

Development of Scheduling Optimization Tool using Excel VBA and Solver for Productivity Improvement of Slitting Machines for PVC/PVDC Film

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Abstract

Scheduling is one of the most important aspects for the efficient operation of any manufacturing industry. Scheduling deals with both time allocation as well as resource allocation to produce required quantity. Scheduling task in the polyvinyl chloride film manufacturing industry was not established any standardized process. This task was person dependent and produced required quantity without using optimum resources. The proposed model aims at automation of scheduling of slitting machines in polyvinyl chloride film manufacturing industry to minimize total processing time by using Integer Linear Programming Technique. Slitting is the process of cutting of bigger length and width of jumbo rolls to the smaller length and width of baby spools. Slitting machines handle a variety of materials, although each machine has its own constraints and capabilities. The proposed model is developed by using MS Excel VBA and Solver for optimum utilization of resources. This helps decision makers in planning and decision-making process of machine allocation.

Keywords

Scheduling Optimization, Solver, VBA, Integer Linear Programming (ILP), Polyvinyl chloride (PVC)

1. Introduction

In this paper we address a real-life scheduling problem related to the production of Polyvinyl Chloride film manufacturing industry. PVC is a thermoplastic polymer which has been one of the most widely produced plastics. The production process of PVC film includes the main machine calender and some peripheral equipment such as super mixer, planetary extruder, mixing mill, cooling unit, b-ray thickness detector, and auto winder. It also includes PVDC coating machine and slitting machines. There are three calenders, one PVDC coating machine, 6 slitting machines and one rewinding machine in the considered PVC film manufacturing plant. In the production process, the materials supplying system provides PVC resin with a proper formula and color and produces different specifications of PVC film products through the calenders in the form of jumbo rolls. Then that jumbo roll is slitted into baby spools. The capacity of the PVC film production system is determined by the slitting machines which become the bottleneck in such a system. Slitting machine is a series of rollers used to slit a variety of materials, although one machine will not usually have the capabilities to slit all types of materials. All 6 machines have different capabilities and constraints. To fully utilize these machines, the objective of this research consists of effective scheduling as a useful tool to increase the Production Efficiency.

The PVC film manufacturing plant receives purchase orders from different customers. Each purchase order contains a request to produce several PVC film products with five attributes: Formulation code, Color code, Outer diameter of spool, Film thickness, Width of spool. The document contains this all information about spool is called as Slitting Plan.

Scheduling is a highly complicated process in any manufacturing industry. Doing it manually is time consuming and ineffective. Scheduling Optimization is allocating right resources to right places at right times. Factors influencing scheduling process are available resources, amount of work to be done, operating constraints. In this paper we focused mainly on the scheduling optimization of slitting machines in PVC film manufacturing industry. All slitting machines have different constraints and capabilities, scheduling was person dependent and decision makers were not following any standard process for machine allocation. So, optimum machine utilization was not there. To solve this issue basic

scheduling optimization model is developed by using MS Excel VBA and Solver Function. This model works on Integer Linear Programming technique. The machine constraints were considered using MS Excel VBA and optimization is done by using Excel Solver function (Fylstra et al. 1998). The objective of Integer Linear Programming model is to minimize total completion time required to complete available slitting plans so that production efficiency will improve.

2. Literature Review

Nurcahyo, Rachman, and Agustino (2016) stated in their paper that the main purpose of optimization in any manufacturing industry is to increase the efficiency in production. They used mathematical model for preventive maintenance and production scheduling. The model used for production scheduling is based on Integer Linear Programming. Bogaerdt and Weerd (2018) stated in their paper that the multi-machine scheduling is a fundamental scheduling problem modeling a range of important real-life problems from scheduling tasks on a CPU to optimizing manufacturing processes. A schedule assigns each job a starting time and a machine such that each machine processes at most one job at a time. They proposed Decision Diagrams formulation for parallel multi machine scheduling. Borissova (2008) presented optimization processing scheduling model for metalworking CNC machines producing company by using MS Excel Solver. His model is based on the practical example, and it was tested and implemented in actual practice.

Giannelos and Georgiadis (2001) proposed the model of Mixed Integer Linear Programming for scheduling cutting operations on multiple parallel slitting machines. The mathematical model was developed to reduce trim loss, avoid production over-runs and avoid unnecessary slitter set ups. Vallada and Ruiz (2011) presented a genetic algorithm for the unrelated parallel machine scheduling problem in which machine and job sequence dependent setup times are considered. The proposed genetic algorithm includes a fast local search and a local search enhanced crossover operator. Two versions of the algorithm are obtained after extensive calibrations using the Design of Experiments (DOE) approach. Laribi, Yalaoui, and Sari (2019) presented a flowshop scheduling problems considering most real-life manufacturing environments. The objective is to find a schedule that minimizes the maximum completion time by using integer linear programming model. They also proposed an approximate resolution method based on genetic algorithm because of computation time constraint.

Shirley Gran (2015) proposed the Mixed Integer Goal Programming Model to solve the flexible job shop scheduling problem. The objective of their research work is to minimize the make span time and total machining time. The model was solved by implementing the preemptive goal programming approach and using the Microsoft Excel Solver. Costa (2015) proposed a genetic algorithm to solve real life batch scheduling problem from the pharmaceutical industry. The proposed genetic optimization model has been embedded in customized production scheduler. Logendran, Salmasi, and Sriskandarajah (2006) proposed three search algorithms to solve industry-size scheduling problem. He focused on minimizing the total completion time in two machine group scheduling problems with sequence dependent setups in discrete part manufacturing.

Tang et al. (2016) proposed an algorithm for solving a dynamic scheduling problem reducing energy consumption and makespan time for flexible flow shop scheduling. The proposed algorithm is based on an improved particle swarm optimization, and it adopted to search for the Pareto optimal solution in dynamic flexible flow shop scheduling problems. Li et al. (2011) proposed a scheduling of steel ingot production in a steel plant. The objective of their research is to minimize the makespan time. They studied parallel batch scheduling of deteriorating jobs with release dates on a single machine. They presented dynamic programming algorithm for bounded and unbounded models. Stefansson et al. (2011) proposed a large real world scheduling problem from a pharmaceutical company. He presented discrete and continuous time formulation to solve this scheduling problem.

Wani and Shinde (2021) proposed the implementing 5S in the workplace is to organize a workspace for efficiency and effectiveness by identifying and storing commonly used objects, maintaining the area and products, and keeping the new order. The decision-making process is frequently triggered by discussion on standardization, which helps employees understand how they should do their duties. The results show that 5S is an effective tool for improvement of organizational performance, productivity, hygienist. 5S technique would strongly support the objectives of organization to achieve continuous improvement in performance and productivity. Li and Liu (2022) presented the algorithms with approximation ratios 2 and 4/3 for the case of inclusive and tree hierarchical restrictions to minimize makespan on uniform machines. The goal of their research is to finish the job as soon as possible.

Martin et al. (2022) presented model which determines the optimal schedule and minimizes the makespan for product test scheduling problem. Their research is focused on product test scheduling with in-process and at-completion inspection constraints. They formulated a mixed integer linear programming model that minimizes makespan and then described an alternative spreadsheet implementation of this problem suitable for optimization using the genetic algorithm in the MS Excel Solver. Bahroun et al. (2021) proposed a flexible decision support tool based on a non-preemptive version of the previously established over-lapping load adjustment approach for dynamic single machine scheduling problem. Hsu et al. (2020) proposed scenario-dependent processing times in the context of a two machine flowshop environment to minimize the total completion time. They derived a lower bound and two optimally properties to enhance the efficiency. They proposed 12 simple heuristics as the 12 initial seeds to design 12 variants of a cloud theory based simulated annealing algorithm.

3. Model Development

The optimization scheduling model is developed for scheduling of six slitting machines. For slitting process of jumbo roll to spools, first scheduling form run by using ERP software. Then supervisors done manual machine allocation. According to that slitting plan print provided to each machine operator. After machine allocation cores and jumbo rolls required for slitting made available near each machine. Slitting process of converting jumbo roll to spools consists of three activities. Those three activities are jumbo roll changeover, size changeover and winding changeover. Jumbo roll changeover activity consists of unloading of previous jumbo roll and loading of new jumbo roll. Jumbo roll should be available near machine before loading on machine. But because of manual scheduling downtime due to jumbo roll searching was more. Size changeover activity consists of cutter setting, film passing and core setting. But cores were not available on right time because of manual scheduling. Winding changeover activity consists of label pasting on spool and unloading of spool. These three activities times are considered as time standards and time study was done to finalize these times. By using these time standards available time required can be calculated and it is taken as an input for optimization model as shown in the Figure 1.

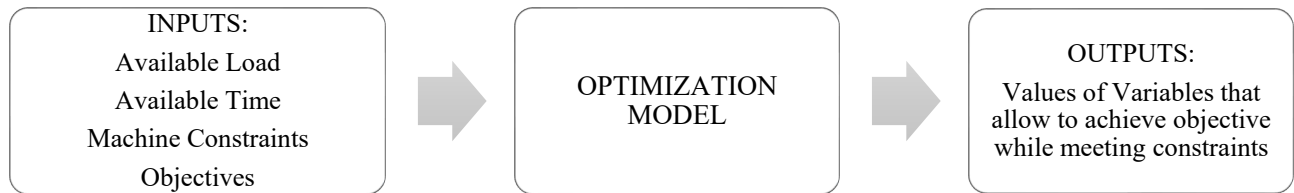


Figure 1. Optimization Model

Scheduling Optimization Model consists of three elements: Objective function, Decision variables and business constraints. This optimization model is based on Linear Programming having available Load, Available time, Machine constraints and objective as input and final machine allocation as an output. While developing a scheduling optimization model for 6 slitting machines following steps were performed as per the process flow shown in Figure 2.

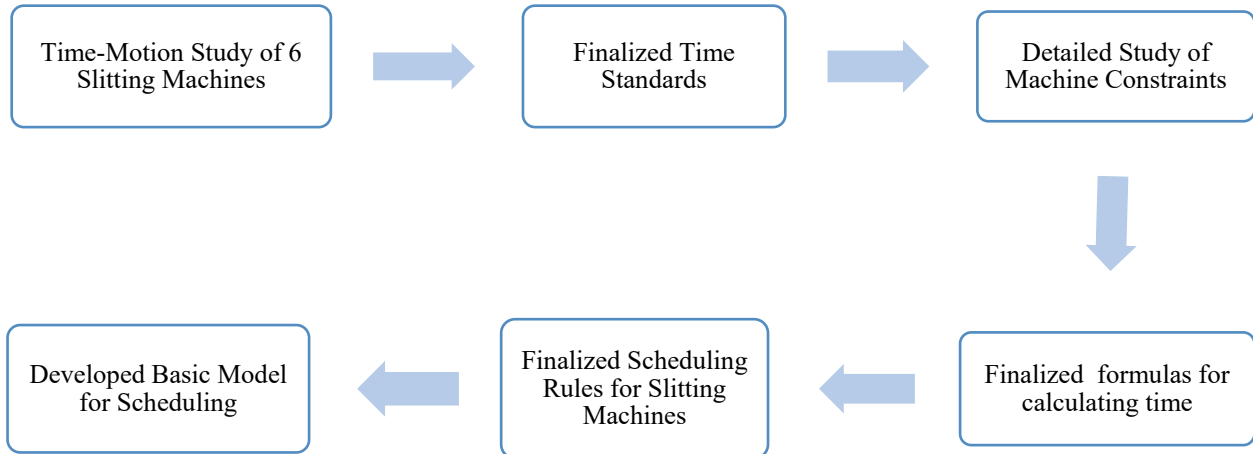


Figure 2. Steps for Development of Scheduling Optimization Model

- 1) Time study was done for each machine to record time for each activity and finalized the final time standards for all six machines. e.g., Size changeover time, Jumbo roll changeover time, winding changeover time
- 2) Machine constraints for all six machines were studied such as speed of machines, maximum and minimum outer diameter of the spool, maximum and minimum number of cuts on machines. The slitting of product should be done in such a way that it should be completed before or on expected delivery date.
- 3) Machine constraints were finalized those can be considered as 100% constraints for each machine.
- 4) The formulation of calculating time required to complete one slitting plan were done.
 - a. Total Roll Meters = Spool meters \times Number of Windings
 - b. Available Meters = $\frac{\text{Total Roll Meter}}{\text{Slitting Plan Quantity}} \times \text{Available Quantity for Slitting}$
 - c. Available Number of Windings = $\left(\frac{\text{Available Meters}}{\text{Spool meters}}\right)$
 - d. Total Time = Size changeover time + Total Roll Changeover time + Total winding Changeover time + Processing Time
 - e. Total Time = Size changeover time + (Number of Lots \times Roll Changeover time) + (winding Changeover time \times Available Number of Windings) + $\left(\frac{\text{Available Meters}}{\text{Average Speed}}\right)$
- 5) Standard scheduling rules for each machine were finalized and Microsoft Excel VBA and macros were used to add machine constraints in scheduling model. Each machine has different constraints following table 1 shows the example of those machine constraints.

Table 1. Slitting Machine Constraints

Machine Name	A	B	C	D	E	F
Minimum Number of cuts	2	1	2	1	2	2
Maximum Number of cuts	15	8	6	7	11	13
Maximum Outer Diameter of spool (mm)	450	700	400	700	500	500
Minimum Outer Diameter of spool (mm)	200	200	200	200	200	200
Input Thickness (mm)	0.25-0.7	0.25-0.7	0.25-0.7	0.25-0.7	0.25-0.7	0.25-0.7
Average Speed (m/min)	120	100	60	100	100	80


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Debug Run Tools Add-Ins Window Help
Ln 1, Col 1
(General) (Declarations)
Sub Allocate()
LR = Cells(Rows.Count, 1).End(xlUp).Row
Range("D2").Select
Range("D2").Formula = "=INDEX($AF$1:$AK$1,MATCH(1,AF2:AK2,0))"
Range("D2").Select
Range("D2").AutoFill Range("D2:D" & LR)
End Sub

```

Figure 4. VB macro for Index-Match function

Slitting Plan Number	Machine	Product	Thickness	OD	A	B	C	D	E	F	Constraints	Optimization
1	F	PVC	0.25	300	0	0	0	0	0	1	1	2585
2	A	PVC	0.25	300	1	0	0	0	0	0	1	
3	B	PVC	0.25	350	0	1	0	0	0	0	1	445
4	A	PVDC	0.25	325	1	0	0	0	0	0	1	440
5	A	PVDC	0.25	350	1	0	0	0	0	0	1	450
6	C	PVDC	0.3	350	0	0	1	0	0	0	1	420
7	E	PVC	0.3	465	0	0	0	0	1	0	1	430
8	C	PVC	0.3	300	0	0	1	0	0	0	1	400
9	C	PVC	0.35	275	0	0	1	0	0	0	1	
10	B	PVC	0.35	300	0	1	0	0	0	0	1	
11	A	PVC	0.35	300	1	0	0	0	0	0	1	

Figure 5. Scheduling Optimization Model

4. Results and Discussion

The reasons and percentage of downtime are related to different areas and those areas are mentioned in the following pie chart. From the chart shown in Figure 6, planning contributes highest downtime compared to others. So, the planning should be done in such a way that downtime related to planning will reduce. The downtime caused due to improper planning such as jumbo roll unavailability, core unavailability and packaging related issues. The scheduling optimization model will reduce the downtime by giving machine allocation at the starting of the production. This will give the availability of all required resources at the right place and at right time.

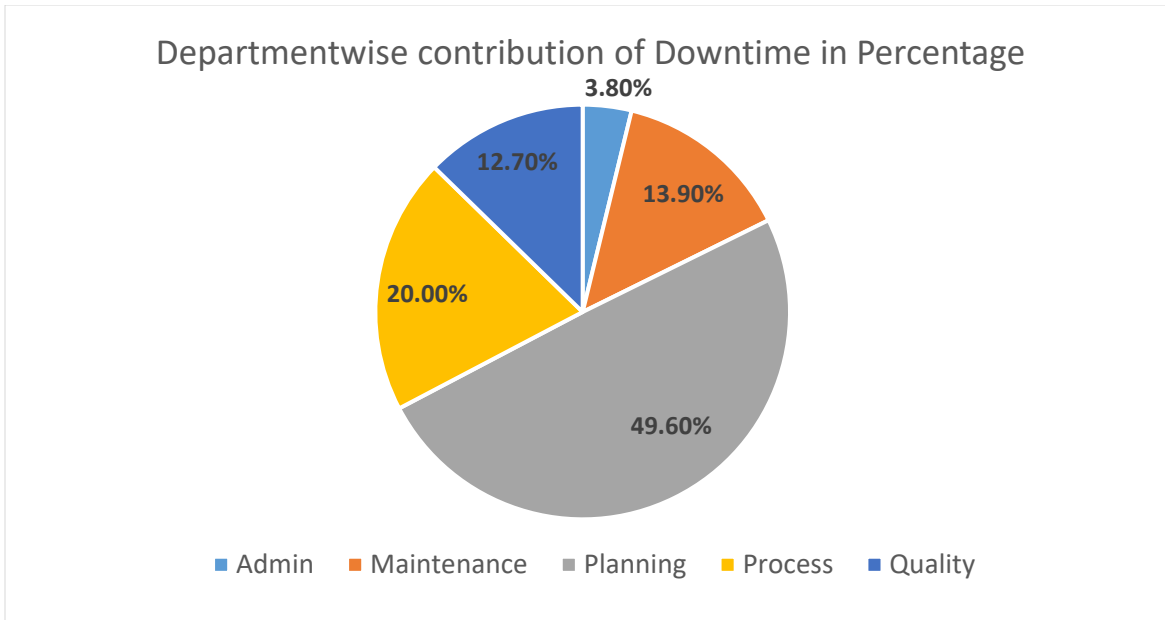


Figure 6. Department-wise contribution of Downtime in Percentage

The analysis of production efficiency has done for before and after implementation of scheduling optimization model. Table 2 shows the 12 days data for production efficiency before implementing the scheduling optimization model and Table 3 shows the 12 days data for production efficiency after implementing the scheduling optimization model. The assumption made while doing analysis is that the available load for before and after conditions is same. As PVC film manufacturing industry works on make to order production strategy, the orders are not fixed. So, the production process totally depends on available load. The formula for production efficiency calculation has given below:

$$Production\ Efficiency = \frac{Actual\ Output\ Rate}{Standard\ Output\ Rate}$$

Table 2. Production Efficiency before implementation of scheduling model

Available Load (kg)	Actual Output (kg)	Standard Output (kg)	Actual Time (mins)	Standard Time (mins)	Actual Output Rate (kg/min)	Standard Output Rate (kg/min)	Production Efficiency (%)
25000	19,452	20,531	2,145	1,771	9.07	11.59	78.22
20000	17,949	19,402	2,055	1,827	8.73	10.62	82.25
23000	17,978	20,574	1,965	1,883	9.15	10.93	83.74
24000	22,041	21,947	2,280	1,626	9.67	13.50	71.62
29000	29,218	28,483	2,460	1,995	11.88	14.28	83.19
34000	23,173	33,563	2,640	3,031	8.78	11.07	79.27
26500	18,497	26,260	2,057	2,075	8.99	12.66	71.05
35000	28,094	33,725	2,760	2,815	10.18	11.98	84.96
31500	27,618	30,442	2,550	2,610	10.83	11.66	92.86

25500	23,117	23,533	2,400	2,088	9.63	11.27	85.46
25500	18,680	25,398	2,050	2,441	9.11	10.40	87.58
32000	24,064	31,901	2,070	2,459	11.63	12.97	89.61

Table 3. Production Efficiency after implementation of scheduling model

Available Load (kg)	Actual Output (kg)	Standard Output (kg)	Actual Time (mins)	Standard Time (mins)	Actual Output Rate (kg/min)	Standard Output Rate (kg/min)	Production Efficiency (%)
25000	22,346	24,464	2,100	2,100	10.64	11.65	91.34
20000	18,167	18,167	1,650	1,613	11.01	11.26	97.76
23000	18,378	22,407	1,770	2,135	10.38	10.50	98.93
24000	18,917	22,818	2,100	2,156	9.01	10.58	85.11
29000	21,242	28,628	2,190	2,626	9.70	10.90	88.97
34000	29,545	33,373	2,310	2,375	12.79	14.05	91.02
26500	19,958	26,405	1,950	2,175	10.23	12.14	84.31
35000	24,065	34,381	2,025	2,610	11.88	13.17	90.22
31500	25,619	31,156	2,025	2,325	12.65	13.40	94.41
25500	23,268	27,189	1,935	2,218	12.02	12.26	98.09
25500	25,253	24,935	1,725	1,562	14.64	15.96	91.71
32000	23,667	31,976	1,905	2,569	12.42	12.45	99.81

The results of model calculation show that after using this model production efficiency increased by approximately 10%. The main purpose of this scheduling model was to attain optimum output in available time. This scheduling model gives the better solution for available load in the considered PVC film manufacturing industry. The graph shown in Figure 7 gives the data of production efficiency improvement after implementing this model in actual production plant.

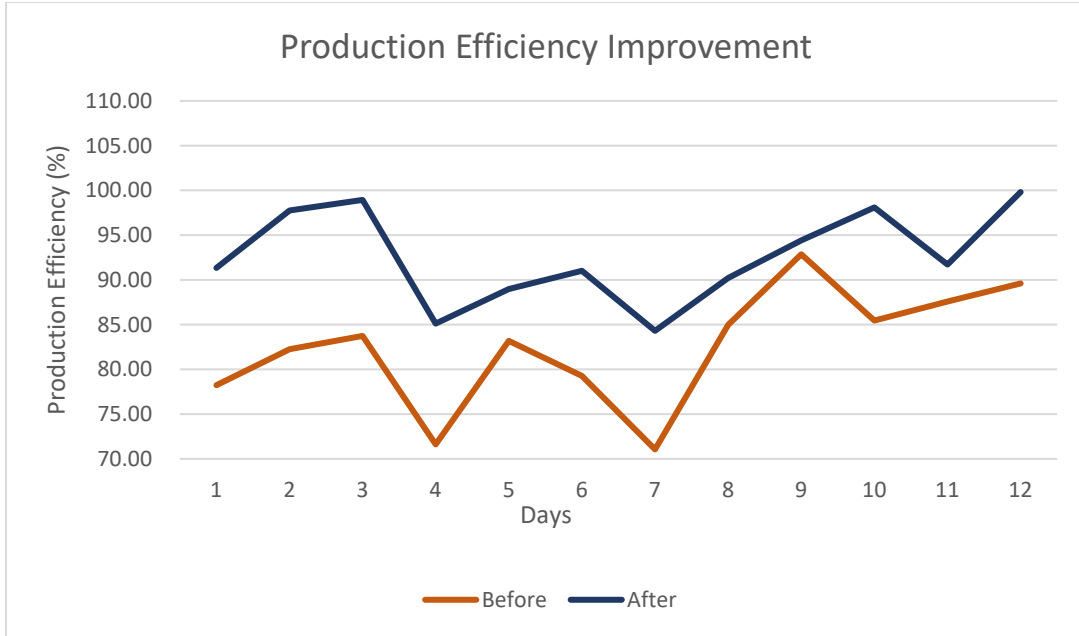


Figure 7. Production Efficiency before and after Implementation of Scheduling model

As shown in above graph, the production efficiency does not follow trend because available load for slitting varies according to customer orders. The common consideration in analysis is that available load is same. For the same load conditions, scheduling optimization model gives the better optimum solution.

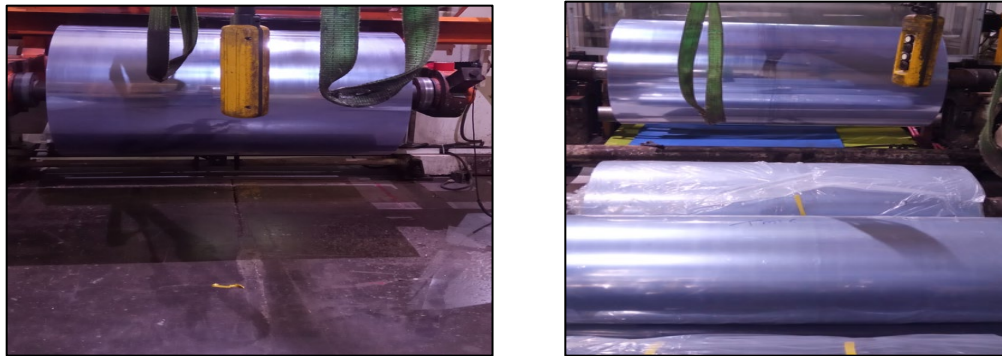


Figure 8. Jumbo Roll Availability before and after Implementation of Scheduling model

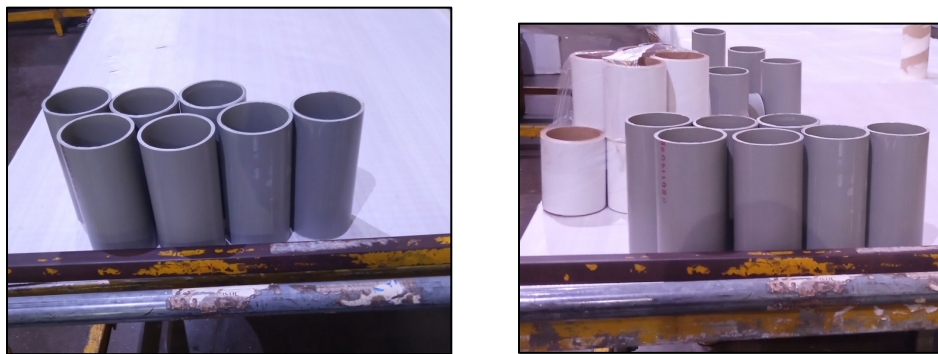


Figure 9. Core Availability before and after Implementation of Scheduling model

After implementation of this scheduling optimization model, supervisor has the machine allocation at the starting of the shift. So, jumbo rolls and cores are available at the right time as shown in Figure 8 and Figure 9. Due to this jumbo roll searching and core unavailability downtime reduced. Hence this model also reduces the downtime due to planning. This results in availability of all resources required for slitting at right time and at right place.

5. Conclusion

A real-life scheduling problem related to the production of Polyvinyl Chloride (PVC) film manufacturing industry is considered. PVC is a thermoplastic polymer which has been one of the most widely produced plastics. The optimization scheduling model is developed for scheduling of six slitting machines. The results of data processing by using scheduling optimization model calculations indicates that the use of this model minimized the total time required to complete the production. It reduced the planning time from hours to minutes. This model has tested and successfully implemented in the industry. By using this scheduling optimization model, scheduling process became lean. Production Efficiency has improved through optimum utilization of six slitting machines. The results of model calculation show that after using this model production efficiency increased by approximately 10%. Thus, this scheduling model gives the better solution for available load in the considered PVC film manufacturing industry.

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Dr. Shinde is lifetime member of ASME (USA), SAMPE (USA), WASET, SAE India, ISTE (India), and AMSI. SAVE International USA. He is recipient of Dr. Wadaran L. Kennedy Scholar Award for 2012-2013 from North Carolina A&T State University, recipient of Graduate Research Assistantship award from North Carolina A&T State University from August 2011 to Dec. 2014. Recipient of Scholarly Accomplishments and Excellence in Academic Performance Award, Division of Student Affair and International Student and Scholar’s office, North Carolina A and T State University, NC 2012. Dr. Dattaji Shinde has awarded Best Dronacharya Award for Innovative product Smart Navigation Band in the National level Entrepreneurship Generation –Y competition Hunar 2.0 organized by Jaro Education for 2018-19. Also, working as Board Studies Member for K K Wagh College of Engineering Nasik for from 2018-19.