7/11/11 7:36 AM	7/11/11 10:28 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	6/30/10 10:42 AM	7/1/10 7:39 AM	7/1/10 9:38 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	7/12/10 11:39 AM	7/13/10 7:37 AM	7/13/10 10:41 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	7/12/10 11:39 AM	7/13/10 7:37 AM	7/13/10 10:41 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	7/24/10 11:55 AM	7/26/10 7:36 AM	7/26/10 11:23 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	7/29/10 1:41 PM	7/30/10 7:32 AM	7/30/10 10:56 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	7/29/10 1:41 PM	7/30/10 7:32 AM	7/30/10 10:54 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	8/6/10 9:28 AM	8/7/10 8:07 AM	8/10/10 9:26 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	8/6/10 9:28 AM	8/7/10 8:07 AM	8/10/10 9:26 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	8/6/10 9:29 AM	8/7/10 8:07 AM	8/7/10 1:27 PM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	8/6/10 9:29 AM	8/7/10 8:07 AM	8/7/10 1:27 PM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	8/10/10 9:12 AM	8/11/10 7:31 AM	8/11/10 9:25 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	8/10/10 9:12 AM	8/11/10 7:31 AM	8/11/10 9:25 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	8/29/10 10:22 AM	8/30/10 7:36 AM	8/30/10 9:40 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	8/29/10 10:22 AM	8/30/10 7:36 AM	8/30/10 9:40 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	2010-09-09 03:28:46.000	2010-09-09 07:36:51.870	2010-09-09 09:28:15.000
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	2010-09-13 08:41:36.000	2010-09-14 07:36:26.040	2010-09-14 09:24:01.000
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	2010-09-14 08:47:06.000	2010-09-15 07:34:02.550	2010-09-15 09:33:52.000
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	2010-09-16 10:47:09.000	2010-09-17 07:37:01.480	2010-09-17 09:23:12.000
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	S	1	PQT (6/UNI	2010-09-17 08:39:21.000	2010-09-18 08:58:30.790	2010-09-18 11:40:35.000
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	2010-09-18 12:01:42.000	2010-09-19 07:56:52.580	2010-09-19 10:27:55.000
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	10/2/10 8:15 PM	10/3/10 8:05 AM	10/3/10 11:46 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	10/11/10 4:00 PM	10/12/10 7:42 AM	10/12/10 10:47 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	10/21/10 4:04 PM	10/22/10 7:37 AM	10/22/10 9:06 AM
P2124C	P2124C	1002738	Bandage rayonne extensib	N	9	6	P	1	PQT (6/UNI	10/23/10 4:04 PM	10/24/10 7:58 AM	10/24/10 10:20 AM

Hospital Data

- Hospital Data – using a Two-Bin RFID System under periodic review
  - Several departments within the hospital
  - Data for one year / hundreds of different items

Hospital Department	Item Code	Item Description	units/bin	Bin type	Bin on Board	Replenishment Ordered	Replenishment Completed
E3511	8901713	Intravascular catheter 1”	36	P	6/27/11 8:02 PM	6/28/11 7:20 AM	6/28/11 11:24 AM

- We were able to obtain from the data:
  - Average demand rates for each item
  - Number of item’s per department
  - Average replenishment lead time
  - Hospital provided information for fixed order cost and stockout costs

Two Bin System - Options for Improvement

- Traditionally bins replenished daily (periodically) - filling up all empty bins

- Bin replenishment involves time/effort
  - fixed replenishment cost

- In case of stockouts – nurse procures item
  - stockout cost

- Too many items to replenish
  - Cost-efficient & practical

Two Bin System - Options for Improvement

1) Improvement: **Parameter Improvement**

- Optimize periodic review parameters to minimize cost – Find right replenishment cycle (daily, weekly, etc.)

- Assuming bin demand follows a Poisson Process
- Average cost per unit time $J^P(T)$; T = periodic replenishment cycle (decision variable)

$$J^p(T) = \frac{1}{T}\Big[K(1-p(0,\lambda NT)) + \eta_L C(1,T-L) + (N-\eta_L)C(2,T-L) + \eta_1 C(1,L) + \eta_2(\rho+\tilde{\rho}L)\Big]$$

Model parameters:

L =delivery lead time; N= number of items; ρ =stockout costs per unit ; ρ= stockout cost per unit time; λ = bin consumption rate; K = fixed order cost

1) Parameter Improvement….

- *We show quasi-convexity of* $J^P(T)$ *with respect to* T (under conditions we specify).

- We can find the optimal average cost for the periodic review model $\boldsymbol{J^P(T)}$ and the optimal review interval $\boldsymbol{T}$ using a search procedure that finds:

$$T^* = \arg\min_T J^p(T)$$

- We use C++ and a Golden Section search approach to find the optimal average cost $\boldsymbol{J^P(T)}$ and the optimal review interval T*

Two Bin System - Options for Improvement

2) Improvement: **Policy Improvement**

- Use of technology to improve inventory visibility – continuous review inventory model

- We formulate a Semi-Markov Decision model

  – Estimate the average cost per unit time J^C under continuous review

  – Similar parameters as in periodic review

  – Orders triggered when:
    - a) secondary bin empty
    - b) when n^* primary bins are empty (decision variable)

2) Policy Improvement…

Bellman optimality equations

$$
\begin{aligned}
h_{(n_1,0)} &= \min_{a\in\{1,0\}} \Bigg[G_{(n_1,0)}(a) - \bar{\tau}_{(n_1,0)}(a) J^c \\
&\quad + \sum_{i=0}^{N} \sum_{j=0}^{1} P_{(n_1,0)(i,j)}(a) h_{(i,j)} \Bigg], \ n_1 \in \{1, ..., N\} \\
h_{(0,0)} &= \Bigg[G_{(0,0)}(0) - \bar{\tau}_{(0,0)}(0) J^c + \sum_{i=0}^{N} \sum_{j=0}^{1} P_{(0,0)(i,j)}(0) h_{(i,j)} \Bigg] \\
h_{(n_1,1)} &= \Bigg[G_{(n_1,1)}(1) - \bar{\tau}_{(n_1,1)}(1) J^c \\
&\quad + \sum_{i=0}^{N} \sum_{j=0}^{1} P_{(n_1,1)(i,j)}(1) h_{(i,j)} \Bigg], \ n_1 \in \{1, ..., N\}
\end{aligned}
$$

Using Linear Programming this model can be solved to obtain the optimal cost J^C and the optimal number of bins that should trigger a replenishment n^*

Parameter vs. Policy Improvement

- From hospital data we obtained a base scenario (median values)
  - T = 24 hrs; N = 200; λ = 0.0028 bins/hr;

    ρ = 55 $/ bin; K = 100 $/replenishment;

    $\bar{\rho} = 0.04$ \$/bin·hr (Damodaran, 2012)

- We obtained the optimal average cost per unit time under periodic, $J^P(T^*)$, and continuous review, J^{C*}, as well as the current hospital periodic average cost per unit time $J^P(T)$.

		Continuous Review		Periodic Review			Ratios		
Parameter Modified	Value	J^{c*} (\$/hr)	n^*	$J^p(T^*)$ (\$/hr)	T^* (hr)	$J^p(T)$ (\$/hr)	$\frac{J^p(T)}{J^p(T^*)}$	$\frac{J^p(T^*)}{J^{c*}}$	$\frac{J^p(T)}{J^{c*}}$
Base Scenario		2.63	33	7.33	28.8	7.45	1.02	2.79	2.83

Optimal Continuous Review

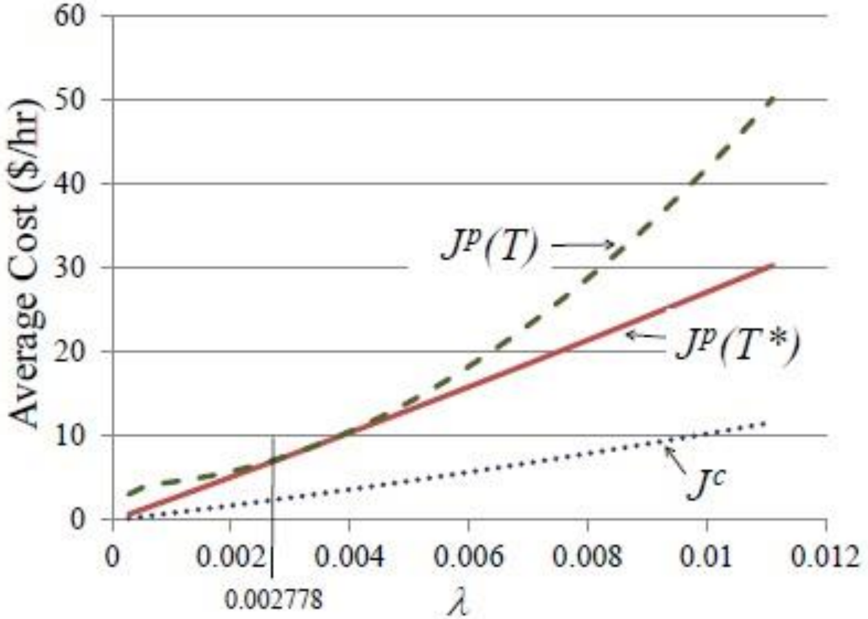
Optimal Periodic Review

Hospital Baseline

Parameter vs. Policy Improvement

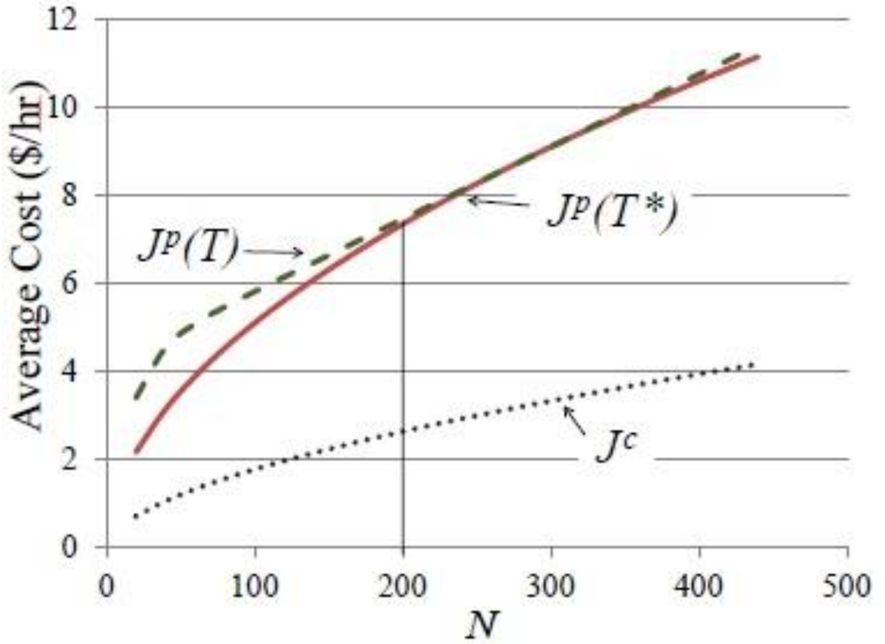
- Lower values of λ (more items per bin) favor the use of periodic review with parameter optimization

- Factor such as expiration dates and inventory rotation should be taken into consideration



Impact of changes in λ

Parameter vs. Policy Improvement



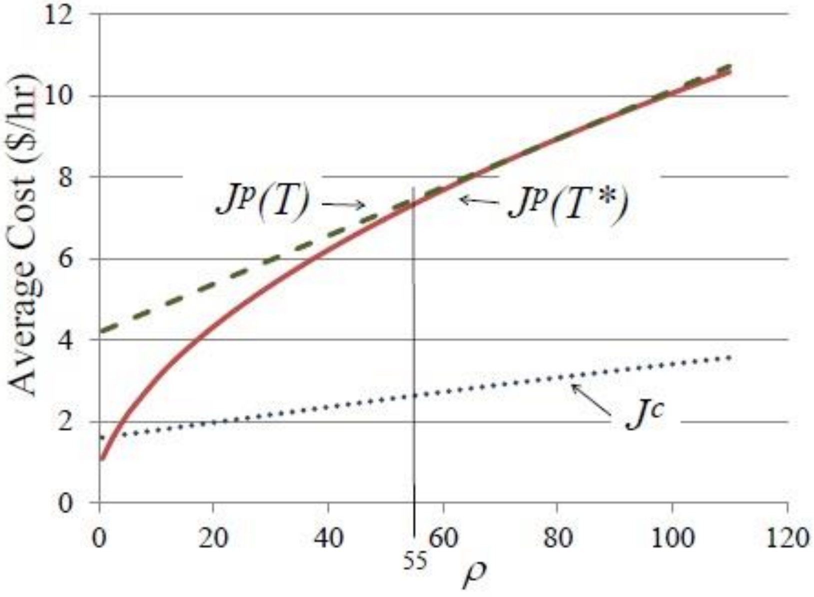
(b) Impact of changes in N

- Costs increase more dramatically under periodic review as N increases
- Less expensive to have a smaller number of large storage rooms than a large number of small storage units. Need to balance with the need to supply stock close to the point-of-use

Parameter vs. Policy Improvement

- Storage areas where most items are non-critical could be replenished using periodic review

- Storage areas where most items are fairly critical and/or expensive (cath lab) can see great benefits from policy improvement



Impact of changes in Average Cost with changes in ρ

Future Work - Impact of Different Demand Processes

- Exponential inter-arrival times good fit for several items, but not all
- Other distributions (Weibull, Beta, Erlang) provided good fit for several items
- Test robustness of results under different distributions
- Simulation model test results under real hospital data

Conclusion

- Expensive items can be closely monitored with ADM machines using simple expressions to compute inventory policy parameters.

- For inexpensive, yet critical items, the two-bin system provides a more parsimonious inventory management system.

- Under the two-bin system, policy improvement (with the use of RFID or barcodes) provides greatest benefits.

Conclusion

- The benefits of policy improvement should be compared to the cost of investing in new technology such as RFID or barcodes.

- We provide a tool that can estimate the economic benefits of technology investment, and can provide hospital management guidelines to improve the use of available resources.

Questions?

Thank you!