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Inventory Management Practices in Hospitals

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Executive Summary

Inventory management practices are essential in the healthcare sector, particularly within hospitals where effective management of medical supplies, medications, and equipment is critical for patient care and operational effectiveness. Hospitals rely on inventory management to ensure that necessary medical supplies are available when needed while avoiding shortages and overstocking. Several techniques are used in hospital inventory management such as Just in Time (JIT) inventory to minimize shortage cost and reduce excess supply in other words waste. Also, ABC analysis to differentiate the importance of each item found in the hospital's inventory. On top of that the hospitals use Vendor Managed inventory (VMI) to have close collaboration with the supplier to make sure the stock is up to date. Additionally, the utilization of AI is crucial to optimize inventory level, Radio-Frequency identification (RFID) technology can be used to help track their inventory. Furthermore, using real life examples this essay will focus on how these methods and strategies are applied in hospital inventory management.

Key words: Inventory Management, JIT, Hospitals, RFID

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Introduction

Inventory management systems in hospitals are a precise process that controls the available storage of supplies, their shelf life, replenishment periods and the usage of those supplies. These systems vary based on their purpose such as, monitoring stock, procurement of medical supplies and the needed equipment, finding suitable storage options by optimizing all related factors, and forecasting the future demand.

A study done by (De Vries, 2011) indicates that the healthcare sector is facing difficulties when it comes to storing medical supplies and equipment. These issues have had a bad influence on how these inventory systems operate, which led to an increase in inventory holding costs and a non-exciting way of identifying the available stock of medical supplies.

Due to the increase of costs related to inventory management and the competition between different medical institutions, hospitals must figure out a way of balancing between having a cost-effective inventory management system and not compromising on their medical quality.

In the following paper, examples will be presented on some of the most effective inventory management systems that are being used in the industry; and limitations that are associated with inventory management systems in the medical sector.

Literature Review

Efficient inventory management is crucial to prevent drug shortages in the hospital context to ensure that the system operates sustainably and maximizes organizational profit (Zwaida et al., 2021). In the same light adopting efficient inventory management systems provides hospitals with a competitive advantage by reducing costs, minimizing waste, and enhancing service delivery, which reflects in the form of improved financial performance (Cranimar & John, 2021). However hospitals tend to have various factors that influence inventory management in their ecosystem ranging from infrastructural, supply chain issues and also choice of system whether traditional, consignment contracts or the more IT centric vendor managed inventory.

Factors:

Inventory management in hospitals is influenced by various environmental factors that can significantly impact their operations and overall performance. Weak inventory management practices, such as inaccurate records, frequent stockouts, high wastage rates, and substandard storage conditions, can lead to inefficiencies and increased costs for hospitals as highlighted in the study by Befekadu et al. (2020). Their study assesses the performance of inventory management for laboratory commodities in public hospitals in the Jimma zone of South West Ethiopia their findings indicate traditional inventory management practices without modernisation and proper infrastructure lead to many problems that affect patient care and help. The study utilized data collected through document reviews, physical observation, questionnaires, and in-depth interviews in seven public hospitals. The hospitals had weak inventory management practices, as evidenced by inaccurate records, frequent stock-outs, a high wastage rate, and storage conditions below the standard. Some of the instances included only 30.4% of the bin-cards were filled accurately, and

57.8% were updated in the last 30 days. Moreover over the past 6 months, four of the hospitals had placed at least one or two emergency orders, indicating frequent stock-outs. The wastage rate of laboratory commodities was 27.2%, resulting in a loss of about $10248.5 . Which was calculated to be much higher than the national baseline of less than 2%. The hospitals also met only 70.6% of the criteria for proper storage conditions, wherein the desired threshold was of ≥80%. Several challenges were identified with their practices, including budget constraints, lack of administrative support and staff commitment, frequent shortages of commodities from suppliers, inadequate storage facilities, and frequent power interruptions. The qualitative findings revealed issues such as the absence of standard ordering systems, stock-outs at the supplier side, lack of commitment from store personnel, and inadequate skills and training in laboratory commodity management. One crucial aspect in inventory management practices is identified as sustainable supply chain management practices which pose to be potent improving performance in hospitals, emphasizing the need for environmentally conscious approaches to inventory management (Duque-Uribe et al., 2019). A very important element happens to be the state of local logistics services infrastructure. As Zepeda et al. (2016) investigated the effects it and demand uncertainty for clinical requirements. Using detailed data from hospitals in California, the authors examined the potential mitigating effects of affiliation with multi-hospital systems while controlling for service performance. They found that the results pointed to potential for improved operating efficiency with system affiliation, a factor often not considered in policy discussions regarding hospital system formation. The authors argued that these arrangements potentially influence managers' confidence in their supply chains, which in turn impacts inventory accumulation.

On a more social factor level, the responsibility for inventory management within hospitals can sometimes be unclear, with staff focused on patient care but not always feeling accountable for inventory availability can pose a challenge in maintaining inventory levels (Neve & Schmidt, 2021). As such implementing patient-centric approaches in hospital facility management, particularly in pharmaceutical inventory management, can contribute to more efficient supply chains and better overall inventory control within hospitals (Xie et al., 2022).

VMIs:

With the recent upsurge in technological adoption and IT, Vendor Managed Inventory (VMI) are an upcoming expression of technology in modern inventory management practices. VMI is a supply chain system where the responsibility and decision-making in managing inventory are transferred from the customer to the vendor or supplier (Kusuma et. al 2022), (Omar et al., 2020). In the context of hospitals, VMI plays a crucial role in inventory management systems by shifting the responsibility of managing inventory levels from the hospital to the suppliers or distributors of medical supplies and pharmaceuticals (Krichanchai & MacCarthy, 2017). This approach ensures that the hospital's inventory is monitored and replenished based on actual usage and demand, rather than relying on internal forecasts or orders placed by the hospital (Soni et al., 2018). However they also require expensive IT infrastructure which certain hospitals may not opt for. A key piece of technology that can be applied in VMIs is RFID, which enables real time tracking unreliability, improve inventory pooling effects, and reduce the need for manual labor in managing inventory (Guchhait et. al, 2019). The paper by Krichanchai and MacCarthy (2017) investigated two contrasting VMI initiatives in Thailand - a successful public sector VMI project involving one public manufacturer (who also acts as a distributor) and three hospitals, and an unsuccessful private sector VMI project involving a private distributor and one hospital. Their observations emphasized on the supplier characteristics, hospital characteristics, product characteristics, and supply chain integration (SCI) characteristics being crucial in influencing VMI adoption in the hospital pharmaceutical supply chain.

For instance, the type of supplier affects the likelihood and feasibility of VMI initiation. In the case of the public manufacturer could implement VMI as the program was funded under the national health scheme while the private distributor preferred to implement VMI with a larger hospital that had greater bargaining power. Hospitals prefer to start VMI for items with steady demand rather than ones with erratic demand since it enables them to evaluate the supplier's replenishment choices, according to further findings. Hospitals, on the other hand, can see dangers associated with the implementation of VMI, such as losing control over essential medical supplies and possible supplier lock-in in the event that competing brands are available. Since the public effort was part of the national strategy and looked profitable, hospitals were less at risk, which is why it was so successful.

Consignment Contracts:

Another common practice in hospital settings is consignment contracts as an alternate to VMIs largely due to unwillingness to afford expensive IT infrastructure. Within consignment agreement, the hospital stores the inventory inhouse however the vendor has the ownership, upon the usage of specific supplies the vendor receives payment within a specified timeframe. The vendor is responsible for the delivery of supplies in specified amounts as decided by the hospital management as such any spike in demands are also on the financial shoulders of the vendor to prevent stockouts. Thus vendors hesitate to consignment contracts unless the purchase price or the guaranteed purchase volumes can account for any resultant costs. In an interesting study by Rosales et. al (2023), they explore consignment in healthcare settings, particularly for general

(GEN) and physician preference (PP) medical supplies. PP supplies tend to be physician preferences that they believe will enhance customer care; these include pacemakers and orthopaedic implants. PP items are acknowledged to be some of the most expensive items in the inventory and can also account for nearly 61% of total cost of purchases as mentioned by the authors. The study's empirical investigation, based on data from a large teaching and research hospital, revealed that consignment agreements lead to higher shrinkage rates and increased spend, especially for PP items. The authors attribute this phenomenon to the unique characteristics of PP items, such as lower demand, higher per-unit prices, and greater demand variability compared to GEN items. To further explore the impact of consignment agreements on GEN and PP items, Rosales et al. (2023) developed analytical investigations that consider two common types of consignment contracts: higher per-unit price and higher purchase volume. These models incorporate the potential for unforeseen increases in shrinkage rates, which hospitals often fail to account for when negotiating consignment agreements. They consider the following equations for total expected annual cost for inhouse inventory (1), total expected annual cost for inhouse inventory with normally distributed demand (2), and after taking into account the terms of consignments that account for ownership of inventory being with the vendor and hospital not accounting for shortages they achieve the total expected annual costs for Consignment supplies as (3):

$$\frac{K\mu}{Q_{Inv}} + hC\left(\frac{Q_{Inv}}{2} + s - \mu L\right) + \frac{p\mu}{Q_{Inv}} \int_{S}^{\infty} (\xi - s)\, f(\xi, L) d\xi + C\mu.$$

$$TC^{u}_{Inv} = \frac{K\mu}{Q_{Inv}} + hC\left(\frac{Q_{Inv}}{2} + z_{\beta}\sigma\sqrt{L}\right) + \frac{p\mu\sigma\sqrt{L}R(z_{\beta})}{Q_{Inv}} + C\mu.$$

$$TC^{u}_{Con}(n) = \frac{K\mu}{Q_{Con}} + (h_o + h_s)nC\left(\frac{Q_{Con}}{2} + z_{\beta}\sigma\sqrt{L}\right) + nC\mu.$$

The analytical results demonstrate that the choice of consignment contract can have different implications for GEN and PP items. For GEN items, a higher per-unit price contract may be more favorable, as the gap between the maximum price increase the hospital should negotiate with and without considering increased shrinkage rates is lower compared to PP items. Conversely, for PP items, a higher purchase volume contract may be more advantageous, as the impact of disregarding increased shrinkage rates is less significant compared to GEN items. The study's findings underscore the importance of considering product characteristics and the healthcare context when applying agency theory to consignment agreements. The authors argue that the healthcare sector differs from the retail context, where much of the theoretical development surrounding consignment inventory management has occurred. Healthcare organizations face unique challenges, such as the influence of physicians in purchasing decisions for PP items and the primary objective of providing quality care rather than maximizing inventory sales.

Proper inventory management practices are of most importance and consideration in hospitals for ensuring patient care and wellness. There are many environmental factors such as logistics infrastructure, sustainable supply chain practices, technology, and also social factors such as staff accountability, and the supplier relationships all play significant roles in influencing inventory management practices within hospitals. By addressing these factors and implementing efficient inventory management systems, hospitals can achieve higher standards in operational performance, reduce costs and improve patient outcomes.

Mathematical Model

According to Wang et al. (2015), “a hospital's internal supply chain, which consists of a central supply chain (CS) and many CUs, has a known and defined average lead time for replenishment from external suppliers to the CS, while external suppliers offer any necessary supplies at any time. Every immediate need must be satisfied, and supplies must constantly be on hand since medical supplies are utilized for diagnosis, treatment, and prevention as well as to alter the human body's structure. As a result, the DDBR mathematical model's notations are defined as follows:

Indices:

t: Index for time period (t= 0,1,2,...,T)

f: Index for CU (f= 1,2,...,F)

m: Index for material (m= 1,2,...M)

Parameters:

Time:

TRFf: Replenishment frequency of CUfvisiting the CS

TRL: Replenishment lead time from external suppliers to the CS

Quantity:

QCmft: Consumption of materialmat CU f during period t

Others:

γf:: Buffer-size-adjustment rate at CU f

γC: Buffer-size-adjustment rate at the CS

ICUmf: Initial inventory days of material m at CU f

ICSm: Initial inventory days of materialmat the CS

Rho: Penalty cost rate

Decision Variables:

Qimft: CU f's inventory quantity for materialmat the end of periodt

QCImt: CS's inventory quantity for materialmat the end of periodt

QRmft: Planned replenishment quantity for materialmat CUfduring periodt

QCRmt: Planned replenishment quantity for materialmat CS during periodt

QARmft: Accumulated planned replenishment quantity for materialmat CUfat the end of periodt

QCARmt: Accumulated planned replenishment quantity of CS for materialmat the end of periodt

QDPmft: Demand-pull replenishment quantity for materialmat CUfduring periodt

QCDPmt: Demand-pull replenishment quantity for materialmat CS during periodt

BMmft: Buffer-management quantity for materialmat CUfduring periodt

BSmft: Buffer-size-adjustment quantity for materialmat CUfduring periodt

BLmft: Buffer-levelling quantity for materialmat CUfduring periodt

BCMmt: Buffer-management quantity for materialmat CS during periodt

BCSmt: Buffer-size-adjustment quantity for materialmat CS during periodt

BCLmt: Buffer-levelling quantity for materialmat CS during periodt

RDmft: Received replenishment quantity of materialmat CUfduring periodt

RCDmt: Received replenishment quantity of materialmat CS during periodt

CPmft: Penalty cost of materialmat CUfduring periodt

CCPmt: Penalty cost of materialmat CS during periodt

δmft: The binary value for rounding the average replenishment quantity for materialmat CU f

δmft = 1 if (QARmft/TRif – QARmft/TRFf >= 0.5), 0 otherwise.

thetamft = 1 if (QCARmt/TRL – QCarmt/TRL >= 0.5), 0 otherwise.

$$Q^{DP}_{mft} = Q^{C}_{mft} \quad \forall m, f, t$$

$$Q^{CDP}_{mt} = \sum_{f=1}^{F} Q^{C}_{mft} \quad \forall m, t$$

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Objective function:

$$\text{Minimize } Z = \sum_{t=1}^{T} \sum_{m=1}^{M} \left[\sum_{f=1}^{F} (Q^{I}_{mft} + C^{P}_{mft}) + Q^{CI}_{mt} + C^{CP}_{mt} \right]$$

Constraints:

Buffer-management constraints:

$$B^{L}_{mft} = (Q^{C}_{mft} - R^{D}_{mft}) \quad \forall m, f, t$$

$$B_{mft}^{S} = \gamma_f (Q_{mft}^{C} - Q_{m,f,t-1}^{C}) \quad \forall m, f, t$$

$$B_{mft}^{M} = B_{mft}^{S} + B_{mft}^{L} \quad \forall m, f, t$$

$$B_{mt}^{CM} = B_{mt}^{CS} + B_{m}^{CL} \quad \forall m, t$$

$$B_{mt}^{CS} = \gamma^{C} \sum_{f=1}^{F} (Q_{mft}^{C} - Q_{m,f,t-1)}^{C}) \quad \forall m, t$$

$$B_{mt}^{CL} = \sum_{f=1}^{F} R_{m,f,t}^{D} - R_{m,t}^{CD} \quad \forall m, t$$

Replenishment quantity constraints:

$$Q_{mft}^{AR} = Q_{m,f,t-1}^{AR} + \int_{t-1}^{t} (Q_{mft}^{DP} + B_{mft}^{M} - R_{mft}^{D}) \mathrm{d}t \quad \forall m, f, t$$

$$Q^{R}_{mft} = \left[Q^{AR}_{mft} / T^{RF}_{f} \right] + \delta_{mft} \quad \forall m, f, t$$

$$R^{D}_{mft} = Min\left(Q^{CI}_{m,f,t-1}, Q^{R}_{m,f,t-1} \right) \quad \forall m, f, t$$

$$Q^{I}_{mft} = \begin{cases} Q^{I}_{m,f,t-1} + \int\limits_{t-1}^{t} (R^{D}_{mft} - Q^{C}_{mft})\mathrm{d}t & \text{if} \quad \forall m, f, t > 0 \\ I^{CU}_{mf}, & \text{otherwise} \end{cases}$$

$$C^{p}_{mft} = \begin{cases} Q^{I}_{mft} \times \rho & \text{if } Q^{I}_{mft} < 0 \quad \forall m, f, t > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$Q^{CR}_{mt} = Q^{CAR}_{mt} / T^{RL} + \theta_{mt} \quad \forall m, t$$

$$Q_{mt}^{CAR} = Q_{m,t-1}^{CAR} + \int_{t-1}^{t} \left(Q_{mt}^{CDP} + B_{mt}^{CM} - R_{mt}^{CD}\right)\mathrm{d}t \quad \forall m, t$$

$$R_{mt}^{CD} = Q_{m,t-1}^{CR} \quad \forall m, t$$

$$Q_{mt}^{CI} = \begin{cases} Q_{m,t-1}^{CI} + \int_{t-1}^{t} \left(R_{mt}^{CD} - \sum_{f=1}^{F} R_{mft}^{D}\right)\mathrm{d}t & \text{if} \quad \forall m, t > 0 \\ I_{m}^{CS}, & \text{otherwise} \end{cases}$$

$$C_{mt}^{CP} = \begin{cases} Q_{mt}^{CI} \times \rho & \text{if } Q_{mt}^{CI} < 0 \quad \forall m, t > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$Q_{mft}^{I},\ Q_{mt}^{CI},\ Q_{mft}^{AR},\ Q_{mt}^{CAR},\ R_{mft}^{D},\ R_{mt}^{CD},\ Q_{mft}^{R},\ Q_{mt}^{CR} \geq 0 \quad \forall m, f, t$$

Data and Results:

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Table 1: consumption data of material number 1 (QC1ft):

Daily consumptions	Consumptions at CU1 Q^C_{11t}	Consumptions at CU2 Q^C_{12t}
Upper limit	12.00	36.00
Lower limit	8.00	24.00
Average	10.00	30.00

Table 2: Computational performance of ROP, conventional DBR and DDBR models:

	Model					
Problem number	Inventory quantity (units)			Stock-out quantity (units)		
ROP	DBR	DDBR	ROP	DBR	DDBR	
1	55,293	13,596	9912	7	0	0
2	89,904	19,967	9142	9	0	0
3	106,611	48,654	8898	8	0	0
4	83,533	40,911	34,724	10	0	0
5	657,401	46,164	34,271	5	0	0
6	75,196	76,426	38,029	36	0	0
7	102,836	68,622	60,996	20	0	0
8	240,632	74,714	60,577	12	0	0

9	219,545	101,274	59,361	20	0	0
10	51,721	15,955	11,557	6	0	0
11	40,127	21,668	11,051	18	0	0
12	114,464	50,450	11,356	14	0	0
13	79,878	45,553	39,990	4	0	0
14	111,313	50,460	40,656	4	0	0
15	208,820	77,748	39,929	4	0	0
16	85,250	72,548	66,677	1	0	0
17	97,704	77,245	65,440	1	0	0
18	156,264	104,299	65,582	1	0	0
19	150,529	29,594	20,855	30	0	0
20	523,975	30,625	23,450	76	0	0
21	316,609	59,058	26,475	55	0	0
22	93,628	66,136	71,098	34	0	0
23	131,691	74,087	64,257	31	0	0
24	263,495	103,704	51,545	30	0	0
25	87,728	69,520	65,632	41	0	0
26	121,450	117,063	106,669	36	0	0

27	213,545	107,123	64,584	37	0	0
28	129,566	49,390	34,253	9	0	0
29	695,108	57,539	27,189	58	0	0
30	1,005,000	87,809	32,462	13	0	0
31	107,007	77,663	65,553	202	0	0
32	80,064	89,254	75,914	221	0	0
33	194,408	109,641	74,268	179	0	0
34	96,260	97,083	109,273	32	0	0
35	121,397	100,337	104,795	45	0	0
36	214,132	134,398	102,973	45	0	0
Average quantity	197,836	68,508	49,705	38	0	0

Procedure: DDBR with the Powell search algorithm

Step 1: Set the start point for searching.

Step 1.1: Set the buffer-adjustment rate at CUs $\gamma_f = 1$.

Step 1.2: Set the buffer-adjustment rate at the CS $\gamma^C = 1$.

Step 1.3: Set initial inventory days at CUs = 1.

Step 1.4: Set initial inventory days at the CS = 1.

Step 1.5: Generate a general point, $x_0 = (\gamma_f, \gamma^C, ,)$.

Step 2: Set initial unit vectors. Let the first search direction, S_i, in the first iteration equal unit vector, e_i ($i = 1,2, \dots ,n$), and these vectors are linearly independent directions in the n-dimensional space, R^n.

Step 3: Set the objective function and search range.

Step 3.1: Set the objective function as minimisation of inventory and penalty quantities at all CUs and the CS.

Step 3.2: Set the search range of the buffer-adjustment rate at CUs, γ_f, and the CS, γ^C, from –100 to 100, a relatively wide range of possible buffer-adjustment-rate values.

Step 3.3: Set the search range of initial inventory days at CUs, , and the CS, , from 0 to 100, implying a wide range for searching. Whereas a value of zero denotes that the initial inventory stock is zero, a value of 100 denotes that initial inventory is 100 times the average demand consumption.

Step 4: Replace the initial search direction with a new direction to iterate the vectors and minimise the objective function of the DDBR model.

Step 4.1: Calculate λ_i for $i = 1, 2, \dots , n$, so that is a minimum, and define .

Step 4.2: Replace search direction S_i.

Step 4 2.1: Replace S_i with for $i = 1, 2, \dots , n - 1$.

***Step 4.2.2*:** Replace S_n with if $i = n$.

***Step 4.3*:** Select so that is a minimum, and replace x_0 with .

***Step 5*:** Repeat Step 4 until the newest solution, x_{n+1}, that can minimise the objective function model is obtained." (Wang, 2015).

<u>GAMS:</u>

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Sets

t /1*T/

f /1*F/

m /1*M/;

Parameters

TRF(f) Replenishment frequency of CU f visiting the CS

TRL Replenishment lead time from external suppliers to the CS

QC(m,f,t) Consumption of material m at CU f during period t

ICU(m,f) Initial inventory days of material m at CU f

ICS(m) Initial inventory days of material m at the CS

Rho Penalty cost rate

gamma(f) Buffer-size-adjustment rate at CU f

gammaC Buffer-size-adjustment rate at the CS;

Variables

Q(m,f,t) CU f's inventory quantity for material m at the end of period t

QCI(m,t) CS's inventory quantity for material m at the end of period t

QR(m,f,t) Planned replenishment quantity for material m at CU f during period t

QCR(m,t) Planned replenishment quantity for material m at CS during period t

QAR(m,f,t) Accumulated planned replenishment quantity for material m at CU f at the end of period t

QCAR(m,t) Accumulated planned replenishment quantity of CS for material m at the end of period t

QDP(m,f,t) Demand-pull replenishment quantity for material m at CU f during period t

QCDP(m,t) Demand-pull replenishment quantity for material m at CS during period t

BM(m,f,t) Buffer-management quantity for material m at CU f during period t

BS(m,f,t) Buffer-size-adjustment quantity for material m at CU f during period t

BL(m,f,t) Buffer-levelling quantity for material m at CU f during period t

BCM(m,t) Buffer-management quantity for material m at CS during period t

BCS(m,t) Buffer-size-adjustment quantity for material m at CS during period t

BCL(m,t) Buffer-levelling quantity for material m at CS during period t

RD(m,f,t) Received replenishment quantity of material m at CU f during period t

RCD(m,t) Received replenishment quantity of material m at CS during period t

CP(m,f,t) Penalty cost of material m at CU f during period t

CCP(m,t) Penalty cost of material m at CS during period t

delta(m,f,t) Binary value for rounding the average replenishment quantity for material m at CU f theta(m,f,t) Binary value for rounding the average replenishment quantity for material m at CS;

Binary Variables

```
deltaBinary(m,f,t)
thetaBinary(m,f,t);
```

Equations

```
BufferManagementConstraint1(m,f,t)
BufferManagementConstraint2(m,t)
ReplenishmentQuantityConstraint1(m,f,t)
ReplenishmentQuantityConstraint2(m,t)
ObjectiveFunction;


BufferManagementConstraint1(m,f,t)..
    BM(m,f,t) =e= gamma(f) * Q(m,f,t);


BufferManagementConstraint2(m,t)..
    BCM(m,t) =e= gammaC * QCI(m,t);


ReplenishmentQuantityConstraint1(m,f,t)..
    QR(m,f,t) =e= QDP(m,f,t) + BM(m,f,t) + BS(m,f,t) + BL(m,f,t);
```

```
ReplenishmentQuantityConstraint2(m,t)..
        QCR(m,t) =e= QCDP(m,t) + BCM(m,t) + BCS(m,t) + BCL(m,t);


ObjectiveFunction..
        // minimizing our objective function
        ;


* Data Section
Parameter TRF(f), TRL, Rho;
Parameter QC(m,f,t), ICU(m,f), ICS(m), gamma(f), gammaC;


* using data from the table 1.


* Binary variables for rounding
binary variables deltaBinary(m,f,t), thetaBinary(m,f,t);


* Constraints to link binary variables with decision variables
equations round_up_cu, round_up_cs;


round_up_cu(m,f,t)..
        deltaBinary(m,f,t) =e= (QAR(m,f,t)/TRF(f) - QAR(m,f,t)/TRF(f) >= 0.5);


round_up_cs(m,t)..
```

```
thetaBinary(m,t) =e= (QCAR(m,t)/TRL - QCAR(m,t)/TRL >= 0.5);
```

Results:

In conclusion, based on the mathematical model which was created in order to compare between two models for hospital inventory management, the main objective was to see which model will satisfy the objective function, minimizing inventory cost and maintaining stock-out occurrence as low as possible in hospital material management, and if so, which is superior. After formulating the mathematical model created by Wang et al. (2015), we were supposed to compare the results of our GAMS solution to the results obtained on this study and change the values in order to verify that the outcome would remain the same and the mathematical model is functional and works according to the values given. Nonetheless, we did not have access to the GAMS software, but we provided the GAMS code formulation for this problem throughout the mathematical model report. In the possibility that we ran the code, it would have verified the feasibility of this mathematical model through the comparison of different results and different outcomes.

Illustrative examples

ABC analysis:

To differentiate between the levels of importance of items that are found in the hospital's inventory they use ABC analysis. They categorize the important items under (A) and then the lesser important items under (B) and then (C). This will help the staff to know which items should be restocked urgently. (Smith & Johnson, 2018).

Just-in-Time (JIT) Inventory:

Hospitals implement the practice of JIT (just-in-time) inventory to ensure that they don't have excess stock leading to an increase in the costs associated with that. Hospitals order the needed medical supplies based on their demand this will reduce how much storage space they need hence a decrease in their inventory holding cost. (Jones et al., 2020).

RFID Technology:

Hospitals use RFID technology to track, in real-time, their inventory. This method allows them to have a clear view of their inventory which will then reduce the need to manually do it. Moreover, the RFID tags will allow the users to identify and monitor the movements of the tools within the hospital. (Gupta & Patel, 2019).

Vendor Managed Inventory (VMI):

When using VMI (vendor-managed inventory) the hospital and its supplier have a close collaboration that allows the supplier to supervise the inventory levels and replenish the stock automatically based on criteria that have been predefined. This approach has been proven to not only reduce stock outs but also improve the efficiency of their supply chain. (Nguyen & Tran, 2020).

Usage Tracking and Forecasting:

Hospitals can track a pattern of the items in their inventory and then use data analytics to forecast the demand in the future. Hospitals can optimize the levels within their inventory by tracking trends of the patients getting admitted, the procedures, and seasonal variations. This method makes sure the hospital always has an adequate number of stocks available. (Wong & Chan, 2018).

Expiration Date Management:

Expiration date management is crucial in the medical industry. Hospitals implement very strict protocols when it comes to managing expiration dates to prevent waste but most importantly to make sure patients are safe. There are many ways they can do that but the most common practices are the following: regular audits, FIFO (first in first out) inventory rotation, and embedding alerts that automatically go off when the expiration date is close to prompt the user of the need to dispose of them. (Garcia et al., 2019).

Centralized Inventory Control:

Hospitals can also implement a centralized inventory control system. This allows them to manage and distribute all their inventory items from a single location. This approach makes it easier for the user to visualize the items in their inventory. Moreover, it standardizes the processes and integrates the inventory within all departments leading to an improved accuracy of inventory. (Li & Wang, 2019).

Demand Forecasting Models:

Hospitals utilize very intricate demand forecasting models to predict future inventory needs accurately based on the following things: historical data, demographics of their patients, and procedure schedules. This procedure reduces excess inventory and minimizes the chances of having stockouts. (Tan & Lim, 2021).

Inventory Optimization Software:

Hospitals often integrate inventory optimization software within their procedures. This software uses specific algorithms to evaluate the patterns in the usage of items found in the inventory, their lead times, and service levels. This method will give them the optimal reorder points and order quantities. This technological-driven approach improves efficiency and reduces costs. (Chowdhury & Rahman, 2020).

Cross-Functional Collaboration:

Oftentimes the biggest issue in inventory management is the lack of communication between the departments. For example, in a setting like the hospital, the nurses' priority is needing the item urgently without considering the cost. Whereas, on the other hand, the finance team's priority is the cost without necessarily understanding how crucial some of the items are.The best way to tackle such an issue is to promote a cross-functional collaboration between clinical staff, procurement teams, and finance departments to optimize inventory management practices. This ensures everyone is on the same page and the needs of the clinic are balanced with having the cost into consideration. (Wu et al., 2018).

Implementations In Practice

Data Segmentation:

Data segmentation is the process of compiling all the data and dividing it and organizing it based on the similarities they have and certain criterion; this method has been applied to hospitals pharmacy. The issue with having to deal with such large and complex data has left hospitals not able to rely on that data due to it being "not available or might not be in the right form" (Bialas et al., 2019). Based on a research conducted by the American Journal of Health-System Pharmacy, A framework was developed using data segmentation based on three classifications, relative importance, clinical criticality and consumption pattern. This system was implemented in a large public hospital using longitudinal data. The outcome of this system has caused a considerable improvement in regards to all the selected key performance indicators and has contributed to huge cost savings because of the shrinkage in carrying inventory costs.

Outsourcing Inventory Management:

Outsourcing non-critical supplies in the healthcare sector saves both time and money; non-critical supplies are those that have a rather long shelf-life and require low-cost storage facilities. A research was done by comparing two models A as an in-house distribution network and B as an outsourced network distribution. For this research the goal was to minimize the holding costs based on the level of inventory in the related departments and the service centers. While comparing the two models, the results indicated that outsourcing the non-critical medical supplies that are delivered to the various hospital departments achieved a lower inventory holding cost than in-house distribution. Another study by Royer, Landry and Beaulieu advises that “outsourcing not only reduces costs but also reduces the full-time equivalent labor hours” (Leaven et al., 2017).

Blood Inventory Management:

Holding of blood is a very complex task for hospitals due to it being delicate and sensitive product to handle; which is why it is incredibly essential to have a very good management of blood inventories. Managing blood inventory is a trade-off between having enough stock of blood ready for use and not having any at all. The goal is to have a 100% supply of blood whilst not losing its value when it expires. A study done by Science Direct determined that the key to managing blood inventory is not about how complex the inventory models and algorithms, but it is about the laboratory staff who must be skilled, trained, and experienced. Along with electronic crossmatching, transparency of the existing inventory and basic management operations. It is about having six main factors that all of them combined lead to a good practice in blood management. The six factors are human resources and training, stock levels and order patterns, transparency of inventories, simple inventory procedures, focus on freshness and internal collaboration between all hospital departments. All these factors highlight that the key to the success of this management system is having top workers with great experience in handling such a delicate product.

Listed below are a list of recommendations that (Stanger et al., 2012) have presented for each factor:

<u>Stock Levels:</u>

- Target stock levels based on experience are adjusted continuously.

- Demand profiling to adjust on daily demand patterns.
- Use information about scheduled treatments.
- Careful handling of recurring orders.
- Full transparency of stock levels including remote and issue refrigerators.
- Frequent monitoring.
- Consideration of recurring and planned transfusions.

Order Patterns:

- Avoid panic orders.
- Keep storage capacity low.
- Train staff.
- Split big orders into several small orders to get different shelf-lives.
- Make use of standing orders to reduce workload and replenish using “top-up orders”.
- Use action levels and predefined order quantities for “out-of-hours” time to prevent panic orders.

Issuing:

- Strict OUFO principle.
- Store units sorted by age and use visual highlighting for units close to expire.

- Try to keep assigned inventories as low as possible.

- Question and challenge internal requests for blood to keep assigned inventories low and reduce just-in-case requests.

- Electronic crossmatching reduces assigned inventories.

Remote Refrigerators:

- Monitor stock levels frequently.

- Allow the removal of reserved blood units from remote refrigerators and assigned inventory when a patient is found for instant transfusion.

- Check regularly and return units to main storage.

Human Resources:

- Train staff and make staff aware of the financial impact of wasting a unit.

- Regular training and refreshing courses.

- Motivate staff to keep wastage low.

- Ensure that experienced staff are placing orders and handling incoming deliveries.

Collaboration:

- Motivate and incentivize hospitals to share knowledge with other hospitals.

- Reduce mistrust between hospitals.

- Reduce mistrust between departments in hospitals.

- Use internal service level agreements to generate trust.

Limitations and Critics of The Concept

Supply Chain Disruptions:

One critical limitation that any hospital might encounter is disruptions in the supply chain. For example, shortages in pharmaceuticals or medical devices can significantly affect inventory management processes. In such instances, hospitals can leverage an ERP (Enterprise Resource Planning) system to accurately forecast the future capacity and demand needed for pharmaceuticals and devices within the hospital. Through the utilization of an ERP system, hospitals can effectively monitor and maintain precise data regarding the stock levels and supplies available in their inventory, thereby enhancing their ability to manage inventory effectively amidst supply chain challenges. The problem with using ERP technology is that it is a complex technology, requires the hospital to change the whole infrastructure, and requires employees to adapt to new systems and processes, which will be expensive and insufficient for a hospital.

Expiry and Obsolescence:

Another limitation that hospitals might face in terms of inventory management is the presence of expiry dates on medical and pharmaceutical supplies, which require diligent monitoring. To effectively track these supplies, hospitals can employ RFID (Radio Frequency Identification) technology to scan items and monitor their arrival and dispatch from the inventory. However, the utilization of RFID technology may be hindered by various factors, potentially reducing its effectiveness. For example, environmental conditions such as humidity, temperature fluctuations during shipping, and mishandling can damage barcodes on supplies, making it challenging RFID systems to read them accurately. Consequently, this may lead to products entering the hospital inventory without proper tracking, thereby compromising inventory management processes and potentially causing inventory discrepancies.

Conclusion

In conclusion, inventory management systems play a vital role in ensuring that the operations running within the hospital are efficient. Whether it's by controlling the storage and replenishment or controlling the usage of medical supplies and equipment.

However, there are challenges such as the increase of inventory holding costs and the need to balance the cost-effectiveness with trying to maintain the medical quality requirements of the hospitals to constantly pursue advanced solutions.

Through many inventory management strategies and technologies mentioned in the paper it was apparent that hospitals can optimize their inventory processes and enhance their overall efficiency. Examples mentioned previously are the following: ABC analysis, Just-in-Time inventory, RFID technology, Vendor Managed Inventory, usage tracking and forecasting, expiration date management, centralized inventory control, demand forecasting models, and inventory optimization software demonstrate the varied approaches available to hospitals. Moreover, real-life implementations emphasize the usefulness of data segmentation, outsourcing inventory management, and approaches like blood inventory management while focusing on inventory challenges within hospital settings.

Despite the advancements that were discussed, it was apparent that the strategies do have limitations such as supply chain disruptions and challenges associated with expiry.

Strategies such as implementing ERP systems and applying RFID technology aim to mitigate such limitations, however those strategies also come with a set of challenges and complications. In tackling these complexities, it was found that the best approach is the collaboration across departments. Moreover, having a cross-functional expertise emerged was a critical factor for ensuring the inventory management runs successfully in hospitals. By adopting collaboration and the implementation of technological advancements while also focusing on the limitations, hospitals can achieve optimal inventory management systems that ensure both cost-effectiveness and the highest standards of patient care.

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