

Lean capacity planning for tool room: An iterative system improvement approach

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ABSTRACT

Capacity planning helps to synchronize demands and production volumes, and assists in early preparedness for dealing with future production imbalances. A tool room of armored manufacturing organization was selected for this work study. Initially, a master production schedule and rough cut capacity plans are prepared based on the delivery commitments of the organization. Time and motion study of the tool room for 28 weeks was performed to determine its current production capacity. It was observed that imbalance between demands and production exists. An iterative system improvement strategy was proposed for exploring the potential of tool room. Lean concepts and methodologies were the essence of the proposed system improvement strategy. It was observed that WIP had been reduced by 18 %, production volumes had improved by 24 % and tardiness reduced by 28 %. This strengthened our belief that lean philosophy is equally applicable within the capacity planning domain. The capacity planning approach presented in this work study could also be generalized for other domains. This approach believes in improving the potential through elimination of wastes, process improvement, defect prevention and total preventative maintenance. This approach improves the system optimally by utilizing existing resources available on the shop floor. This research will be further expanded towards the major production units of this organization. We are currently working on capacity planning for rebuilding the activities of T-80 UD battlefield tanks.

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1. Introduction

Capacity planning helps organizations to know their capabilities to produce. Organizations can respond to forthcoming production forecasts by exploiting this potential and maintaining desired rate of production. This proactive response can manage production imbalances and succeeds in retaining existing customers. A transparent and smooth production flow owing to customer demands can help plan for expansion in business. Management can optimally assign resources and reduce costs incurred on carrying unnecessary inventories. Organizations make sensible commitments and systematically move forward with their customers. Furthermore, this helps organizations to design suitable facility layouts that can guarantee higher productivity and minimal costs. Capacity planning is dependent upon proper evaluation of certain input factors that may include raw material, plant downtime, inventory, workforce and market share [1].

Granularity of understanding can be improved by decomposition of capacity planning process. Initial level (0-level) performs resource planning for organization. At 0-level, key resources are defined to determine appropriate layout required for organization. Furthermore, infrastruc-

ture and logistics requirement is established. Level-1 plans within the facility and determines requirements of workstations suitable for production activity. An estimated capacity from these workstations can be calculated based on available workstations and process flow. Level-2 decomposition identifies execution plans, how to monitor and control production activity. This level of decomposition determines inputs and output at shop floor. It is common practice to define three level of capacity planning [2]. In an existing facility, capacity planning can be implemented through re-engineering. A re-engineering process for an existing facility will adopt bottom up strategy and will be reverse capacity planning activity [1, 3].

Mostly, organizations believe in 'make to order strategy' to produce desired production volumes. Fluctuations in demand may arise under certain circumstances. Such abrupt increases or decreases in demand will result in failure to meet customer demands. This situation will result in failure of 'make to order' strategy. Whenever, there exists possibilities that abrupt changes in demands may occur, organizations follow contingency plan by adopting lead or lag strategies for capacity planning. None of these strategies can be trusted altogether and each has its own prospects and consequences. Any increase in demand can be fulfilled by 'production in advance'. This strategy will help in winning confidence of customers through timely delivery of product. 'Production in advance' will require extra space for additional products to store. In worst case situation, an abrupt drop in demand will cause salvage of overproduced products. Inventory carrying cost and wastage due to overproduction are two major drawbacks of lead or production in advance strategy. With 'delayed production', possibilities of drops in demand can be managed. In case of sudden escalation of demands, this strategy will not be able to fulfil customer demands and will subsequently result in losing the confidence of customers. Preferably, each organization must have its own customized capacity planning strategy exploiting blend of more than one strategy. Make to order strategy is suitable for low volume production activity and "lead" can be adopted for higher volume production. It is common practice that organizations run at lower than designed rates of production due to real life constraints and production losses [1-4].

In an existing facility, capacity planning can be implemented through re-engineering. A re-engineering process for an existing facility will adopt bottom up strategy and will be "reverse capacity planning" activity. Existing and proposed organizational setups can be modelled to support capacity planning process. Proposed organizational setups result from implementation of capacity planning strategies e.g. value stream map in lean capacity planning process. Lean philosophy was implemented in capacity planning domain by Linne and Ekhal [3]. Authors proposed methodology to identify problems in capacity planning process and resolution of these problems through lean. Their work supported high level implementation of lean in capacity planning process. Their proposed solution can be taken as Pre-Capacity Planning Process lean implementation. It is useful to implement lean more rigorously during capacity planning process. An amalgam of lean and capacity planning process may result in cost effective capacity enhancement.

This research work proposes bottom up lean capacity planning strategy for an existing organizational setup. An integrated implementation of lean and capacity planning during re-engineering activity is presented. In this model, each level of capacity planning is given "lean attention". Initially, lean is implemented at level-2 and its prospects improve level-1. Lean implementation at level-1 improves capacity planning process at 0-level. Proposed model will provide better solution for effective capacity planning.

Remainder of the paper is organized as follows. Related work is outlined in Section 2. In section 3, we have briefly identified the problems being faced by tool room. Section 4, is about the capacity planning initiative taken in this research to study the existing capacity and future demands for tool room. Proposed capacity planning approach has been described in Section 5. In order to validate the suitability of proposed approach, performance measures have been discussed in section 6. We have briefly discussed our experimental study in Section 7. Results are discussed in section 8 and reviewed and analyzed in Section 9. Section 10 is the last but not the least and concludes our research work and gives future directions.

2. Related work

It is possible to identify issues and their root causes associated with a capacity planning process. Panacea to these issues can be found in lean principles [3]. These lean principles can be implemented in a capacity planning process. Based on this implementation, an improved model for capacity planning can be presented. This is high level application of lean in capacity planning process. Decomposition of capacity planning process allows implementation of lean principles and tools at lower levels. Introducing lean capacity planning process is preferable than implementing lean principles only on identified problem areas [3]. Production activities can be modelled using value stream maps (VSM) [5]. Furthermore, it is possible to analyse and review value stream maps and identify potential improvements. Well worked value stream maps can be used to identify starving, saturated and bottleneck stations. Simulation models can replace value stream maps to validate suggested improvements. Complimentary use of value stream map and simulation model can be suggested. Proactive and reactive lean logistics for resource planning phase of capacity planning are suggested using value stream map and identification of bottleneck resources [5]. Capacity planning has also been extensively studied in service sector apart from manufacturing sector e.g. emergency departments of hospitals [6-7]. Long waiting times in queue affect provisioning of service to patients in hospital. Value stream mapping of current scenario can be used to identify root causes of long queues. Simulation model identified flaws in current resource planning with identification of possible improvements. These improvements can be iteratively used to identify suitable solution [8]. Alternate solutions achieved through iterative improvements provide flexibility to adopt suitable solution for enhanced capacity planning. This approach was implemented in automotive sector of Thailand using Tecnomatrix software. Re-engineering the facility and inclusion of further resources to enhance capacity for escalated demands was achieved through simulation of fabrication shop models [9]. Identification of saturated and starved resources helped reduce workers and adjustment of arrival and indexed times for conveyors. This was also helpful to propose better layout and facility design. Similarly, excessive transportation and undesired motion of workforce can also be addressed through value stream mapping [10].

Apart from value stream mapping, other lean methodologies like 5S, Meiruka and Kaizan helped propose "to-be" model from "as-is" model [11]. Regression analysis conducted on these methodologies determined the effectiveness of these methodologies. "Tam the" model improved the effectiveness of lean capacity planning process. This research study believes in utilizing bottom up lean methodology in capacity planning.

Reviewed literature shows that existing initiatives partially implement lean philosophy in capacity planning. Lean capacity requirement planning can improve rough cut capacity plans and subsequently lean rough cut capacity plans can be used for better resource planning. Existing research is focused on lean resource planning and ignores lean capacity requirement planning and lean rough cut capacity plans.

3. Problem statement

Precision Defense Organization (PDO) is a strategic organization and is rebuilding and manufacturing armored vehicles of Chinese, Russian and American origin. It has five major units for manufacturing and rebuilding of battlefield tanks, gun barrels, armored personnel carriers and self-propelled guns. These units have assembling, heat treatment, machining and fabrication shops. Manufacturing and rebuild of armored vehicles demands rigorous machining operations with special purpose tooling, jigs and fixtures. Special purpose tooling is required for complex and specific machining tasks e.g. machine gun holes etc. Tool manufacturing shop also known as tool room is primarily responsible to provide standard and special purpose tooling to these units. PDO believes in indigenous production of armored vehicles and discourages import of tooling, jigs and fixtures from abroad.

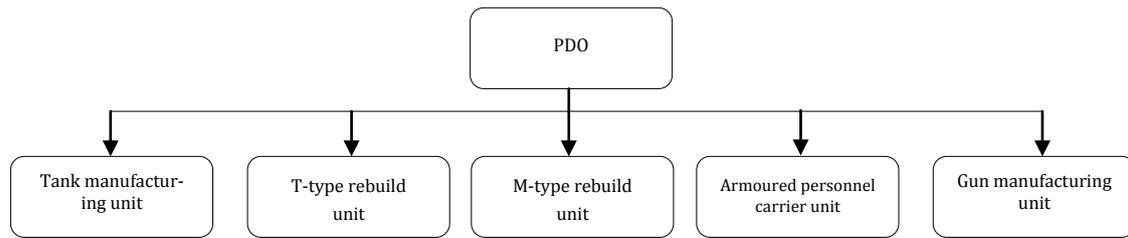


Fig. 1 Manufacturing units of PDO

Senior management decides production targets keeping in view the strategic position of customer. Suppose a strategic decision is made to upgrade fleet of 500 old t-type battlefield tanks. Customer demands completion of this task in five years. Senior management has no option other than upgrading 10 battlefield tanks in a month. This results in unwanted burden on major and supporting units. PDO has a team of experts who prepares master production schedules, rough cut capacity plans and bill of materials for these targets. This team prepares detailed demand of tooling, jigs and fixtures for tool room supervisors. Due to technical and managerial constraints, tool room suffers failure to manufacture demanded quantity of tooling. Some of the work orders are returned without any action due to heavy workload on machining facility of tool room. Special purpose tooling e.g. corn mill cutters and long shank drills are not available in local market.

There exist two alternatives to resolve this problem. Initially, PDO units seek help of local vendors for procurement of these tools. Inability of local vendors to provide special purpose tooling forces import of these tools from brotherly country, China. Import of these tooling is expensive and time consuming activity. Long lead times of these tooling hamper the production activity and non-availability of tooling on time results in delayed production of final products. Customer keeps on sending armored vehicles according to promised schedules. Strategic assets get strangled at PDO with large work in process inventory and holds up. Held up vehicles, suffer wear and tear due to harsh weather as these wait for their turn. This results in weak strategic position of customer on its borders.

Senior management of PDO is more interested to provide viable delivery targets to its customer. These viable targets can be set after detailed analysis of existing system and proper capacity planning. This study is aimed to provide solid foundations for capacity planning of tool room.

4. Capacity planning initiative

Three basic steps of capacity planning include determination of capacity requirements, evaluation of existing capacity and prepare future plan to meet the capacity requirements [12]. Our initial response towards this problem was to prepare Master Production Schedule (MPS) and perform rough cut capacity planning for tool room [13-14]. An initial MPS for PDO is given in Table 1. Production targets for each unit are set by top management after high level meeting with representative group of customer.

After inquisitive meetings with production managers of manufacturing units, MPS for tool room was prepared (Table 2). This MPS contains desired quantities for critical tools in next 8 weeks. It was observed that tool room has to constantly feed major units and any slackness may bring miseries for tool room and PDO. Some of these tooling have complicated machining processes and require skilled workforce e.g. corn cutter, module cutter.

Table 1 Monthly production volumes of vehicles at PDO

Vehicles	T-90 manufacturing	T-59 upgrade	M1-113 rebuild	M1-113 manufacturing	Gun barrel manufacturing
MSP	15	10	5	5	25

Table 2 MPS for tool room

Part	W1	W 2	W 3	W 4	W 5	W 6	W 7	W 8
Corn cutter	4	3	4	3	4	3	4	3
Side and face cutter	4	3	4	3	4	3	4	3
Module cutter	4	3	4	3	4	3	4	3
End mill cutter	4	3	4	3	4	3	4	3
Reamers	6	6	6	6	6	6	6	6
Drills	6	6	6	6	6	6	6	6
Miscellaneous shafts	6	6	6	6	6	6	6	6
Gears	5	6	5	6	5	6	5	6
MPS	39	36	39	36	39	36	39	36

Table 3 Typical MPS for corn cutter

Week	1	2	3	4	5	6	7	8
Forecast	3	2	2	3	3	2	2	3
Projected available	0	2	1	1	0	2	1	1
MPS	0	4	3	4	3	4	3	4

We prepared MPS for each tooling and then individual MPS were summed up to make MPS for tool room. A typical MPS record for corn mill cutter is given in Table 3. It was supposed that there exists a beginning inventory of three corn cutters in tool room.

Our next step was to prepare rough cut capacity plan for tool room. Planning factor (α) for work centres defined in Eq. 1. We performed time and motion study of tool room for consecutive eight weeks. We observed sequence of processes, set up times, processing times, wait times, arrival times, man hours spent and idle times.

$$\text{Planning factor}_{\text{work centre (wc)}} = \frac{\text{Processing per part}}{\text{total parts produced}} \quad (1)$$

We calculated total machining hours required for scheduled production of each part in tool room using Eq.2.

$$\text{Work centre Time} = \text{Target Qty} \times \text{Planning Factor} \quad (2)$$

Based on this time and motion study, processing times, parts produced, planning factor and machine hours for each part are given in Table 4.

Table 4 Rough cut capacity planning for tool room

Part	Processing [h]	Parts produced [qty]	Planning factor [wc]	Target [qty]	Machining [h]
Corn cutter	1481.8	2.3	10.52	4	42.06
Side and face cutter	1362.5	2.5	8.89	4	35.56
Module cutter	1249.3	2.7	7.47	4	29.90
End mill cutter	861.52	4	3.55	4	14.22
Reamers	481.86	7	1.11	6	6.67
Drills	703	5	2.37	6	14.20
Miscellaneous shafts	405.73	8.5	0.79	6	4.73
Gears	1105.7	3.14	5.86	5	29.28

We determined percentage of processing time spent on manufacturing processes for each tooling using Eq. 3 and is given in Table 5.

$$\text{Percentage processing time} = \frac{\text{Workcentre time}}{\text{Total processing time}} \times 100 \quad (3)$$

Table 5 Percentage of processing time for tool production

Part	Heat treatment	Turning	Milling	Grinding	Other
Corn cutter	20	20	35	20	5
Side and face cutter	15	25	45	15	0
Module cutter	15	20	40	20	5
End mill cutter	15	25	45	15	15
Reamers	10	25	50	10	5
Drills	10	25	50	10	5
Miscellaneous shafts	5	70	20	5	0
Gears	10	20	60	5	5

Processing time required for each manufacturing process to produce desired quantity of tooling in a week time is determined using Eq. 4 and is given in Table 6.

$$\text{Processing time} = \text{Percentage Processing Time} \times \text{Workcentre hrs} \quad (4)$$

Table 6 Processing time for tool production (h)

Part	Heat treatment	Turning	Milling	Grinding	Other
Corn cutter	8.41	8.41	14.72	8.41	2.10
Side and face cutter	5.33	8.89	16.00	5.33	0.00
Module cutter	4.49	5.98	11.96	5.98	1.50
End mill cutter	2.13	3.56	6.40	2.13	2.13
Reamers	0.67	1.67	3.34	0.67	0.33
Drills	1.42	3.55	7.10	1.42	0.71
Miscellaneous shafts	0.24	3.31	0.95	0.24	0.00
Gears	2.93	5.86	17.57	1.46	1.46

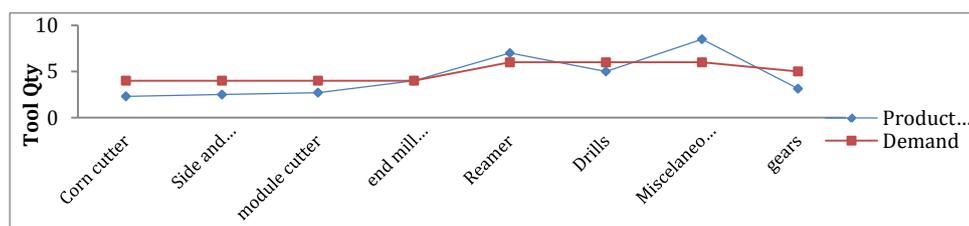
It is true that capacity plan and MPS helped to understand the demand of customer and identified the shortcomings of the existing system. An important step in capacity planning was to determine whether the tool room is capable to work according to MPS and rough cut capacity plan. Research analysis of existing system performed over 8 weeks, necessitated process improvement to fulfil targeted deliveries reflected in MPS.

In order to exploit the potential of tool room and synchronize demand and production, it was decided to model the existing system and identify grey areas hampering production capability of the existing system.

5. Proposed capacity planning approach

This research identified the production gap existing between the desired and produced quantities of tooling (Fig. 2). It shows that all tooling is suffering under production except end mill cutters, reamers and shafts (Table 4). It is important to mention here that most of the gears are used in different machine tools. An inability to replace these gears in machine tools due to non-availability may affect production of end mill cutters, reamers and shafts as well. Corn cutters and side and face cutters are used in initial machining phase of turrets and hull assemblies of battlefield tanks and armoured personnel carriers.

Ideally, it was possible to modify the MPS of PDO based on production feasibility analysis of tool room (Fig. 3). Unfortunately, there was no two ways communication between PDO and tool room and PDO management was imposing production targets on tool room.

**Fig. 2** Manufacturing units of PDO

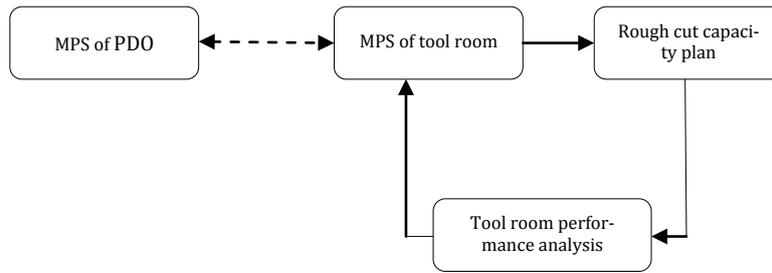


Fig. 3 Ideal capacity planning strategy

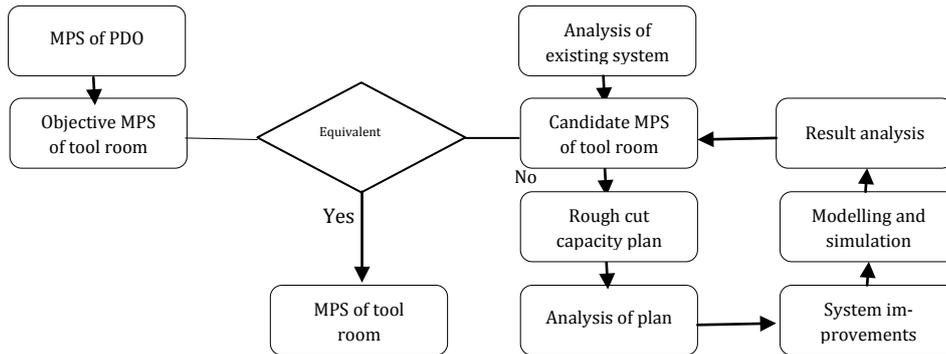


Fig. 4 Proposed capacity planning strategy

Our proposed iterative improvement strategy to tune demands and production is shown in Fig.4. This proposed approach was developed on motivation from genetic algorithms and computational intelligence domain [15].

Objective and candidate MPS are prepared using MPS of PDO and analysis of existing system respectively. If objective and candidate MPS of tool room are equivalent, candidate MPS becomes final MPS for tool room. In case of non-equivalence, iterative strategy for process improvement is implemented. A rough cut capacity plan is prepared using candidate MPS of tool room and is thoroughly reviewed for system and process improvements. Improved system is modelled and simulated for preparation of refined and improved candidate MPS of tool room. These steps are repeated for iterative improvement until objective and candidate MPS are equivalent. Although our proposed approach is specific to capacity planning of PDO tool room, yet it can also be equally used in other domains.

In proposed approach, we have used lean thinking for system improvement. Lean principles used in our approach for continuous improvement are given in Fig. 5.

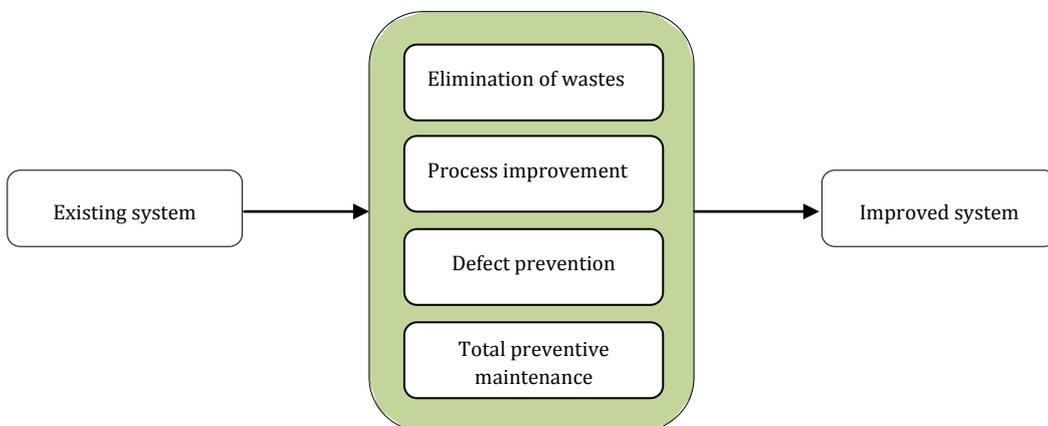


Fig. 5 Lean methodologies for system improvement

6. Performance measures and evaluation criteria

Performance measures to evaluate the usefulness of proposed approach are defined as:

- Production volumes
- Work in process (WIP) inventory
- Mean flow times
- Mean tardiness
- Mean queue times

6.1 Production volumes

Productivity of a system is called its throughput and is gauged by the production volumes of the system. Objectively, production volumes of a system must match the demanded quantities.

6.2 Work in process (WIP)

Unfinished parts present in a system for value addition are termed as work in process (WIP) inventory[11]. Lower WIP inventory is an indication of efficient system. Preferably, WIP should be equal to the number of work centres in the system. Thus WIP can never be lower than the number of work centres. If $WIP > \# \text{Work centres}$ then system is in saturation state else if $WIP < \# \text{Work centres}$ then system is in starvation state.

6.3 Mean flow times

It is the time spent by a part as WIP in the system and is also known as time in process (TIP) or process time [17-18]. Less mean flow times can be helpful to reduce WIP and improve production capacity of a manufacturing setup.

6.4 Mean tardiness

Any lateness in delivering the targeted production is termed as tardiness. Tardiness shows an inefficiency of the system and is discouraged by production managers. Ideally, there should be zero tardiness in delivering the targeted production volumes.

6.5 Mean queue times

It is total waiting time spent by a part in queues before some value addition at work centres. When WIP is equal to number of workstations, mean queue time is zero.

7. Experimental study

Our research encompasses 28 weeks time and motion study of tool room. Initial three steps of our proposed approach that include preparation of candidate MPS, rough cut capacity plan and system analysis have already been performed in sections 3 and 4. Our next step in proposed methodology is to improve the system. It was discussed in section 4 that we have used lean thinking for system improvement. These proposed lean improvements are discussed as under;

7.1 Elimination of wastes

Lean identifies seven types of wastes in production systems. Elimination of these wastes helps to reduce flow times of parts produced. Some wastes found in tool room were due to poor layout and facility design. These wastes include undue transportation of tools and movement of work force. Other wastes in tool room include improper utilization of resources and long wait times before value addition.

This work addressed these wastes through re-arrangement of work centres after generation of part families and making of cells (Table 7). In order to optimize resource utilization and reduce wait times, one piece flow strategy was implemented.

Table 7 Identification of part families [16]

Serial No	Part Family	Parts
1	Cutter family	Side and face cutter, Hobbing cutter, Corn mill cutter, End mill cutter, Slit saw cutter, module cutter
2	Reamer & drill family	Taper drill, Twist shank drill, Reamers
3	Gear family	Worm, Bevel, Spur gears
4	Lathe tool family	Right, left turning tool, parting tool, grooving tool, universal turning tool, 3&4 Jaw chucks
5	Gauge family	Ring, Snap, Plug gauges
6	Jigs and fixture family	Fixtures

7.2 Process improvement

Kaizan highlighted that system must be evolved through continuous improvement. Our first initiative was to ensure quick changeover of tooling by inclusion of automatic tool changers on machines. We also identified starving and saturated stations and enhanced bottleneck work centres in number and improved value added manhours. Improvement in value added manhours was achieved through reduction in breakdown time and mean time to failure. This was achieved by ensuring the availability of inventory for frequently wearing and tearing parts of machine tools [20].

Arrival time of parts to the tool room from heat treatment shop was adjusted using input analyzer of Arena 10.0 and using poisson distribution. These requirements were communicated to manager of heat treatment shop for adherence.

7.3 Defect prevention

Production of defect free tooling is very important to meet delivery targets. Most of the parts in tool room were being rejected due to variations in heat treatment aspect of cutters. Unnecessary annealing and hardening made machining processes impossible on some parts. We suggested preparation of process sheets, inspection manuals and quality assurance for heat treatment process to prevent scrapping of tooling after hardening and annealing processes.

Secondly, we suggested improvements in programming blocks of numeric controlled machines to avoid manual errors caused by operators.

7.4 Total preventive maintenance

We observed long breakdown times for some work centres especially gear lathe and universal grinding machines due to non-availability of different machine tool parts. As discussed earlier, we have ensured that breakdown time is minimized through preventive maintenance and availability of frequently wearing out parts in inventory.

We modelled and simulated the improved system using Arena 10.0. Experimental results are discussed in Section 8.

8. Experimental results

Results obtained after simulation of improved system were analysed and reviewed with focus on predefined performance measures [19]. These findings are discussed as under;

8.1 Production volumes

Capacity planning is used to improve the existing production volumes of an industry and synchronize production with demands such that imbalances does not occur. It is observed that capacity of tool room has improved after lean based system improvements. Proposed approach has been successful to meet the demands for next 28 weeks except for gears (Fig. 6).

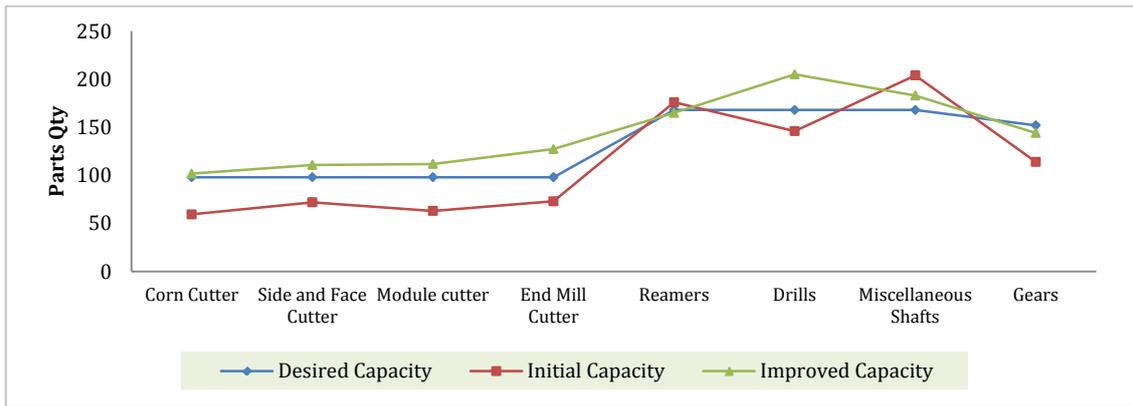


Fig. 6 Lean capacity planning of pool room

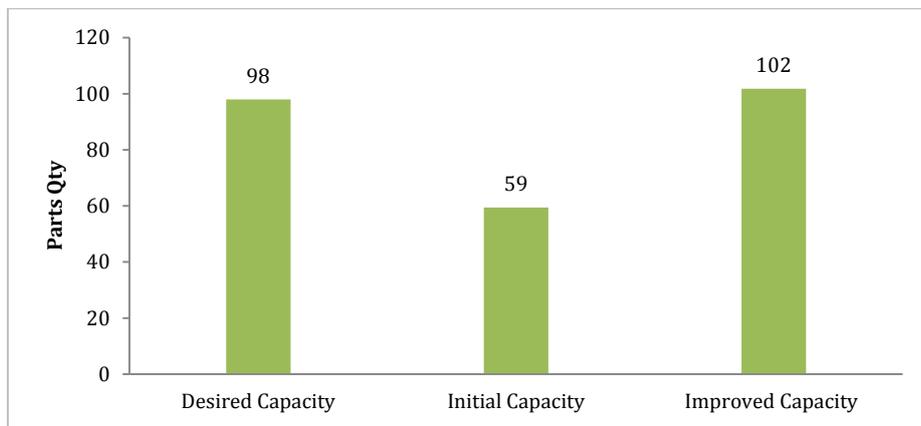


Fig. 7 Production volumes of corn mill cutter

Tool room management can seek alternatives to acquire or produce 8 deficient gears for machine tools. We have considered corn mill cutters and gears for detailed description of the proposed approach.

Corn mill cutters are used to machine trunions of gun mount assemblies on turrets in battlefield tanks. Initial candidated MPS reflects that existing tool room can produce upto 61 corn cutters in 28 weeks. Whereas objective MPS desires a production of 98 corn cutters. Proposed approach was successful to increase the production of corn cutters to an optimal level of 10 (Fig. 7).

Initial production of corn cutters was 60 % of the desired production volumes. Its detailed production for 28 weeks is shown in Fig. 8. In addition to lower weekly production, missing production weeks 16, 20 and 25 are also observed.

Most of the machine tools in PDO are conventional and require frequent repair. Gears are used for repair of these machine tools. Bevel, spur and worm gears are manufactured in tool room with quantity of 2 for each gear. Existing system was producing 114 gears with big fluctuations of quantities each week (Fig. 9 and Fig. 10). System improvement resulted in 144 gears with almost smooth quantities each week.

These gears do not require longer times for surface treatment and are wholly solely managed by tool room. We can see better performance of tool room in production of these gears. Secondly, these gears do not require special machining processes except indexing on milling machines.

We have given a brief comparison of initial and improved production volumes in Table 8. These results show that room for further improvement in tool room still exists.

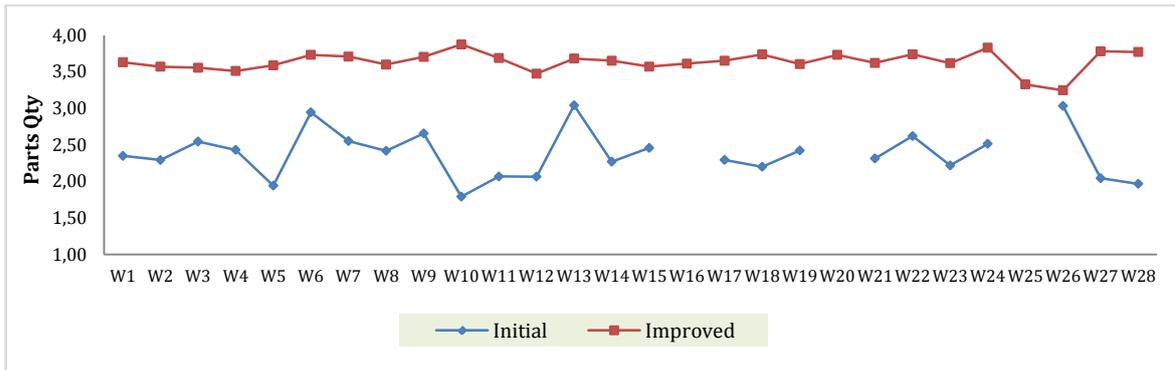


Fig. 8 Production volumes of corn mill cutter

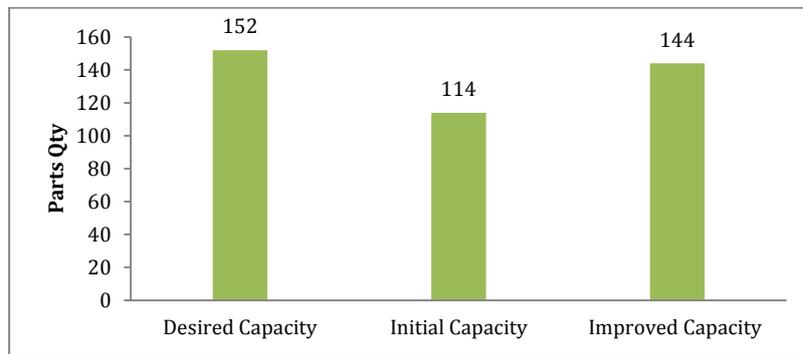


Fig. 9 Production volumes of gears

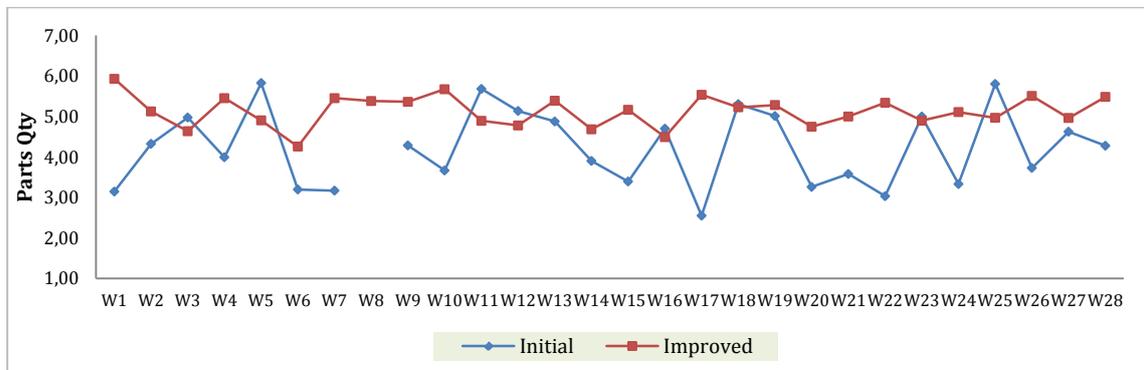


Fig. 10 Production volumes of gears

Table 8 Comparison of production volumes

Part	Desired capacity	Initial capacity	Improved capacity
Corn cutter	98	59	102
Side and face cutter	98	72	111
Module cutter	98	63	112
End mill cutter	98	73	127
Reamers	168	176	165
Drills	168	146	205
Miscellaneous shafts	168	204	183
Gears	152	114	144

8.2 Mean work in process (WIP) inventory

Ideally WIP should be equal to the number of work centres in a manufacturing setup. An improvement in mean WIP for proposed approach was noted. But it was still greater than no. of work centres in the system. There were 11 work centres in the system.

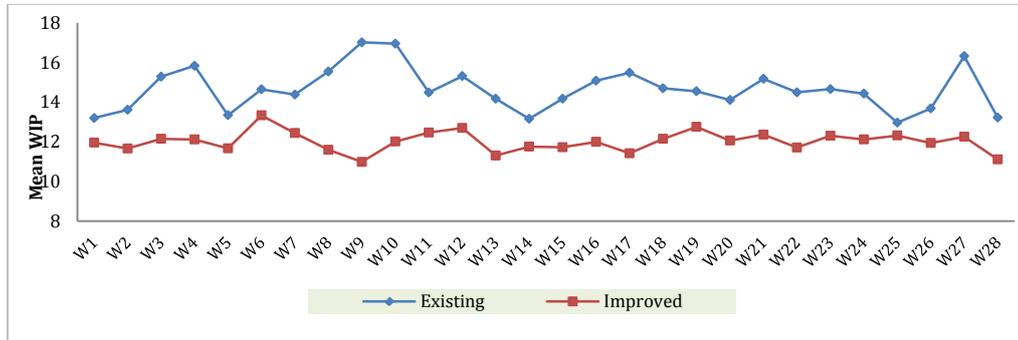


Fig. 11 Mean WIP inventory

8.3 Mean tardiness

This performance measures indicates deviation from promised delivery dates. Mean tardiness is measured in hours and it is for whole period of 28 weeks (Table 9). Comparatively, improved system has shown considerable improvements in reducing the tardy jobs. It is interesting to discuss that despite improvements in arrival times, transportation times, set up times and reduction in WIP, the improved system is also having tardiness. Further investigations showed that there are few tardy weeks for corn cutter, module cutters and gears. There is no tardy week for side and face cutters and drills. But there are many tardy weeks for end mill cutters, reamers and shafts. Although, improved system is having tardy weeks, it is still performing good in delivery of tooling to the major units(Fig. 12).

Table 9 Mean tardiness of tool room

Part	Initial mean tardiness	Improved mean tardiness
Corn cutter	-5755.01	-42.00
Side and face cutter	-4581.63	0.00
Module cutter	-3841.81	-37.29
End mill cutter	-9863.78	-300.86
Reamers	0.00	-360.23
Drills	-2908.78	0.00
Miscellaneous shafts	-39.9704	-201.84
Gears	-5755.01	-42.00

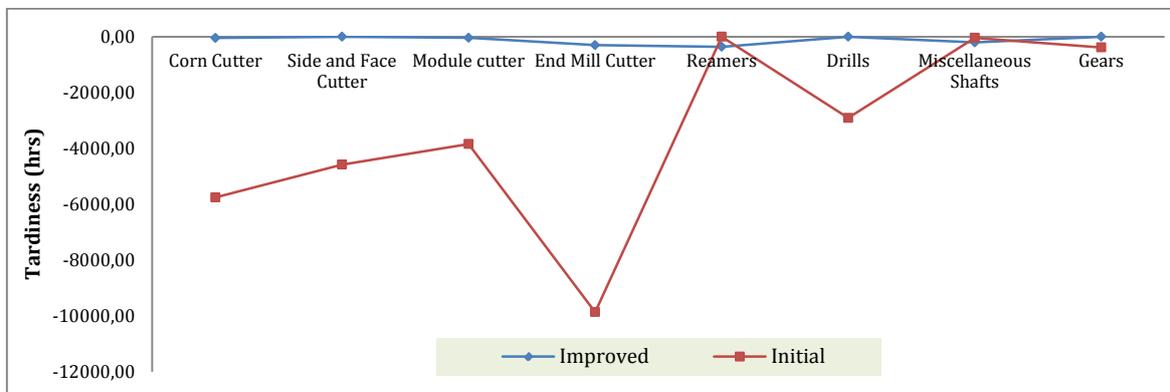


Fig. 12 Mean tardiness for improved and initial systems

8.4 Mean queue times

This performance measure was included to reveal the reasons for tardy jobs, observed in section 8.3. We studied only those work centres that were having long queue times for improved system as well. Initially, we studied tool grinding machine (Fig. 13). Except gears and shafts, all parts are visiting this work centre. Improved system was having mean queue times for the parts, but these were acceptable and can not contribute to tardiness of the job.

Mean queue times on tool mill and vertical grinder indicated the reasons for delayed delivery of parts. End mill cutters and module cutters visited these work centres and were resultantly having tardiness due to longer queue times (Fig. 14).

Tool mills are used for reamers and cutters and longer queue times on this work centre contributed to overall delay in production of reamers and cutters (Fig. 15).

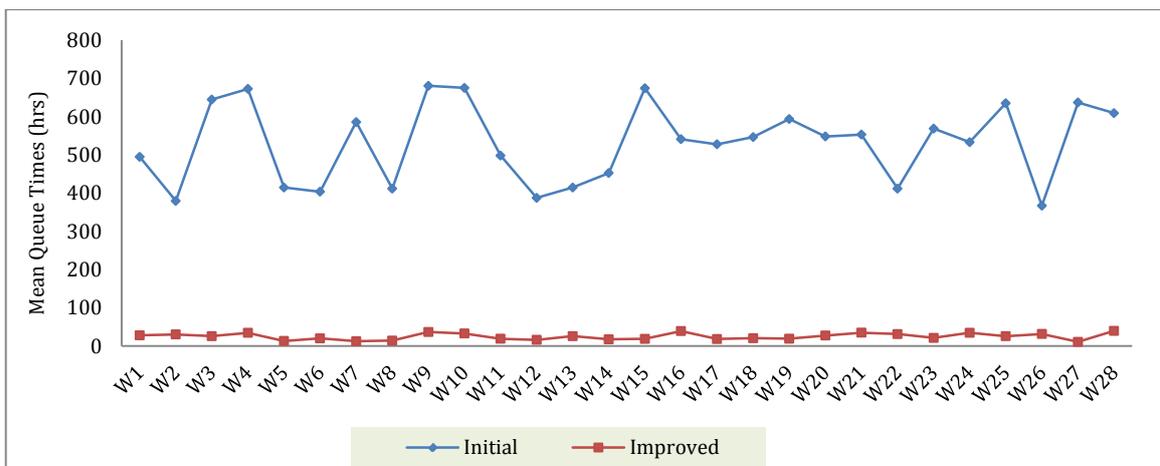


Fig. 13 Mean queue times for tool grinder

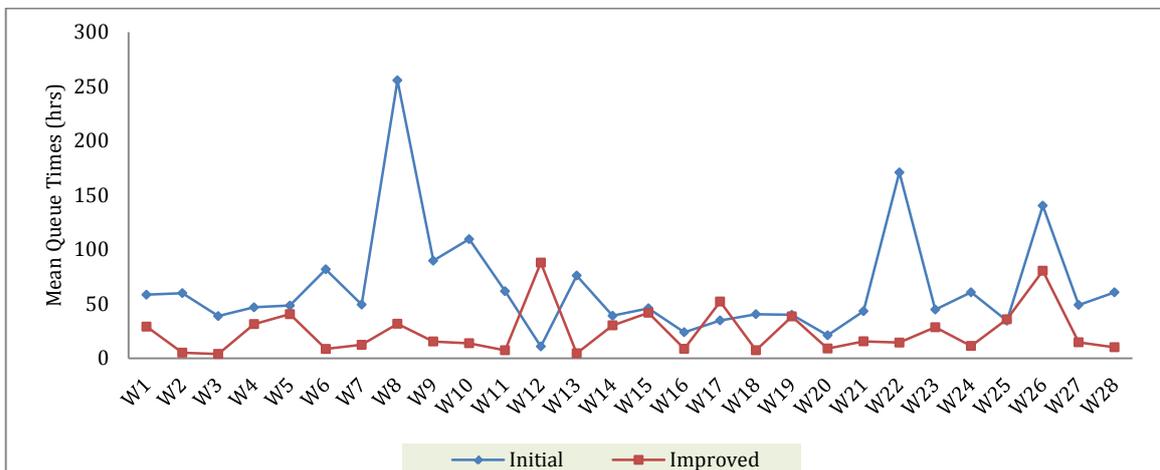


Fig. 14 Mean queue times for vertical grinder

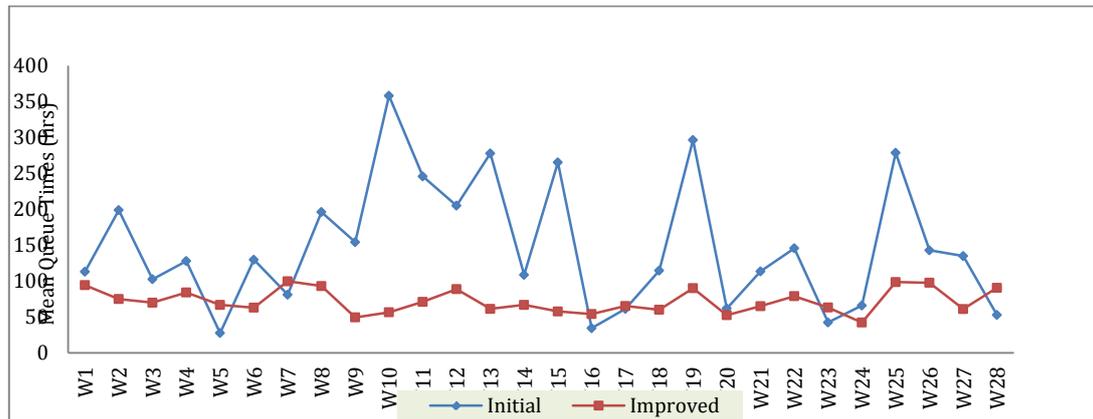


Fig. 15 Mean queue times for tool mill

9. Review and analysis of results

This section is essence of our research and explains lean based system improvement initiatives taken during this study.

Going through results discussed in previous sections, it can be inferred that WIP is larger than work centres, tool room is having waste of overproduction, toolings are having tardiness and resources are saturated due to long queue times. System improvement strategy for iterative improvement is discussed in Table 11.

This research emphasized on elimination of wastes to improve capacity of organization. Results indicate that proposed system is having waste of overproduction. How to eliminate this waste to improve the system? Overproduction can be eliminated by restricting the issuance of blanks to tool room for value addition. Alternatively, operations supervisor can maintain the counts of parts produced and stop processing on further parts or components. What will be the benefit of controlling overproduction? It will be helpful to reduce queue times on bottleneck work centres and alleviate state of saturation.

Tardiness and larger WIP can be controlled by adjusting arrival times of blanks from heat treatment shops. If work centres are producing almost desired quantity of products, it is insane to increase arrival times and cause saturation of work centres. Arrival times in improved system are manually managed and can be re-adjusted to suit one piece flow production. Although, control on overproduction will be helpful to improve WIP yet reduction of processing times on saturated work centres can be equally useful.

Every production unit has 10 % of quality allowance for defective parts and unexpected situations. We have reduced this allowance to 2 percent in our workstudy.

Each work centre is assigned mean time to failure based on work history of existing system. Preventive maintenance of work centres can be used to improve this time. An improvement in this time will result in quick processing of toolings on work centres and will reduce queue times. Mean time to failure can be improved through periodic inspection of work centres and availability of alternative in case of failures.

This work used this type of system improvement suggestions during each iteration. Last iteration was left to present overall working of proposed approach.

Table 11 Iterative system improvement approach

Serial No.	Lean improvement	System improvement initiatives
1	Elimination of wastes	Overproduction control
2	System improvement	Fixing blank quantity, Adjusting arrival times, Improving process times
3	Defect prevention	2per cent quality waste
4	Total preventive maintenance	Revisiting breakdown times

10. Conclusion and future work

This study has proposed an iterative improvement strategy using lean concepts and methodologies. Although, proposed strategy is for tool room capacity planning yet it can be equally used for other domains as well. Proposed approach was validated through modelling and simulation of tool room. Actual execution of the approach can be used to assess its true suitability. It was assumed that breakdown times of work centres have been controlled. Inability to control these times in real implementation will deter the performance of our proposed approach. Despite the requirement of defined quantities of toolings for major units, there might occur situations that require additional tooling for normal production process. Our research has also considered this situation. This approach has suggested minor changes in design and layout of tool room to reduce transportation of parts and motion of workforce. Besides PDO management, whether senior management of other organizations will be interested to relocate work centres for suggested changes in layout. This might hamper suitability of our proposed approach in other domains.

System improvements in tool room resulted in enhanced production volumes with existing resources. It shows that lean iterative strategy can be used for capacity planning and exploiting the potential of an organization (Table 10 and Fig. 16). An understanding of the results encouraged us to suggest reduction in production of end mill cutters, drills, side and face cutters and module cutters for proposed strategy.

There was an improvement of 28 % in delivery of tooling to major units and 24 % in enhancing the production capability of existing system. Mean WIP was reduced by 18 percent with considerable reduction in queue times. These are remarkable achievements and pave the way for future implementation of this approach in major production workshops too. This research has proven that lean philosophy is also applicable in capacity planning of manufacturing setups. We are currently working on implementation of lean in assembly shop capacity planning of T-80 UD tanks. Since proposed approach believes in continuous improvement until stopping criteria is met, thus same approach was iterated thrice. However, results obtained in second iteration were discussed and lean evaluation process for the third iteration was presented in review section to provide better understanding of the approach. An improvement in the proposed system can also be seen in Fig 17.

Table 10 Performance comparison of systems

Part	Initial capacity, %	Improved capacity, %
Corn cutter	61	104
Side and face cutter	73	113
Module cutter	64	114
End mill cutter	74	130
Reamers	105	98
Drills	87	122
Miscellaneous shafts	121	109
Gears	75	95

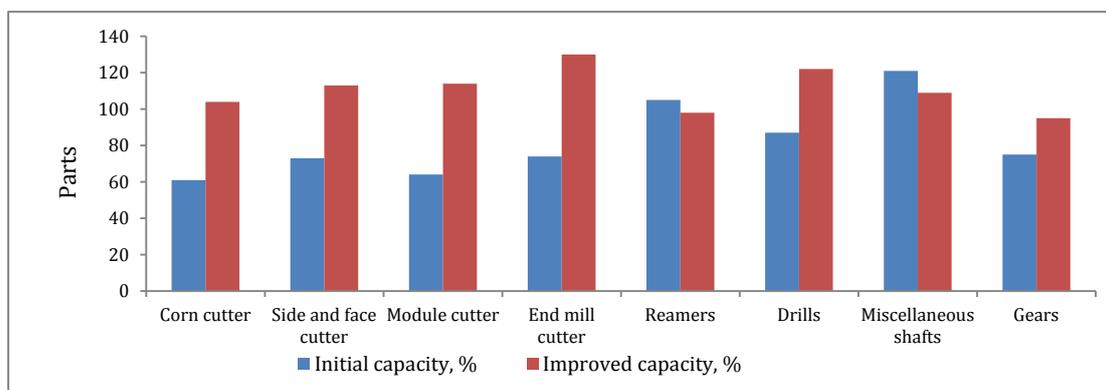


Fig. 16 Improvements in proposed system

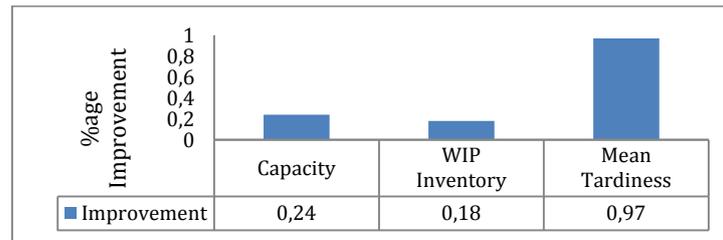


Fig. 17 Improvement in comparison parameter

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