DEVELOPMENT OF DIRECT MATERIAL INVENTORY OPTIMISATION MODEL FOR A BUS MANUFACTURING INDUSTRY

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Abstract

In order to achieve organisation's objectives and gain competitive advantage, it is crucial to maintain optimum inventory levels. Inventory control has become more complex due to higher customer service levels, cost control, space constraints and newer technologies. But, the traditional approach lacks to provide optimal solutions such as reduced inventory related cost, avoid excess stocking and shortages.

The inventory turnover days depicts blocked capital investments which needs be optimised to facilitate a successful business function. Inventory optimisation is sought for having a better managerial control on parts based on consumption value and priority. In this paper, the demand data of the direct materials used in the bus manufacturing has been collected for analysis. With the collected demand data, part prioritisation has been done based on consumption value, criticality of parts and consumption rate using FSN, ABC, VED and ABC-VED matrix. The outcome of the analysis classified 517 parts into three classes such as high, medium and low priority. In addition, the manual procurement process has been converted to an auto-MRP system which schedules the part quantity and date.

The optimal order quantity for multiple parts inventory model has been applied to standardise "when" and "how much" order to be placed. 141 parts (27%) were classified into Class 1 for stringent managerial control. After implementation of different inventory models based on the three classes of parts, 4% reduction in overall stock value has been achieved. Based on the pilot study, optimisation has been horizontally deployed for other possible parts which resulted in 7% reduction of inventory turnover days from existing levels.

Keywords: Optimum Order Quantity, Inventory Turnover, Procurement Process, Part Prioritisation

Nomenclature

C	Cost per Unit
Ci	Cost of Product i
D	Annual Demand
D_i	Annual Demand for Product i
m_i	Frequency of Ordering Product i
n^*	Optimal Order Frequency
S	Fixed Ordering Cost
S^*	Consolidated Ordering Cost
s_i	Product i Specific Ordering Cost
Q^*	Optimal Lot Size

Abbreviations

FSN	Fast Slow Non-Moving items
ROP	Reorder Point
SOP	Standard Operating Procedure
VED	Vital Essential Desired

1. INTRODUCTION

Inventory management has become difficult for industries due to the economy, fierce competition, short product life cycles, increased demand variation and uncertainty [1]. Traditional inventory management does not yield benefits of lowered associate inventory costs, desired customer service levels, stocking of excess inventory and situations of material shortages [2]. The emerging trend in the recent years is the adoption of scientific and mathematical inventory models for inventory optimisation [1]. Inventory optimisation is sought to improve cash flow cycle, inventory related cost reduction and storage space utilisation. This reduces capital investment, which can be used for other business functions [3]. Various critical parameters need to be considered for the development of mathematical models to optimise inventory level across the organisation supply chain. Demand variation in the supply chain is the most critical parameter to be considered [4, 5]. It is imperative to optimise inventory levels in order to balance working capital investment, desired customer service level and reduce overall inventory holding costs [5]. It is necessary to identify the beneficial trade-off desired while optimising inventory simultaneously. To realise this, suitable inventory models needs to be synthesised and applied based on the dynamics of the operating environment.

1.1 Overview of bus manufacturing industry

India along with China is becoming the global manufacturing hub for buses and coaches, as they are habitat of the largest population in the world. Although the bus penetration is 0.7 per 1000, it is drastically low in India as compared to other Asian countries. There are policy frameworks being put in place by various authorities towards up-gradation, standardisation and passenger safety, which promise tremendous scope in bus body manufacturing. Moreover, bus manufacturing in India is turning over a new leaf due to the new technologies and trend development. Some of the trends as observed in the recent past of the industry include – sleeper and luxury coaches, low floor and semi low-floor monologue buses, intra and intercity buses, etc. for better serving of the customers.

1.2 Organisational Information - Place of Work

Volvo buses entered the Indian market in 2001 with a world-class air-conditioned intercity coach based on a true bus chassis and rear engine. The introduction of Volvo buses has been the catalyst that infused a whole new range of technology and level of comfort that set the benchmark in the Indian bus industry. Today, there are over 4,000 Volvo buses connecting the cities and towns of India. In 2008, Volvo Buses set up a complete plant in India at Hosakote near Bangalore. The plant is built on Volvo's global practices, quality standards and adopts the best practices from similar Volvo plants across the world making it a complete bus manufacturing facility. The study deals with direct material inventory that is the parts that get into the bus in the assembly process.

1.3 Rationale for selection of project area

- Volvo has an Indian market share of 76% of the commercial luxury vehicle. There is a need to hold market position even in a slow down by being cost effective
- 85% of the Volvo bus cost is attributed to the direct material used in manufacturing of the bus
- The number of bus parts is high and requires stocking material for production due to a wide spread vendor base
- The inventory turnover days is high resulting in a slower cash flow cycle
- The inventory carrying cost, stock out due to product unavailability affecting production leading to higher manufacturing costs
- The number of purchase orders released, goods receipt notes and related activities being highly repetitive for fast moving parts
- The presence of high number of obsolete parts due to inaccurate planning and procurement of the same

2. PROBEM DEFINITION

The problem behind the situation was inefficient procurement process leading to parts in extremities such as in excess or deficient and obsolescence of parts due to short product life cycles. High inventory levels have been maintained by the organisation with the intention of providing a higher customer service level. As a result of which huge capital being held up as unused cash, which does not free up capital for further investments. This situation has created a project theme of "Development of Direct Material Inventory Optimisation Model for a Bus Manufacturing Company". The aim of this work is to reduce direct material inventory turnover days by 5%.

Figure 1 shows the inventory turnover days value for three months. The current inventory turnover days that is average of three months is 12.7. The target inventory turnover days is 12.1 which is 5% reduction from the current level.

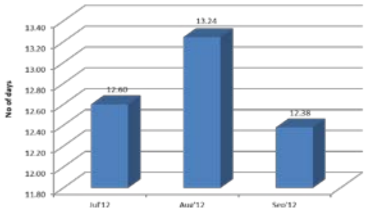

Fig. 1 Inventory turnover days data

2.1 Methodology

- Existing process has been studied through process mapping
- Data has been collected using company documents and observations
- Collected data of the direct material consumption have been classified into:
  - FSN (Fast, Slow and Nonmoving parts)
  - Identified the certain demand of fast moving parts which are common to more than one model
  - ABC analysis has been carried out to map the cost proportion of parts
  - VED analysis has been used to categorise the direct material parts based on criticality to production
- ABC-VED coupling matrix has been used to categorise the parts based on cost and criticality into three classes of parts
- Develop mathematical model to optimise the order quantity and frequency through tailored aggregation, aggregate planning and optimum order lot size for the three classes of parts categorised by the ABC-VED analysis
- Validate the model by comparing the existing method and developed mathematical model
- Standardise the material procurement process through Standard Operating Procedure (SOP)

3. DATA COLLECTION AND ANALYSIS

Data analysis and interpretation has been the method to derive the implication from the information collected. Its significance and validation of the root cause of the existing problem or variations has been clearly identified. Furthermore, accurate data collection, sorting and interpretation have been critical for understanding the errors that exist in the process. Therefore, identification of the best-suited improvement actions was necessary to achieve the project target.

3.1 Demand data

Figure 2 shows the model-wise demand data. It indicates:

- A total of five different bus models have been produced
- Annual production requirement is around 850 buses
- Average rate of production is around 4 buses per day
- CNG bus as the recently launched model

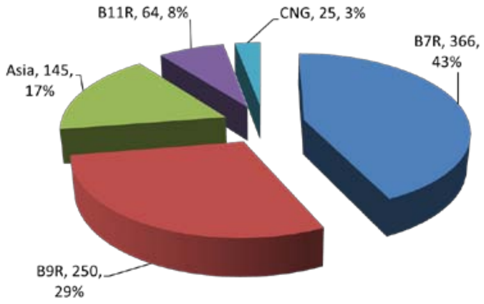

Fig. 2 Model wise demand

3.2 Cause and effect diagram

In order to identify the possible causes leading to high inventory turnover days, cause and effect diagram was drawn under four major drivers namely, procurement, production, supplier and stores [6]. The cause and effect diagram has been shown in Figure 3.

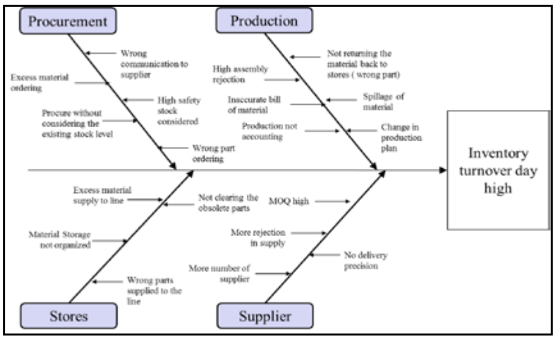

Fig. 3 Cause and effect diagram

Inference of Cause and effect diagram:

- *Production, supplier and stores driver:* Causes identified having lesser impact on the inventory cost. Since it has a minimal effect on the store stock value
- *Procurement driver:* Procurement driver has been identified as vital, since it has a direct relation between the store stock value and excess material stocking with inventory turnover days

3.3 Why-Why analysis

From the above cause and effect diagram, the probable causes of excess material ordering were identified as vital based on the inputs from experts. Why-Why analysis was carried out to bring out the root cause as depicted in Figure 4.

Inference of Why-Why analysis:

- *1st why for excess inventory:* Re-order Point (ROP) and order quantity was fixed. It varies radically in every order and lack of value based ordering led to excess stocking of high value items in stores
- *2nd why for excess inventory:* Excess inventory was found due to manual ordering process. The purchase orders were released manually based on the current stock and anticipated consumption rate
- *3rd why for excess inventory:* No procurement strategies were followed. All class of parts were ordered in the same manner and no special attention was provided for the high valued and vital items
- *Idea generation for root cause elimination:* Optimisation model development was proposed to reduce the inventory levels and standardisation of the procurement process

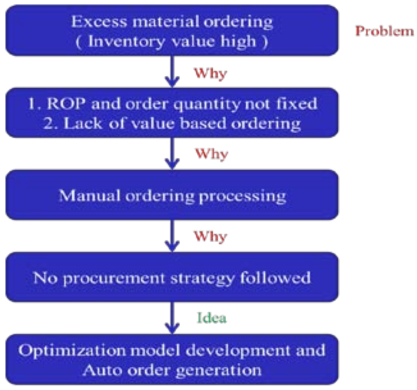

Fig. 4 Why-why analysis

3.4 Part categorisation for inventory optimisation:

Step 1: FSN analysis

FSN parts were classified inventory based on average stay in the inventory and consumption rate of material. This analysis was used to group the parts into three categories. The fast moving parts were considered as the frequently procured items and highly consumed parts. The slow and non-moving items were considered as a liability. Since, their consumption rates were based on a much longer time frame is shown in Figure 5.

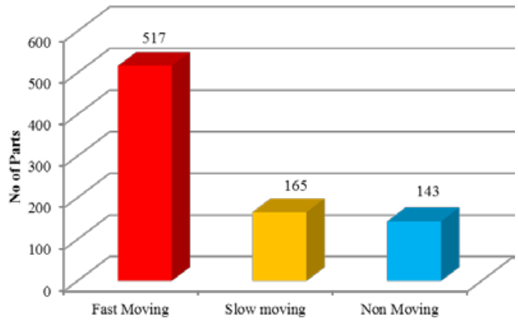

Fig. 5 FSN classification

Step 2: ABC analysis

ABC analysis was carried out for allocating inventory into three classifications based on annual consumption value. Using the classification, each category should be managed in different ways with more attention being given to A-class, less attention to B-class, and least attention to C-class. Criteria set to classify the inventory are as follows:

- A-class items - 10% of total inventory items representing around 70% of the total value
- B-class items - 20% of total inventory items representing around 20% of the total value
- C-class items - 70% of total inventory items representing around 10% of the total value

Figure 6 shows the ABC classification based on value for 517 parts. As per the criteria 69.92% of the total value were categorised as A-class parts, 20.05% of the total value were categorised as B-class parts and 10.04% of the total value were categorised as C-class parts accordingly.

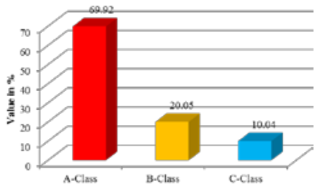

Fig. 6 ABC classification

Figure 7 shows the number of parts based on ABC classification. Total of 73 parts (14%) accounting for 69.92% of the total value in A-class, 87 parts (17%) accounting for 20.05% of the total value in B-class and 357 parts (69%) accounting for 10.04% of the total value in C-class.

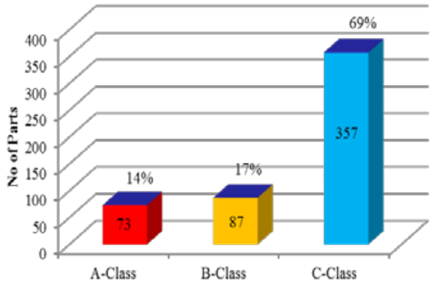

Fig. 7 Number of parts based on ABC classification

Step 3: Vital Essential Desired (VED) analysis

VED analysis was used for allocating inventory into three categories based on functional criticality of the material. Production and cost loss due to non–availability of material was the criteria for categorising the material into VED classes. Before classifying, lead-time of the parts was analysed. Since, delay in material leads to line stopper.

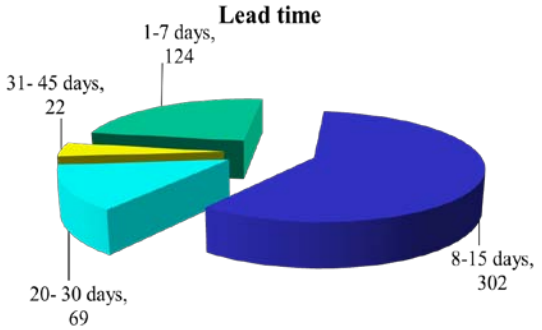

Fig. 8 Lead-time of part procurement

The part procurement critically depends on the lead-time required by the vendor to deliver the specified parts to the organisation. Lead-time indicates the precarious nature and amount of pre-planning time required by the material controller to procure the desired parts for production process. Lead-time is the cumulative time required for order processing, manufacturing and transportation time. Figure 8 shows lead-time of part procurement.

Figure 9 depicts the number of parts based on VED classification. In a total of 517 parts - 84 parts were identified as vital parts, 233 parts were identified as essential parts and 200 parts were identified as desired parts.

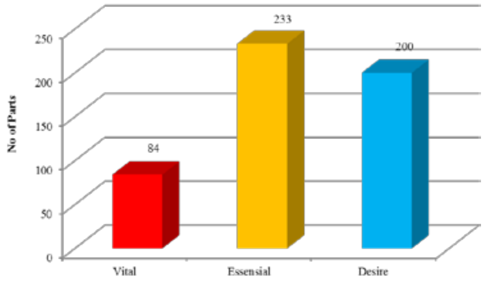

Fig. 9 VED classification

Step 4: ABC-VED matrix

ABC-VED matrix - hybrid model [7] was used to further classify ABC parts into sub-categories (VED) for extensive consideration of inventory management. This classification of the parts helps in prioritising the materials and executing better inventory control.

Figure 10 shows the ABC-VED matrix. ABC and VED analysis were combined and the materials were grouped into the following classes to set the priority:

Class I: AV+BV+CV+AE+AD: highest priority group needs greatest attention

Class II: BE+ BD+ CE: Moderate priority group, lesser attention

Class III: CD: Low priority group, least attention

	V	E	D
A	AV	AE	AD
B	BV	BE	BD
C	CV	CE	CD

Fig. 10 ABC-VED matrix

Figure 11 shows the output of ABC-VED matrix. Parts classified in ABC and VED analysis were combined and parts under each category were indicated.

Figure 12 shows the number of parts under each category. 141 parts were identified as Class-1, 243 parts were identified as class-2 and 133 parts were identified as class-3 parts.

	V	E	D
A	16	22	35
B	20	35	32
C	48	176	133

Fig. 11 Output of ABC-VED matrix

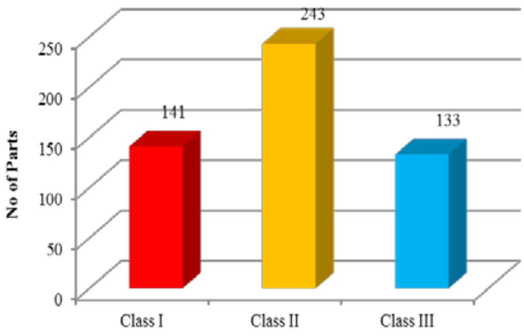

Fig. 12 ABC-VED classification

4. SOLUTION PROCEDURE

Inventory model:

Mathematical inventory models were applied to optimise the inventory levels. Optimisation of the direct material parts inventory was carried out to avoid both, that is excess material procurement and shortage of material. The main objective was to improve the cash flow of the organisation. Deterministic model [8] for inventory optimisation was used and the methods used are shown in Figure 13.

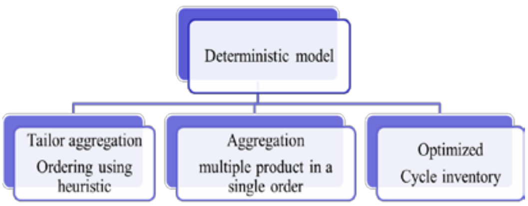

Fig. 13 Types of deterministic model

Table 1 shows the inventory model selection. The table indicates the different mathematical models based on the three classes of parts identified on basis of priority.

Class 3 – Optimised cycle inventory (CD)

The optimum lot size model was selected for the class 3 – low cost and desired parts.

Optimal lot size Q^*

$$Q^* = \sqrt{\frac{2DS}{hC}} \quad ..(1)$$

Table 1. Inventory model selection

Class	Category		Model	Step 1	Step 2
I	AV, BV, CV, AE & AD	High value & priority	Tailor aggregation Ordering using heuristic	Frequently ordered product	Ordering size
II	BE, CE & BD	Medium value & priority	Aggregation multiple product in a single order	Optimum order frequency	Optimal lot size
III	CD	Low value & priority	Optimization Cycle inventory	Optimal lot size	Optimal ordering frequency

Optimal ordering frequency n^*

$$n^* = \frac{D}{Q^*} = \sqrt{\frac{DhC}{2S}} \quad ..(2)$$

Average flow time

$$\frac{Q^*}{2D} \quad ..(3)$$

Cycle inventory

$$\frac{Q^*}{2} \quad ..(4)$$

Equations 1 to 4 were applied to compute the optimised cycle inventory and specified in a sequential order. Table 2 shows the sample calculation carried out for 10 parts out of 133 parts identified in this class. It incorporates the unit cost of material (C), annual demand (D) – based on per bus quantity for calculation. The order frequency and optimal order lot values were furnished.

Table 2. Optimised cycle inventory calculation

S No	Object ID	Qty	UOM	Unit Price	Demand	(Q*=Sqrt 2DS/hC)	# of Order (n*=D/Q)	Cycle inventory	Avg flow time (wks)
1	70393338	1	PCE	137.88	1000	190	5	95	8.4
2	70393341	1	PCE	137.88	1000	190	5	95	8.4
3	70345453	7	PCE	19.63	7000	505	14	252	3.2
4	70400565	1	EA	135.00	1000	192	5	96	8.5
5	21921469	2	PCE	65.00	2000	277	7	139	6.1
6	21162987	1	PCE	129.58	1000	196	5	98	8.7
7	70398198	3	PCE	42.84	3000	342	9	171	5.0
8	21658991	2	PCE	63.81	2000	280	7	140	6.2
9	70400567	1	EA	125.00	1000	200	5	100	8.8
10	70400569	1	PCE	125.00	1000	200	5	100	8.8

Inference from the before and after comparison of mathematical model application:

- The existing practices were not standardized. Order quantity varied from part to part even though they had the same demand
- The mathematical model standardises the order size and frequency based on the demand

Class 2 - Aggregation Model - BE, CE and BD

The aggregation model was selected for the class 2 – medium cost and essential parts.

Optimal order frequency:

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} DihCi}{2S^*}} \quad ..(5)$$

Ordering cost:

$$S^* = S + s_i \quad ..(6)$$

Optimum lot size:

$$Q^* = \frac{D}{n^*} \qquad ..(7)$$

Average flow time:

$$\frac{Q^*}{2D} \qquad ..(8)$$

Cycle inventory:

$$\frac{Q^*}{2} \qquad ..(9)$$

The equations 5 to 9 were used to compute the optimal order frequency and lot size was specified in a sequential order.

Table 3. Aggregation model calculation

S No	Object ID	Qty	UOM	Unit Price	Demand	n*	Order size Q=d/n*	# of Order (n*=D/Q)	Cycle inv	Avg flow time (wks)
1	70392434	2	PCE	94.26	2000	22622	99	20	49	2.18
2	70357596	2	PCE	95.22	2000	22853	99	20	49	2.18
3	21200236	1	PCE	191.43	1000	22972	49	20	25	2.18
4	70392437	1	PCE	199.48	1000	23938	49	20	25	2.18
5	70392440	1	PCE	199.48	1000	23938	49	20	25	2.18
6	21711882	1	PCE	204.06	1000	24487	49	20	25	2.18
7	21149788	1	PCE	217.93	1000	26152	49	20	25	2.18
8	21180813	1	PCE	218.91	1000	26269	49	20	25	2.18
9	20916827	1	PCE	221.86	1000	26623	49	20	25	2.18
10	20916830	1	PCE	221.86	1000	26623	49	20	25	2.18
					Sum	246476				
					Num/Den	410.794				
					n*	20.26805368				
					Order fz.	12				

Table 3 shows the sample calculation carried out for 10 parts out of 242 parts identified in this class. It incorporates the unit cost of material, annual demand – based on per bus quantity for calculation. The order frequency and optimum order lot values were furnished based on the calculation using the equations 5 to 9.

Inference from the before and after comparison of mathematical model application:

- The existing practices were not standardized. Order Quantity varies from part to part even though they had the same demand usage
- The mathematical model standardises order size and frequency with constant average flow time

Class 1 - Tailored Aggregation - AV, BV, CV, AE and AD

The tailored aggregation were identified for the class 1 – medium cost and essential parts.

Maximum ordering frequency:

$$\bar{n}_i = \sqrt{\frac{hCiDi}{2(S+si)}} \qquad ..(10)$$

Most frequently ordered product:

$$\bar{\bar{n}}_i = \sqrt{\frac{hCiDi}{2s_i}} \qquad ..(11)$$

Evaluate frequently of product and fraction round off:

$$\bar{m}_i = \frac{\bar{n}}{\bar{\bar{n}}} \qquad m_i = [\bar{m}_i] \qquad ..(12)$$

Ordering frequency:

$$n = \sqrt{\frac{\sum hC_i m_i D_i}{2(S + \sum s_i/m_i)}} \qquad ..(13)$$

Equations 10 to 13 were used to compute the optimum order frequency and lot size was specified in a sequential order.

Table 4. Tailored aggregation model calculation

S No	Object ID	Qty	UOM	Unit Price	Demand	n bar Sqrt(hCD/2S)	(Q*=D/n*)	Cycle inventory	Avg flow time (wks)	n doubl bar Srqt(hCD/2s)	mbar=n bar/ndoub bar	m (m bar round off)	# of order (n*=n bar/mbar)
1	980138	6	PCE	31.46	6000	6	1059	529	7.8	6.1	2.8	3	6
2	21554107	3	PCE	54.40	3000	6	529	265	7.8	5.7	3.0	3	6
3	21551506	1	PCE	270.84	1000	7	176	88	7.8	7.4	2.3	3	6
4	21555510	24	PCE	37.62	24000	13	1412	706	2.6	13.4	1.3	1	17
5	21554408	4	PCE	262.73	4000	14	471	235	5.2	14.5	1.2	2	9
6	21551501	4	PCE	381.37	4000	17	235	118	2.6	17.5	1.0	1	17
7	21551504	4	PCE	381.37	4000	17	235	118	2.6	17.5	1.0	1	17
8	21551533	1	PCE	122.16	1000	5	235	118	10.4	4.9	3.4	4	4
9	21551535	1	PCE	122.16	1000	5	235	118	10.4	4.9	3.4	4	4
10	70399183	2	PCE	112.90	2000	7	353	176	7.8	6.7	2.5	3	6

Table 4 shows the sample calculation carried out for 10 parts out of 141 parts identified in this class. It incorporates the unit cost of material, annual demand – based on per bus quantity for calculation. The order frequency and optimal order lot values were furnished based on the calculation using the equations10 to 13.

Inference from the before and after comparison of mathematical model application:

- The existing practices were not standardized. Order quantity varied from part to part even though they had the same demand usage
- The mathematical model standardises the order size and frequency was derived from frequently ordered product

5. IMPLEMENTATION

Appropriate mathematical model was selected to reduce the inventory turnover days. To obtain and sustain the identified improvement - standardisation, continuous review and updation was necessary. Following steps were identified to implement the solution in a systematic way as shown in Figure 14.

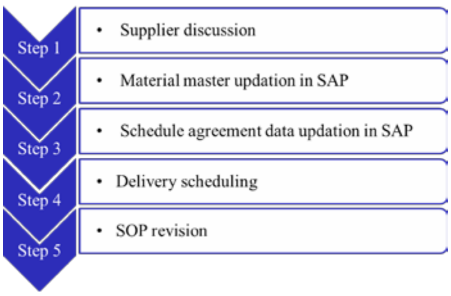

Fig. 14 Implementation steps

6. RESULTS

Figure 15 gives the store stock value comparison. After taking necessary action, the overall stock values of 517 parts were reduced from existing level which is around 4% reduction.

Figure 16 shows before and after comparison of inventory turnover days. After implementing the mathematical model for 517 parts based on class, the overall inventory turnover was reduced from 12.7 days to 11.8 days. Through horizontal deployment of the inventory models an overall 7% reduction was achieved.

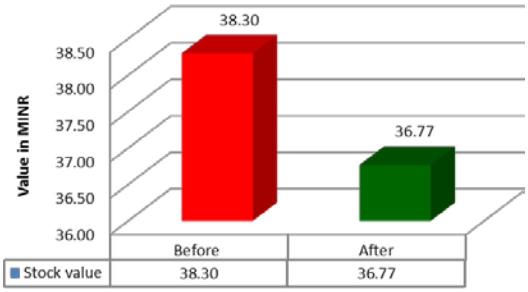

Fig. 15 Stock value of stores

Fig. 16 Before and after comparison

6.1 Benefits from this study

Tangible:

- Inventory turn-over days reduced from 12.7 to 11.8 days
- Store stock reduced by 4%
- Manual procurement dependency eliminated

Intangible

- Better cash flow due to reduction in inventory turn
- Ordering cost reduced due to multiple parts in single order
- Manual error avoided as order released through IT system
- Line stopper reduced due to shortage of material
- Space utilisation improved due to optimised inventory level
- Customer service level improved based on material consumption and demand

6.2 Validation of the proposed model

Figure 17 shows the store stock comparison. Similarly, class wise material stock value was compared. It depicts the significant reduction in class-B and C parts, since, they were not vital and optimised stock in class-A was priority. Improvement yielded the overall reduction in stock value. Hence, deterministic mathematical inventory models had positive impact on inventory levels.

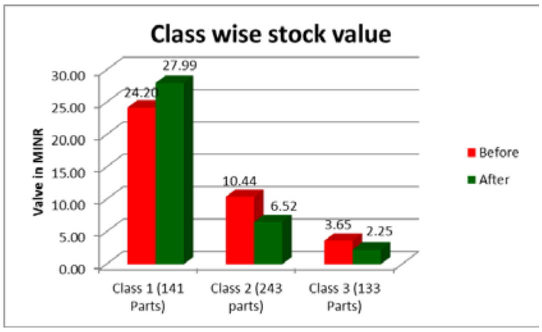

Fig. 17 Class wise cost comparison

7. CONCLUSION

- After a series of part classification based on FSN, ABC and VED, the overall 517 parts were classified based on criticality and value
- Class-wise parts details are as follows:
  - CLASS 1: AV, BV, CV, AE and AD – 141 parts
  - CLASS 2: BE, CE & BD - 243 parts
  - CLASS 3: CD – 133 parts
- After taking necessary action, the overall stock value of 517 parts was reduced from existing level which is a 4% reduction
  - CLASS 1: AV, BV, CV, AE AND AD - stock value increased by 3.79 MINR
  - CLASS 2: BE, CE AND BD - stock value reduced by 3.92 MINR
  - CLASS 3: CD - stock value reduced by 1.4 MINR
- The overall inventory turnover was reduced from 12.7 days to 11.8 days, which is a 7% reduction from existing and horizontally deployed
- ABC-VED matrix accurately identified three classes of parts which required different leverage of managerial control
- Aggregation and tailored aggregation models helped to yield the inventory turnover days reduction targeted
- IT enabled material procurement system enabled auto-purchase order generation which specified order quantity and delivery schedule

7.1 Recommendation for future work

Following recommendations have been suggested to further reduce the inventory levels of the organisation:

- Extensive usage of SAP-ERP software for integrating the production, accounting and synchronising the various business operations
- Lean procurement, JIT concepts and Kanban implementation for further reducing inventory levels to eliminate storage and retrieval activities in the stores
- Improve the supplied parts quality, eliminate part accumulation in quality inspection and introduction of part supply directly to the line- increase green channel parts
- Accurate physical inventory stock in the system and inventory visibility to be improved – FIFO to be implemented

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