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Development of Multi Bin Inventory Maintenance Management System in Lean Manufacturing using Arena

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Abstract: Inventory management system is one of the main parameter that is most desirable to be considered in manufacturing industries to satisfy the customer. The aim of this case study is to develop a multi bin inventory system instead of forward cover system and to compare with the usage of basic inventory policy. In lean manufacturing system the Kanban tool is one of the production strategies with minimal inventory to reduce the overall cost of the products. Multi bin system is a sign, flag or signal within the manufacturing process to trigger the production and supply of product as part of just in time in lean manufacturing. In addition, this research work has also tried in looking for a period of inventory maintenance management system, so that, it can find the minimum cost incurred or the period which could still be tolerable for tracking inventory management system. From the final results it was concluded that, all of our proposed formulae under this study are really fit for multi bin system. Also found that the periodic review policy has less inventory value as compared to continuous review policy and based on simulation result, the multi bin system could restrain the inventory cost as compared to forward cover system.

Key words: Multi bin system inventory, lean manufacturing, C programming, ARENA, policy, production

INTRODUCTION

The term “inventory” refers to the stockpile of manufacturing that a company is offering for sale and the components that make up the production. Maintenance of inventory means blocking of funds that involves interest and opportunity cost to the company. In most of the countries, especially in Japan great emphasis is placed on inventory management. Efforts are made to minimize the stock of inputs and outputs by proper planning and forecasting of demand of various inputs and producing only the quantity which can be sold in the market. The inventory cost is not only interest on stocks but also cost of building for storage insurance and obsolescence and movement of inputs from place of storage to the factory where the materials have to be finally used to convert them into finished goods. The primary objectives of inventory management are to minimize the possibility of disruption in the production schedule of a company for the need of raw material, stock and spares and to keep down the capital investment on inventories.

Excessive inventory is an idle resource of a manufacturing company which should be always avoided. The investment in inventories should be just sufficient to the optimum level. The major problems occurring due to excessive inventories are the unnecessary tie up of the manufacturing industries funds and loss of profit, excessive carrying cost and risk of liquidity. The excessive level of inventories consumes the funds of business which otherwise is not available other essential purchases and thus involves an opportunity cost. The carrying cost such as the cost of storage, handling insurance, recording and inspection also increases in proportion to the volume of inventories. Further these costs will impair the overall profitability of the company. To overcome this inventory problem a case study was carried out in a leading manufacturing and distributor of automotive service equipments in Chennai and a new inventory system was proposed.

Literature review: Inventory management is an ongoing process of planning, systematizing and controlling the inventory to minimize the investment in inventory through balancing supply and demand (Wei *et al*., 2013; Nallusamy *et al*., 2017). Inventory management is one of the supply chain management segments which is part of the regular internal research inside the company. Generally inventory is classified into four categories such

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as raw material inventory, research in progress inventory, finished goods inventory and maintenance, repair and operating inventory (Liu and Papageorgiou, 2013; Nananukul, 2013). If the company can manage inventory system effectively and efficiently, it could result in reduction of operating costs. Inventory system refers to the solving problems of stock in the business. Good stock management will maximize business benefits and vice versa, the failure to control the stock will result in a loss benefit to the company (Nallusamy, 2016a). There are two replenishment policies often used in inventory practice, like continuous review policy and periodic review policy. Continuous review policy indicates that inventory status is continuously tracked and the ordering is done according to lot size when the level reaches the entrusted inventory reorder point. Periodic review policy indicates that, the inventory status is tracked at regular periodic intervals and reorder is made to raise the inventory level to the point of predefined. These inventory system policies are not comprehensive but are sufficient to provide solutions to problems concerning the safety of the inventory management system (Kumar and Anas, 2013; Nallusamy, 2016b). The advantage of continuous review policy is to address the situation where demand is high but the disadvantage is variable order quantity. The supplier can make mistakes more often and they would prefer the customers who ordered the fixed order quantity but this situation is vice versa with periodic review policy (Kampf *et al*., 2016c). Effective and efficient inventory management system affects supply chain management significantly to improve cycle service levels and reduce costs (Nallusamy, 2016c).

Kanban is a subsystem of the lean manufacturing system which was created to control inventory levels, production and supply of components (Atieh *et al*., 2016). Knowledge is the creation and accumulation of Kanban system, the implementer can classify and analyze the variations of the Kanban system (Nallusamy, 2016d; Nallusamy and Saravanan, 2016a, b; Rouibi and Burlat, 2010). Classifications of the Kanban system into dual card like Kanban system for production signaling and Kanban system for transportation signaling. During demand uncertainty the buffer maintenance is necessary for smoothening production flow and reconfigures the Kanban system in order to minimize the inventory level. Thus, Kanban system provides mixed model production along with optimal inventory level which results in less lead time in product delivery and effective utilization of resources such as man, materials, machines, etc. The company never achieves a low-cost strategy without good inventory management policy and system. Since, inventories are important in an organization, managing these inventories becomes complicated, since, it involves storage and holding costs and space in a manufacturing plant. Inventory management is a complex problem area owing to diversity of real life situations (Nallusamy *et al*., 2015; Saric *et al*., 2014). Kanban system requires supplier commitment in providing fast services to provide effective supply of raw materials. Basically Kanban system only requires minimum level of inventories in the production line where the inventories number should be equal with the production numbers (Nallusamy and Ahamed, 2017; Hedenstierna and Disney, 2016). Therefore, supplier commitment plays an important role in order to ensure that production lines operate smoothly and efficiently. There are five important criteria while choosing supplier which includes quality, willingness to work together, technical competence, geography and price. The aim of just in time is to eliminate stocks rather than move them to another point in the supply chain and again, the way to achieve this is through co-operation (Nallusamy *et al*., 2015; Russell and Urban, 2016; Balakannan *et al*., 2015).The Japanese Kanban process of production is sometimes incorrectly described as a simple just-in-time management technique, a concept which attempts to maintain minimum inventory. The Japanese Kanban process involves more than fine tuning production and supplier scheduling systems where inventories are minimized by supplying these when needed in production and work in progress in closely monitored (Nallusamy, 2016e; Millstein *et al*., 2014; Nallusamy *et al*., 2015). Based on the above study, an attempt was made to develop a new inventory formula using C programming and a case study was undertaken in MAK automotive private limited Chennai for the analysis. The proposed inventory policy was also validated using ARENA (Nallusamy *et al*., 2016a, b).

MATERIALS AND METHODS

Problem statement and methodology: Traditional manufacturing strategy is driven by "Push system" which aims to keep large inventory of product according to customer forecast. However, this has created big problem to people with rise in raw material inventories, unsynchronized production processes and producing unnecessary stock. The difficulties in forward cover system are identification of unmet needs, placing this need in the context of procurement, high level of leadership and staff commitment, ability to make a forward commitment of sufficient strength to generate the required market pull and financial loss and ineffectiveness of the inventory management system. Because no money gets exchanged initially, there is counterparty credit risk involved with forward contracts. Since, the company

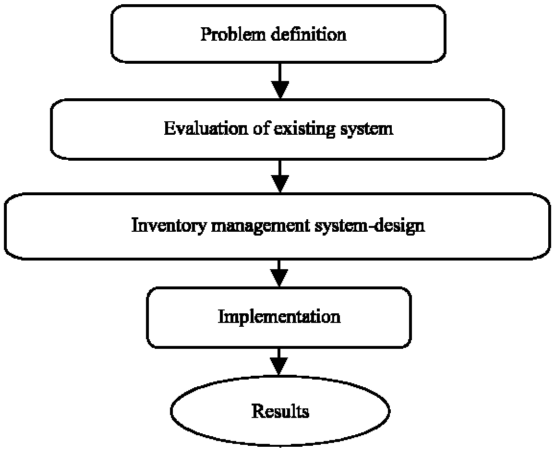

Fig. 1: Methodology flow chart

depends on the counterparty to deliver the asset and in case the counterparty defaults between the initial agreement date and delivery date, one can incur a loss. Similarly during procurement capital investment in inventories is high, raw material inventory is high as compared to usage and safety stock amount for each product is high as compared to usage. The research methodology has been directly translated to the case study. The methods to develop Kanban system and procurement policies are presented and the methodology flow chart is shown in Fig. 1. The method to develop Kanban system consists of collecting relevant parameters, calculating Kanban quantity, establishing pull mechanism and rule. The method to develop procurement policy consists of collecting appropriate data, calculating safety stock, reorder point, economic order quantity and average inventory level. Finally, the continuous review policy and the periodic review policy were compared (Nallusamy and Majumdar, 2017).

Data collection and analysis

ABC analysis: The existing data for the period of 6 months were collected from the selected case company from July 2016-December 2016. The ABC analysis was carried out for the selected company based on the existing data collected. The numbers of items with the respective total inventory value were calculated by category wise and are given in Table 1. Similarly the percentage of product utilization with the inventory value percentage for all the categories were calculated and are shown in Fig. 2.

Multi bin Kanban system: In multi bin Kanban system, the bins are topped up at regular intervals by the supplier. They often have multiple locations within their facility and

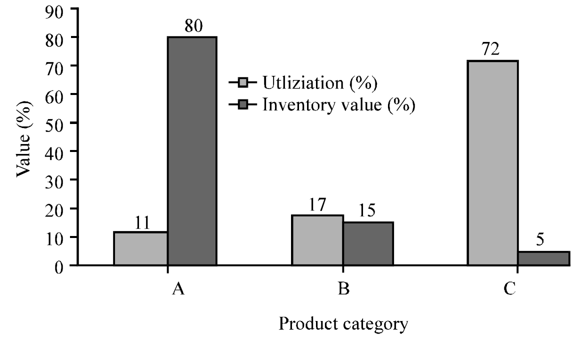

Fig. 2: Percentage of inventory value with product utilization

Table 1: Inventory value with total number of products

Categories	Number of products	Inventory value (Rs.)
A	280	30998530
B	440	5830840
C	1880	1918325

the operators help themselves to full bins after returning the empties for replenishment. The system works as follows:

- The first bin is stacked on top or in front of the second bin
- A reorder card is placed on the bottom of each bin
- Material is drawn from the first bin only
- When the first bin is empty, it is exchanged with the second bin
- The reorder card is used to replace items in the first bin
- Material is then drawn from the second bin while waiting for receipt of the material on order
- When the new material arrives, it is placed in the empty bin and the reorder card is returned to its proper place in the bin
- The procedure is continued with material being selected from one bin until it is depleted and then replenished through the reordering card
- In a Kanban system there are different types like Kanban cards e-bands, 2 bin systems, 3 bin systems, hybrid systems, etc.

Kanban cards: Kanban card is used to convey a research item's progress visually as it flows through a system or process. At the same time though it is not intended to replace the need for conversation but by using Kanban cards the groups central information hub can reduce the time spent in status meetings, establish high value teamwork openings and improve overall efficiency. The values of batch size and number of cards proposed for multi bin system is given in Table 2:

Table 2: Batch size and number of cards proposed for multi bin system

Description	Replenishment lead time (days)	Batch size	No. of cards
Wheel aligner kit DWA 1000 W	90	4	6
Kit wheel balancer F7D	90	10	6
A power pack with motor assembly-F	90	6	6
Blower fan model TA/R 18-18	90	11	3
Vacuum pump	90	31	3
1/2" Impact wrench SP-1140EX	90	8	7
1/2" Ratchet wrench SP1133EX	90	8	7
Power pack	90	4	3
Burner Bentone B30A/47 CPU	60	11	5
Electric 3 HP induction motor	60	46	4
3HP Electric motor-B3/B14	60	18	6

$$\text{Number of Kanban cards} = ((DD \times LT)+SS)/KBS$$

Where:

DD = Daily Demand
LT = Lead Time (days)
SS = Safety Stock
KBS = Kanban Size (Batch Size)

Basic simulation using c programming:

Flow chart using C programming: The basic simulation using c programming was carried out with multi-bin system and the common flow chart using C programming is shown in Fig. 3.

Coding for C programming: The coding written using C programming for multi-bin system is discussed as follows Algorithm 1.

Algorithm 1: C programming

```
#include<stdio.h>
#include<conio.h>
void main()
{       int ai,i,d,bs,nb,nee,m,lt,tmp=0,opt,b[100]
        clrscr()
printf("\n Enter demand value = ")
scanf("%d"&d)
printf("\n Enter number of bins = ")
scanf("%d"&nb)
printf("\n Enter batch size =" )
scanf("%d"&bs)
printf("\n Enter manufacturing lead time in months =" )
scanf("%d"&lt)
printf("\n The Monthly demand is = %d\n Number of bins
        = %d\n Batch size = %d\n Manufacturing lead time =%d
        months \n ",d,nb,bs,lt)
printf("\n Enter the simulation period in months =")
scanf("%d"&m)
for(i = 1;i< = nb; i++)
{       b[i] = bs
        printf("\n Bin %d = %d",i,b[i])
}       for(ai = 1;ai<= m;ai++)
{       nee = d
for(i = 1;i<= nb;i++)
{       if(nee<= b[i])
{       b[i] = b[i]-nee
nee = 0
}       else
{       nee = nee-b[i]
tmp = tmp+b[i]
b[i] = 0
} } }   for(i = 1;i<= nb;i++)
{       printf("\n\n Bin %d = %d",i,b[i])
        }   getch()
}
```

Arena simulation: The flow chart for 2 bin systems was developed and is shown in Fig. 4. For every multi-bin system the arena simulation model was used to validate the results. The simulation model for 2 bin systems is shown in Fig. 5. Similarly, flow charts were developed for 3-6 bin systems and shown in Fig. 7-12, respectively. The appropriate Arena simulation models were also used to validate the results obtained by various multi-bin systems and shown in Fig. 6-13, respectively.

Inventory management system-procurement policies: Procurement policy for inventory management system was developed for continuous review policy and periodic review policy and the results obtained by both models where then compared.

Continuous review (Q method):

$$SS = FS\text{-}1(CSL)\times\sigma L \quad (1)$$

$$ROP = DL+SS \quad (2)$$

$$CI = Q/2 \quad (3)$$

$$AIL = CI+SS \quad (4)$$

$$DL = DL \quad (5)$$

$$\sigma L = \sqrt{L}\sigma D \quad (6)$$

$$Q = \sqrt{(2DeS)}/hC \quad (7)$$

Periodic review (method):

$$SS = Fs\text{-}1(CSL)\times\sigma T+L \quad (8)$$

$$DT+L = (T+L)D \quad (9)$$

$$\sigma T+L = \sqrt{(T+L)}\sigma D \quad (10)$$

$$OUL = DT+L + SS \quad (11)$$

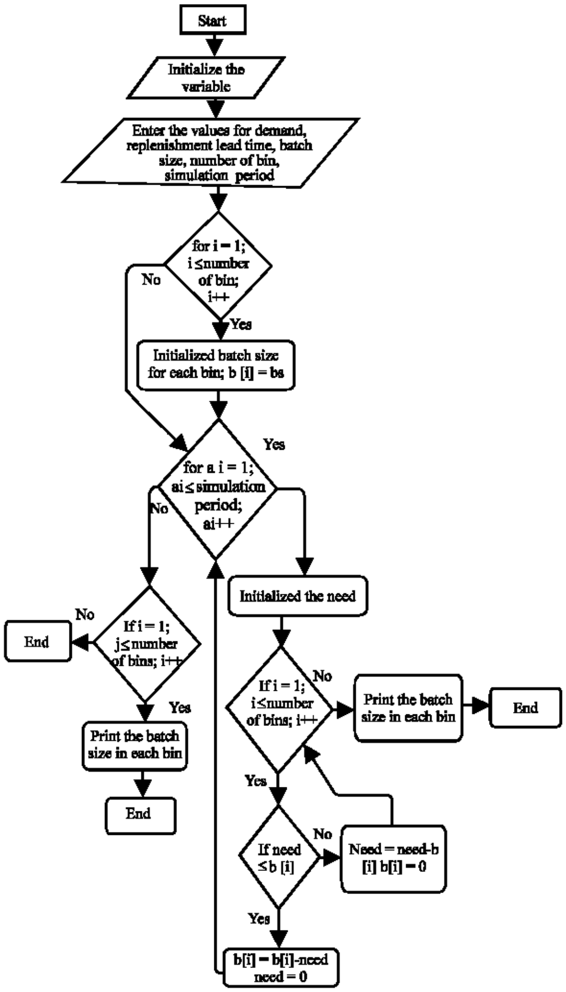

Fig. 3: C programming flow chart

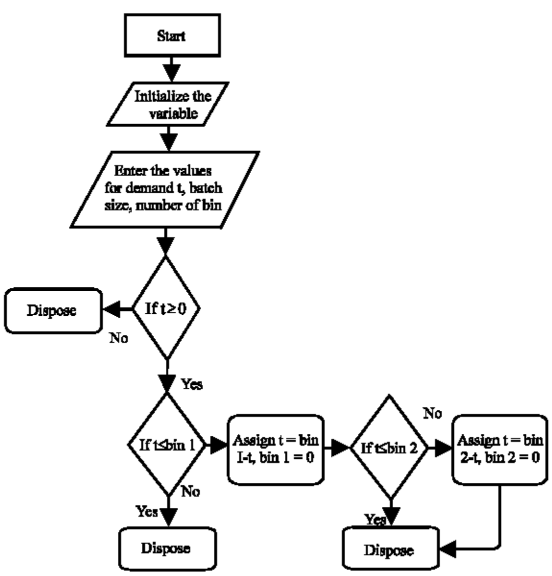

Fig. 4: Two bin system flow chart

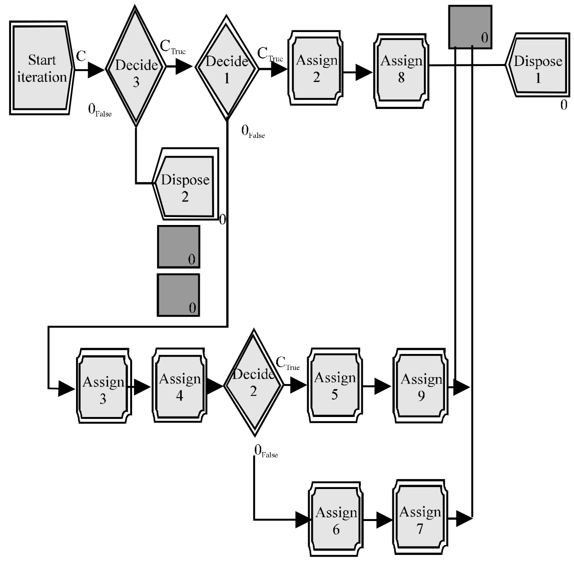

Fig. 5: Two bin system simulation model

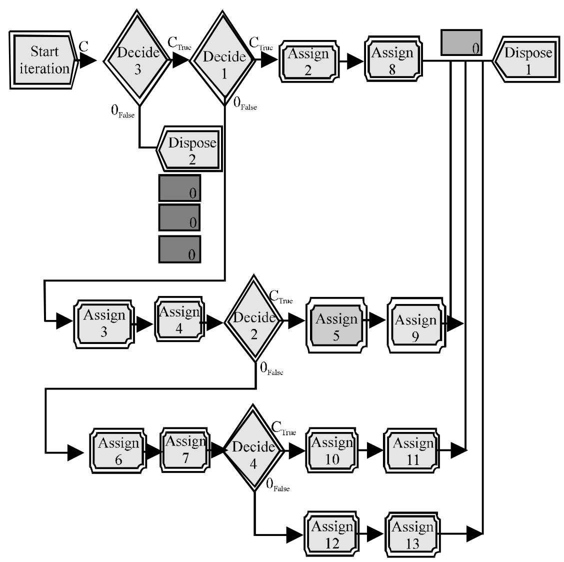

Fig. 6: Three bin system simulation model

$$AIL = (DT)/2 + SS \qquad (12)$$

Definition of a few terms:
Where:

SS	=	Safety Stock
CSL	=	Cycle Service level
CI	=	Cycle Inventory
ROP	=	Rreorder Point
Fs-1	=	Normsinv
σT+L	=	Std. deviation of demand during T+L
T	=	Review interval

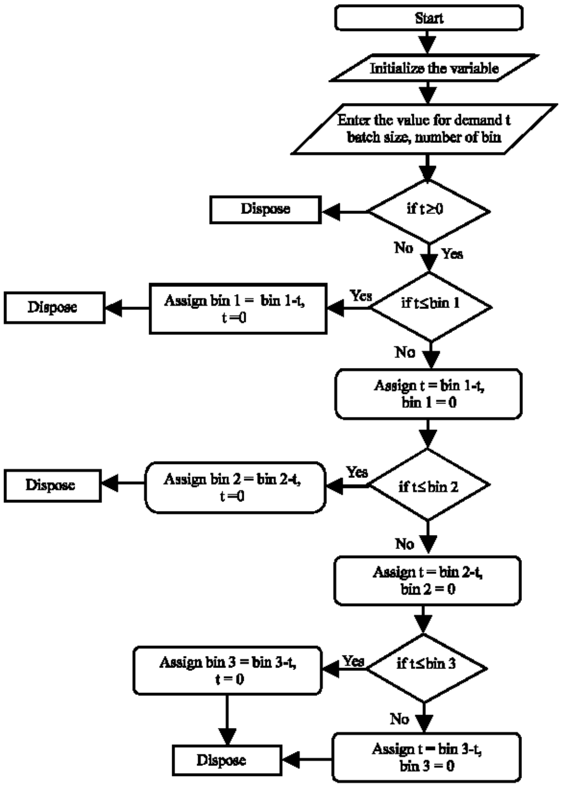

Fig. 7: Three bin system flow chart

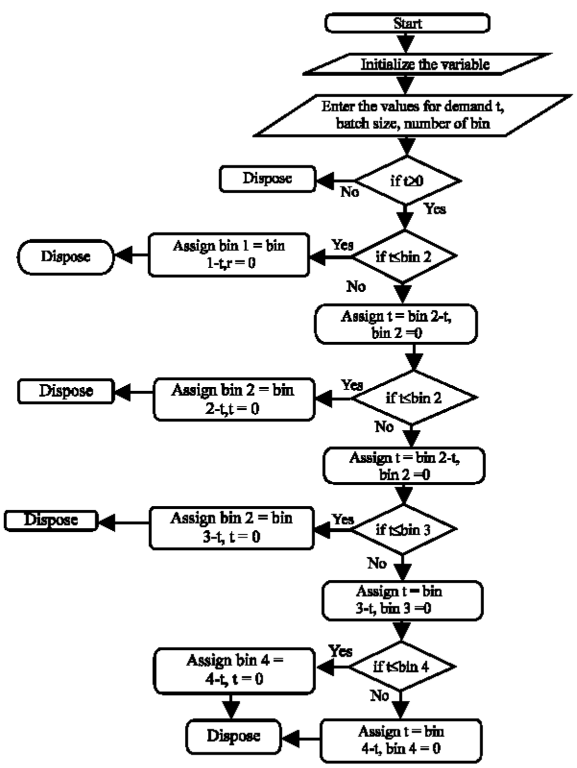

Fig. 8: Four bin system flow chart

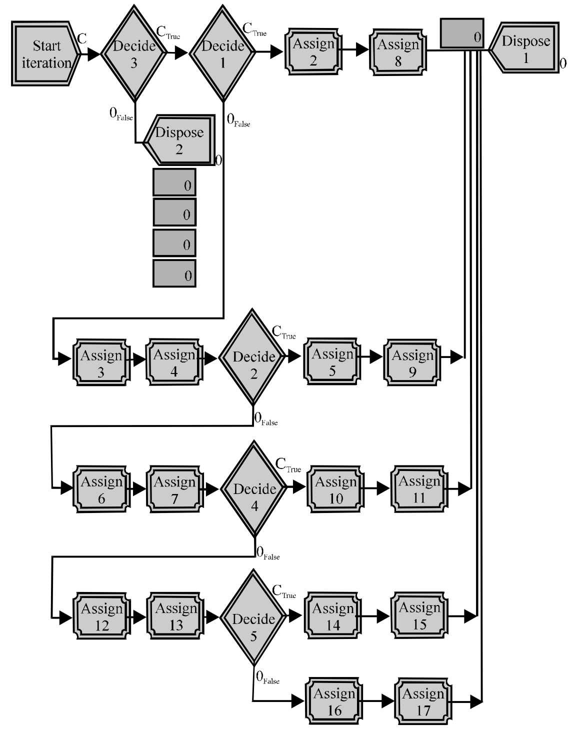

Fig. 9: Four bin system simulation model

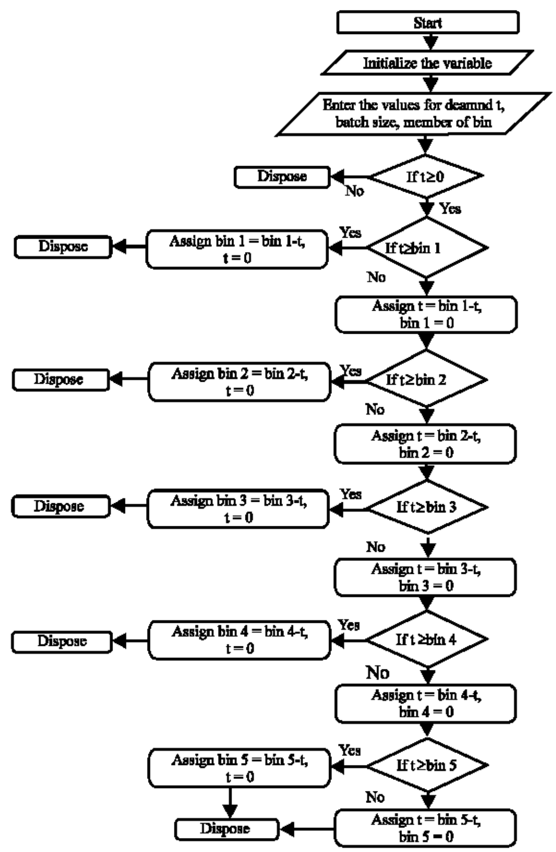

Fig. 10: Flow chart for 5 bin system

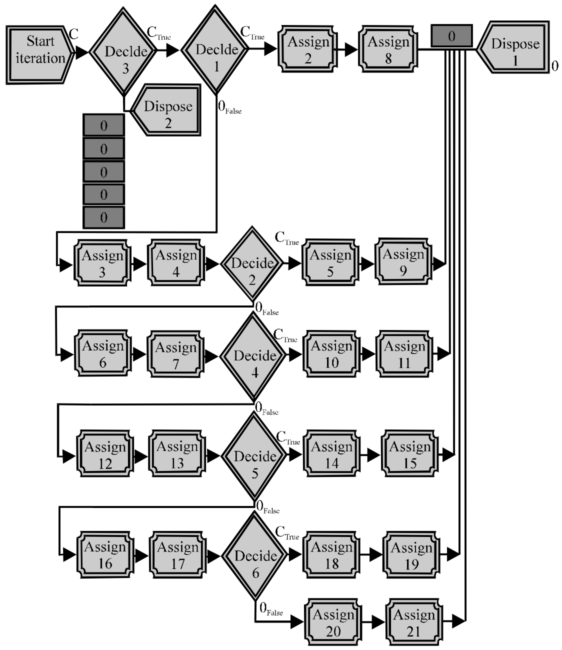

Fig. 11: Simulation model 5 bin system

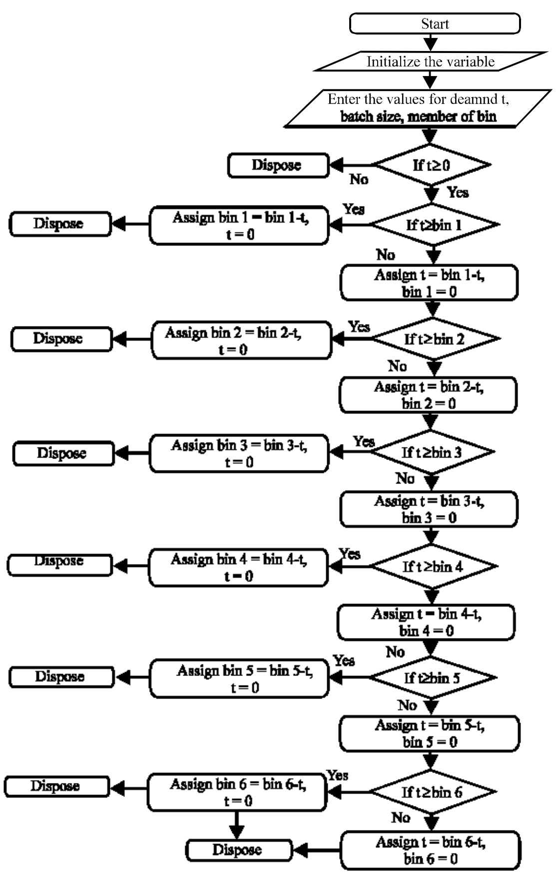

Fig. 12: Six bin system flow chart

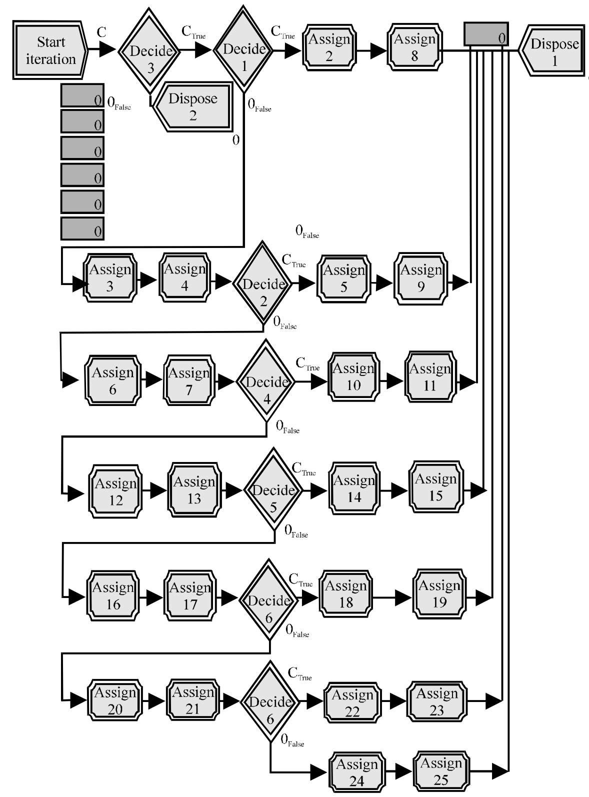

Fig. 13: Six bin system simulation model

L = Average Lead time for replenishment
D = Average Demand per period
σD = Std. Deviation of demand per period
σL = Std. deviation of demand in Lead time
DT+L = Mean Demand during T+L
OUL = Order Up to Level
AIL = Average Inventory Level
Q = Lot size
De = Annual Demand
S = Order cost per lot
h = Holding cost
c = Unit cost

RESULTS AND DISCUSSION

Comparison of continuous review policy and periodic review policy: The cycle inventory and average inventory level for the various items were identified through the proposed continuous review policy inventory system also called as Q-policy and the average inventory values were also calculated and are given in Table 3. Similarly, the values for the proposed periodic review policy inventory system also called as P-policy were identified and calculated and are given in Table 4. The observed values

Table 3: Inventory system through proposed continuous review policy

Descriptions	Cycle inventory	Average inventory level	Averageinventory values (Rs.)
Power pack with motor assembly-F	16	25	373778
Sensor head kit truck aligner	1	1	240187
Blower fan model TA/R 18-18	16	54	681215
Ramp assembly	5	8	110117
Vacuum pump	47	113	413569
½" Wrench impact SP 1140SX	23	40	216489
½" Wrench ratchet SP 1133SX	23	43	122154
Blower 8000 CMH Italy.TA-S15	10	3	283980
Electric 3HP induction motor	92	133	731889
Oxygen sensor	45	77	206671

Table 4: Inventory system through proposed periodic review policy

Descriptions	Cycle inventory	Average inventory level	Average inventory value (Rs.)
Power pack with motor assembly-F (A)	37	14	211540
Sensor head kit truck aligner (B)	2	2	400115
Blower fan model TA/R 18-18 (C)	72	47	598156
Ramp assembly (D)	16	24	334957
Vacuum pump (E)	159	93	331125
½" Wrench Impact SP 1140SX (F)	60	26	138259
½" Wrench ratchet SP 1133SX (G)	62	30	825790
Blower 8000 CMH Italy.TA-S15 (H)	4	2	242870
Electric 3HP Induction motor (I)	205	90	493745
Oxygen sensor (J)	115	55	150964

Table 5: Comparative results of p-policy and q-policy savings

Descriptions	Average inventory value by Q-policy	Average inventory value by P-policy	Existing average inventory value
Power pack with motor assembly-F (A)	373778	211540	1315613
Sensor head kit truck aligner (B)	240187	400115	2837945
Blower fan model TA/R 18-18 (C)	681215	598156	2313750
Ramp assembly (D)	110117	334957	1980554
Vacuum pump (E)	413569	331125	1647763
½" Wrench Impact SP 1140SX (F)	216489	138259	4381720
½" Wrench ratchet SP 1133SX (G)	122154	825790	2478540
Blower 8000 CMH Italy.TA-S15 (H)	283980	242870	8517360
Electric 3HP Induction motor (I)	731889	493745	5148945
Oxygen sensor (J)	206671	150964	1394172

through Q and P-policy were compared and the percentages of savings were also calculated and compared and are given in Table 5 and Fig. 14. From the results, it was found that the periodic review policy has less inventory value in many products as compared with the continuous review policy like 28% less in power pack with motor assembly-F, 11% less in vacuum pump, 22% less in ½" wrench impact SP 1140SX, 20% less in ½" wrench ratchet SP 1133SX, 20% less electric 3HP induction motor and 16% less in oxygen sensor. Hence, it could be seen that the overall periodic review policy to be better as compared with the continuous review policy.

Table 6: Inventory in terms of quantity through forward cover system

Description	2016 Sep	Oct	Nov	Dec
Wheel alignment kit DWA 1000w	2	3	2	2
Kit WB F7D	2	12	7	3
Power pack with motor assembly-F	3	2	6	6
Sensor head kit truck aligner	0	0	0	0
Blower fan model TA/R 18-18	26	51	17	41
Vacuum Pump	13	13	10	90
½" Wrench impact SP1133EX	5	4	4	4
Power pack	39	36	18	34
Blower 8000 CMH Italy.TA-S15	5	4	4	4
Power pack	39	36	18	34
Burner Bentone –B30A/AS47CPU	17	20	90	14
Electric 3HP induction motor	62	83	40	35
3HP electric motor B3 B14	39	49	97	82

Table 7: Inventory value in terms of rupees through forward cover system

Descriptions	2016 Sep	Oct	Nov	Dec
Wheel alignment kit DWA 1000 W	371614	541856	383542	392943
Kit WB F7D	110752	681009	396473	165176
Power pack with motor assembly-F	505400	29318	881170	881170
Sensor head kit truck aligner	0	0	0	0
Blower fan model TA/R 18-18	817890	160143	534580	140950
Vacuum pump	361540	361450	277620	249630
½" Wrench impact SP1133EX	538960	430960	431150	430650
Power pack	333615	308844	157968	298976
Blower 8000 CMH Italy.TA-S15	539879	430960	431150	430650
Power pack	334445	308844	157968	298976
Burner Bentone-B30A/AS47CPU	407784	489454	216144	343214
Electric 3HP induction motor	351465	469455	208989	183229
3HP electric motor B3 B14	222312	278435	533945	451328

The inventory in terms of quantity for various items were calculated through forward cover system for the period September-December 2016 and are given in Table 6. The inventory value in terms of rupees for various items were also calculated through forward cover system for the period September-December 2016 and are given in Table 7. Similarly, the inventory in terms of quantity for various items were calculated through multi-bin system for the same period and are given in Table 8 and the inventory value in terms of rupees for various items were also calculated through multi-bin system and are given in Table 9. From the simulation results, it was observed that, the inventory value through multi bin system adopted for various products are less than the forward cover system. For example, the inventory value in multi bin system has got reduced by about 70% in Kit WB F7D, 10% reduced in power pack with motor assembly-F, 28% reduced in blower fan model TA/R 18-18, 58% reduced in ½" wrench impact SP1133EX, 80% reduced in power pack, 36% reduced in electric 3HP induction motor and 56% reduced in 3HP electric motor B3 B14. Hence, it was concluded that the multi bin system is better as compared to forward cover system in keeping down the inventory cost.

Table 8: Inventory in terms of quantity through multi bin system

	2016			
Description	Sep	Oct	Nov	Dec
Wheel alignment kit DWA 1000 W	2	3	1	2
Kit WB F7D	2	4	8	1
Power pack with motor assembly-F	1	2	4	5
Sensor head kit truck aligner	0	0	0	0
Blower fan model TA/R 18-18	6	6	6	6
Vacuum Pump	20	25	30	35
½” Wrench impact SP1133EX	6	8	10	4
Power pack	3	4	4	4
Blower 8000 CMH Italy.TA-S15	0	0	0	0
Power pack	24	48	1	24
Burner Bentone-B30A/AS47CPU16	16	8	8	12
Electric 3HP induction motor	16	32	1	16
3HP electric motor B3 B14	24	30	36	23

Table 9: Inventory value in terms of rupees through multi bin system

	2016			
Description	Sep	Oct	Nov	Dec
Wheel alignment kit DWA 1000 W	414054	621890	102988	414374
Kit WB F7D	118813	238953	478852	29893
Power pack with motor assembly-F	726000	293500	51380	73450
Sensor head kit truck aligner	0	0	0	0
Blower fan model TA/R 18-18	73190	73190	73190	73190
Vacuum Pump	70176	87656	104348	121945
½” Wrench impact SP1133EX	16686	22192	27772	11154
Power pack	25675	34284	34284	34284
Blower 8000 CMH Italy.TA-S15	0	0	0	0
Power pack	205167	411564	8492	205564
Burner Bentone-B30A/AS47CPU	391344	195277	195455	293366
Electric 3HP induction motor	857250	171563	5272	85725
3HP electric motor B3 B14	134275	167935	201899	128654

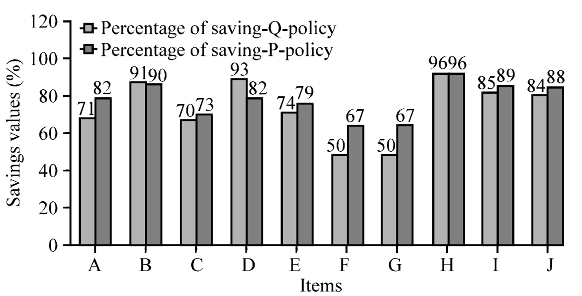

Fig. 14: Comparison of P-policy and Q-policy savings in %

CONCLUSION

As per our objective, a multi bin inventory system was developed as a replacement for forward cover system and the results were compared with the usage of basic inventory policy. Based on the procurement policy and observed results the following conclusions were made.

Safety stock, reorder level, average inventory level, average inventory value and savings in inventory cost were analysed. From the results, it was found that the periodic review policy has less inventory value in many products as compared with the continuous review policy like 28% less in power pack with motor assembly-F, 22% less in ½” wrench impact SP 1140SX, 20% less in ½” wrench ratchet SP 1133SX, 20% less electric 3HP induction motor and 16% less in oxygen sensor.

Hence, it could be seen that the overall periodic review policy to be better as compared with the continuous review policy. Similarly through the multi bin Kanban system the simulation results were arrived. From the results, it was observed that, the inventory value through multi bin system is less than the forward cover system such as, it has got reduced by about 70% in Kit WB F7D, 28% reduced in blower fan model TA/R 18-18, 58% reduced in ½” wrench impact SP1133EX, 80% reduced in power pack, 36% reduced in electric 3HP induction motor and 56% reduced in 3HP electric motor B3 B14. Therefore, it was concluded that the proposed multi bin system is better as compared to forward cover system in keeping down the inventory cost.

REFERENCES

Atieh, A.M., H. Kaylani, Y. Al-abdallat, A. Qaderi and L. Ghoul *et al*., 2016. Performance improvement of inventory management system processes by an automated warehouse management system. Procedia CIRP., 41: 568-572.

Balakannan, K., S. Nallusamy, P.S. Chakraborty and G. Majumdar, 2015. Selection and evaluation of supplier by decision model of hybrid data envelopment analysis. Int. J. Appl. Eng. Res., 10: 123-127.

Hedenstierna, C.P.T. and S.M. Disney, 2016. Inventory performance under staggered deliveries and autocorrelated demand. Eur. J. Oper. Res., 249: 1082-1091.

Kampf, R., S. Lorincova, M. Hitka and Z. Caha, 2016. The application of ABC analysis to inventories in the automatic industry utilizing the cost saving effect. J. Mar. Sci., 63: 120-125.

Kumar, P. and M. Anas, 2013. An ABC-Analysis for the multiple-products inventory management-case study of scooters India limited. Intl. J. Res. Eng. Adv. Technol., 1: 1-6.

Liu, S. and L.G. Papageorgiou, 2013. Multiobjective optimisation of production, distribution and capacity planning of global supply chains in the process industry. Omega, 41: 369-382.

Millstein, M.A., L. Yang and H. Li, 2014. Optimizing ABC inventory grouping decisions. Intl. J. Prod. Econ., 148: 71-80.

Nallusamy, S. and G. Majumdar, 2017. Enhancement of overall equipment effectiveness using total productive maintenance in a manufacturing industry. Int. J. Performability Eng., 13: 1-16.

Nallusamy, S. and M.A.A. Ahamed, 2017. Implementation of lean tools in an automotive industry for productivity enhancement-a case study. Int. J. Eng. Res. Afr., 29: 175-185.

Nallusamy, S. and V. Saravanan, 2016b. Enhancement of overall output in a small scale industry through VSM, line balancing and work standardization. Int. J. Eng. Res. Afr., 26: 176-183.

Nallusamy, S. and V. Saravanan, 2016a. Lean tools execution in a small scale manufacturing industry for productivity improvement: A case study. Indian J. Sci. Technol., 9: 1-7.

Nallusamy, S., 2016c. A proposed model for lead time reduction during maintenance of public passenger transport vehicles. Int. J. Eng. Res. Afr. 23: 174-180.

Nallusamy, S., 2016d. A proposed model for sustaining quality assurance using TQM practices in small and medium scale industries. Int. J. Eng. Res. Afr., 22: 184-190.

Nallusamy, S., 2016d. Frequency analysis of lean manufacturing system by different critical issues in Indian automotive industries. Int. J. Eng. Res. Afr., 23: 181-187.

Nallusamy, S., 2016a. Overall performance improvement of an small scale venture using critical key performance indicators. Int. J. Eng. Res. Afr., 27: 158-166.

Nallusamy, S., 2016e. Productivity enhancement in a small scale manufacturing unit through proposed line balancing and cellular layout. Int. J. Performability Eng., 12: 523-534.

Nallusamy, S., A.M.M. Umarmukdhar and R.S. Rekha, 2016b. A proposed supply chain model for productivity enhancement in medium scale foundry industries. Int. J. Eng. Res. Afr., 20: 248-258.

Nallusamy, S., D. Kumar, K. Balakannan and P.S. Chakraborty, 2016a. MCDM tools application for selection of suppliers in manufacturing industries using AHP, fuzzy logic and ANN. Int. J. Eng. Res. Afr., 19: 130-137.

Nallusamy, S., R. Balaji and S. Sundar, 2017. Proposed model for inventory review policy through ABC analysis in an automotive manufacturing industry. Int. J. Eng. Res. Afr., 29: 165-174.

Nallusamy, S., S. Satheesh, P.S. Chakraborty and K. Balakannan, 2015. A review on supplier selection problem in regular area of application. Int. J. Appl. Eng. Res., 10: 128-132.

Nananukul, N., 2013. Clustering model and algorithm for production inventory and distribution problem. Appl. Math. Modell., 37: 9846-9857.

Rouibi, S. and P. Burlat, 2010. The impact of the vendor managed inventory on supply chain performance. Proceedings of the 2010 40th International Conference on Computers and Industrial Engineering (CIE), July 25-28, 2010, IEEE, Awaji, Japan, ISBN:978-1-4244-7297-0, pp: 1-6.

Russell, R.A. and T.L. Urban, 2016. Offsetting inventory replenishment cycles. Eur. J. Oper. Res., 254: 105-112.

Saric, T., K. Simunovic, D. Pezer and G. Simunovic, 2014. Inventory classification using multi-criteria ABC analysis, neural networks and cluster analysis. Tech. Bull., 21: 1109-1115.

Wei, Y., H. Wang and C. Qi, 2013. On the stability and bullwhip effect of a production and inventory control system. Intl. J. Prod. Res., 51: 154-171.