A Study on Job Scheduling Based on Setup and Release Time

Submitted in partial fulfillment of the requirements for the degree of

Master of Philosophy

by

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DECLARATION

I here by declare that the thesis entitled "**A Study on Job Scheduling Based on Setup and Release Time"** submitted by me, for the award of the degree of *Master of Philosophy* to VIT University is a record of bonafide work carried out by me under the supervision of **Dr. A. David Maxim Gururaj**, Assistant Professor (Sr), SAS, VIT University, Chennai.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

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Date: **Signature of the Candidate**

CERTIFICATE

This is to certify that the thesis entitled " **A Study on Job Scheduling Based on Setup and Release Time"** submitted by **Mr. ANANTA PRAVEEN KUMAR MVR**, School of Advanced Sciences, VIT University, Chennai for the award of the degree of *Master of Philosophy*, is a record of bonafide work carried out by him under my supervision, as per the VIT code of academic and research ethics.

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(Dr. A. DAVID MAXIM GURURAJ)

ABSTRACT

Scheduling on a single machine with sequence-dependent setup time and release time in a multi-part metal manufacturing is a decision making task. It deals with assigning jobs to a single machine and its goal is to improve machine efficiency. For every part manufactured, setup time is the most crucial factor which reduces the machine efficiency. The issue of setup time is solved by sequencing the parts in batches. This approach may lead to miss the due dates for delivery. The thesis addresses setup time issue with priority to customer delivery.

The decision making study takes two forms. The first part deals with the machine scheduling by formulating a mechanism for sequencing the jobs into family of parts, batch sizing based on monthly demand, priority of parts based on customer etc. Second part deals with the analysis of inbound raw material and outbound finished goods inventory management, lead time, safety stock, reorder point etc for each part.

To improve the overall machine efficiency, it is important to simultaneously study the sequence dependent scheduling with setup time which includes release time of production and deliveries.

The objectives of the real time study is minimize cost, maximize output and minimize time.

Keywords: *Single Machine*, *Scheduling*, *Setup time*, *release time*, *Sequence dependent setup time* , *Inventory Management*.

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Place: Chennai

Date: **Ananta Praveen Kumar MVR**

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CHAPTER 1

Introduction

1.1 About the company

Any product in the market for consumers has to go through a process called manufacturing. It may be an edible item, a machinery item or any product. Manufacturing can be categorized as standardized products such as biscuits, soaps, paste etc, and non-standard parts like metal fasteners, chemical, automobile spare parts etc. Standardization of parts is very much important and necessary to produce a product and it reduces the wastage of raw material and time. When the demand and supply of a product do not change over a period of time, the manufacturing process can be done systematically.

The thesis focuses on manufacturing of non standard / special metal fasteners by Chunzu Cold Forging machine using hammering or a die. In heat forging the metal is liquefied followed by series of operations transforms to a desired shape. The cold forging method is preferred by many manufactures as it is cost effective with minimum wastage of raw-material and retains the properties of the raw-material.

The cold forging process makes small weight screws and bolts from a 1-ton standardized coil. The coil is fed to chunzu machine which cuts the coil into the desired size and followed by sequence of operations which results to specific design. The product design for each part needs a unique tools and dies that are to be arranged before mounting into the machine. This mounting of tools and dies with each station takes a minimum of 30 min.

The simple cold forging process on a single machine environment with multi part, variable periodic demand from customers, high quantity production takes huge time. The production have various time consumptions like, change over time from one product to other, coil change time, production time, tool breakage time, others like idle time of the machine, waiting time for raw material etc.

1.1.1 **Cold Forging Process**

Cold Forging or Cold Forming is the process of shaping the metal under room temperature conditions to the desired shape and dimension. There are mainly two types of machines that are used for Cold Forging.

1. Vertical Press or the Vertical Forging Machine
2. Horizontal Press or the Horizontal Forging Machine

1.1.2 **Why cold forging process**

In the commercial scenario, parts and components are manufactured by machining, hot forging and cold forging. The manufacturer chooses the method of manufacture based on the following factors.

- Machining:

  In the process of machining, the metal is cut into bars of required length and diameter and fed in to a lathe, CNC (Computer Numerical Control) Machine or a VMC (Vertical Machining Centre) . The machines are pre-programmed to cut the bar with the desired shape and size. This method is known for its high accuracy. On the other hand, as the cycle time for each operation is high, this method does not support projects with high volumes. Moreover, since the metal is cut, there is a huge loss in terms of turning scrap which enhances the cost of the product.

- Hot Forging :

  In this method, the product is heated to temperatures of 1150 C depending on the metal or the alloy. As the metal is heated to very high temperature, it renders the metal soft and hence, the shaping of the metal happens easily. This process renders the metal highly ductile, The surface of the products manufactured in this process possess a smooth and a very high polishes surface. But, the limitations of this process are- As the product is heated up to very great temperatures, there is a possibility of the composition of the material changing . This may cause the end product to behave differently than expected.

- Cold Forging or Cold Forming :

  In this method, the metal is acted upon by a heavy hammer which drives the metal to flow in solid state in a pre-prepared die to assume the shape of the die. This method is appropriate where the production quantities are large as the machines are capable of delivering higher quantities per minute. The chemical composition of the metal does not change under this method and hence the product answers to the standard description of the metal used. The raw material at times needs to be heat treated to remove cracks, which adds cost to the process. Where greater accuracy of the product is needed, the product may be cold forged to the nearest dimension and machined from there to reduce the input weight of the product and also the cycle cost of the machining process, thereby deriving time and cost efficiencies.

1.2 Scheduling - Its role and significance

Decades ago,(Pinedo 2012) put across scheduling as a decision making task of assigning resources to activities over a time interval such that some measurable performances such as job completion time, missing due date for job, number of late jobs, can be minimized. In a Small and Medium Enterprise (SME) organization the challenge is to survive in business, to make profits by competitive pricing and maintain quality to customer demand. They face continuous challenges from customers over changes in product design, prompt and fast respond to deliver products. Every SME is intent to adjust itself for this dynamic business environment. It is necessary for the SMEs to improve the production and scheduling to meet deadline / due date, improve machine efficiency, retain customer trust and to make profits.

Few decades ago, academic research on traditional scheduling approach had ignored the importance of setup time and release time. They assume the setup time is negligible and start time of the jobs are always given. Over four decades, setup time is vital in production scheduling. Setup time is termed as the job changeover time between two different parts. The quantity of parts produced between two setups is termed as a batch with the number of items in the group is termed as lot size. Clustering of parts in batch will help the manufacturer to curtail the repeated setups. Many times the SMEs likely to produce parts in bigger lot size to shrink job change over time. By choosing extended production time for a particular part it will prompt to postpone other parts past their due date. If SMEs adopt to due date criteria by downsizing the lot size of part boost the number of setups.

On basis of lot size with compulsion on due date, schedulers frame detailed scheduling with the following two major concerns.

1. Machine utilization.
2. Capacity considerateness.

1.2.1 Flow of information in Production Planning and Scheduling

The firm manufactures more than one lakh of pieces using a single cold forming machine with a maximum of 5 stations. The firm deals with the following

- They manufacture 40 parts.
- Using 29 different raw materials.
- For 20 various customers.

There are few high priority customers who places order every month. Some customers place order once in 3 months and others place orders once in 6 months. Due to this uncertain demand, the company prefers make-to-order rather than make-to-stock. Due to oxidation of metal, it is risky to keep both raw material and finished parts in inventory for long time. Hence inventory control plays a vital role in production of metal fasteners. The raw material is ordered based on demand and the respective release time into the shop floor be identified. Accordingly the lot and batch are evolved. The finished parts inventory be managed by lead times of the customers demand.

To avoid the setup time, the firm manufactures the parts and it has to be kept in stock for few months based on the lead time, reorder point, sale / usage of parts monthly. This inventory needs a special care for the firm as unsold pieces which reduces the overall profits that tends to put into scrap.

The flow of information is given in fig. 1.1. A master schedule is built resulting in the demand of end product quantities and their desired due dates, priority to customer, setup related information, sequence dependent / sequence independent, release dates, number of setups in month / year, production time, necessary tools and dies.The management applies the following procedure in production schedule.

- By end of every month the organization calls their customers to ask for their month demand.
- Based on the feedback they seize the monthly demand and sale by 1st of next month.
- Then the order for the required raw material is placed to the suppliers.
- Production planning and scheduling prepares master schedule.

1.3 Machine details

The fig 1.2 shows the machine used in the organization for cold forging operations. It can produce 40-60 pieces per minute depending on the weight of the product.

The fig 1.3 shows the sample metal coil / raw material used in the production. This coil is feeded into the machine. Generally the coil comes in a specific standard and multiples of tons. If the demand is only for 400kg , the company still buys the material in 1 ton

The fig 1.4 shows the various stages of screw. The metal coil is cut into the required size in the first stage and later on each station the metal takes its shape.

1.3.1 Production Activities

The production schedule depends on the following factors.

1. **Job Setup time:**

   This time involves in setting up the machine with tools and dies that is absolutely essential for the product to be manufactured. Time components are

   (a) Tool and Die removal (of the earlier job).

   (b) Tool and Die mounting (of the current job).

   (c) Quill Cutter fixing of the current job.

   (d) Sample setting.

   (e) Transfer setting.

2. **Coil Change time:**

   (a) When the product is being setup by Team A, Team B takes care of coil loading. Hence no additional time is required for coil change when the first coil is mounted on the machine.

   (b) For all successive coils, there is a time requirement of 10-20 minutes to change the coil.

3. **Production Time:**

   (a) The machine runs at varying speeds ranging from 35 pieces per minutes to 60 pieces per minute. The speed depends on the shape, weight , size and the complexity of the product. The average speed is 45/50 pieces per minute.

4. **Tool Breakage / stoppage time:**

   (a) Due to the impact of a 2 ton hammer on the tool and die during manufacturing the product, components of the tool and die are subject to wear and tear and break. Any change of these components or repair of the same would be classified as tool breakage or stoppage time.

5. **Others:**

   (a) All other time spend like, machine repair time, power cut time, getting the approval from the customer time etc, shall be classified as other times.

The current break-up of the time is as follows in the following table

Table 1.1 Time for Activities

SL NO	Time for Activity	Time
a	Job Change	38%
b	Production	20%
c	Coil Loading	5%
d	Tool Breakage /Stoppage	18%
E	Supplementary	19%

1.3.2 Machine Utilization and factors effecting the production

Factors that affect / impact machine setting

- Removal of old tools
- Quell / Cutter dismounting and mounting
- Punch side tools mounting
- Die Side tools mounting
- Sample setting
- Arm setting
- Transfer settings
- Manual run for testing of design
- Approval

1.4 Problem Statement

To have a detailed study on single machine scheduling problem with setup time to improve the machine utilization. One year historic production data is collected and analyzed. The details of various parts, clients, raw materials, time details are extracted from the data for analysis. The use of release time of job into the system will make sure the parts are manufactured only after the required raw material is available for production. The current work not only deals with scheduling but also the inventory management of raw material and finished good inventory. The heuristic methodology applied helps in effective scheduling in a multi-part environment and improve the availability of parts.

1.5 Organization of the thesis

This thesis is organized in the following way. Chapter 1 starts with introduction and discuss about the details of the product and company.

Literature review is presented in **Chapter-2** involving concepts of scheduling with setup time and release time. Various types of scheduling, terminologies, algorithms are discussed extensively. Sequence dependent and independent setup related problem over scheduling, importance of batching and job family setup time are reviewed.

Data Analysis part is dealt in **Chapter-3** which giving an insight into the one year production data collected for analysis. The data gives the daily production activities with time taken for activities. The number of parts with details of raw-material used and the customer details are analyzed. The monthly and annual percentage of time spend on each activity helps us to identify the importance of good scheduling system. The data is evident to the fact that the setup time is high and it needs to be reduced for improving the efficiency of the machine.

The methodology of scheduling with setup time and release dates are explained in **Chapter-4**. The study identifies repeated setup of similar part in the same month, annual number of setups for each part, priority of each customer based on the monthly demand, annual demand, lead time for each part, family of each part based on the raw material.This methodology not only deals with scheduling with setup time but also helps the manufacturer in dealing with inventory control of raw material and finished goods. Initially a setup matrix between families of parts based on diameter of coil is formulated to reduce the job change over time. The concept of sequence dependent setup time along with the setup matrix will reduce the job change over time. Secondly, based on lead time the inventory safety stock, reorder time, finished good inventory are handled. Third the modified lot sizing will help in improving the availability of parts for the customers.

Results and Conclusions in **Chapter-5**describes the brief summary of the study, results and improvements and suggestions for future work. The scheduling algorithm objective is to reduce the setup time. After thorough analysis, the factors resulting in low inventory, frequent setups in same month, availability of raw material contribute to the reduced setup time of the parts.

Appendix - 1 gives the sample code of python and R used for data extraction and manipulation. **Appendix -2** gives the raw production data collected for few months. The daily data is converted into monthly data using R and Python over excel sheet.

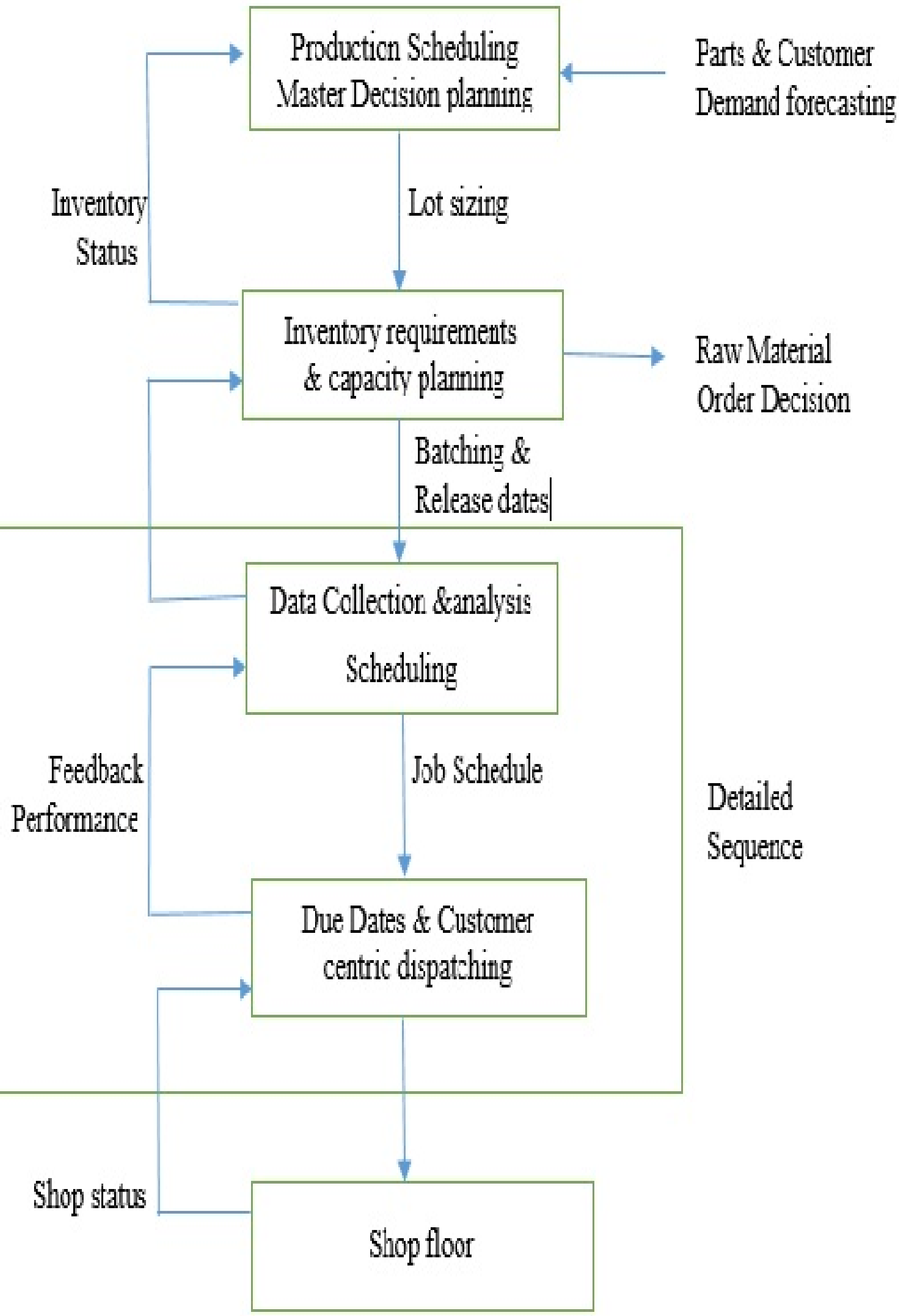

Fig. 1.1 Flow of Manufacturing Process

Fig. 1.2 Sample Chunzu Machine

Fig. 1.3 Sample Metal Wire coils

Fig. 1.4 Five station screw manufacturing stages

CHAPTER 2

Review of Literature

Scheduling is a vital decision making task which is used regularly by manufacturing and services companies. The allocation of fewer resources to jobs over a given time intervals to optimize one / more objectives. Every industry is unique in their own and follows a system that suits their size of company, machines, products, sales, profits / revenue, geographical location, work culture etc. Hence the types of scheduling depends on the issues in the system and the objectives they wish to achieve.

After the first industrial revolution, huge amount of work is carried out in the field of scheduling. Starting from basic level to advanced levels many books and articles are published in the past 3-5 decades. The decades old topic still finds it valuable place in industry. Many updates, advancements and technological innovations the study on scheduling still offers a lot to both academicians and many industries. Many aspects of scheduling, published in books by (Pinedo 2012), (Blazewicz 2007) provide vast list of references to sequencing and scheduling problems.

Scheduling problems which has relevance to both practical and problem complexity have guided the group of comprehensive research with complex problems, priority rules and algorithms.

2.1 The essentials of scheduling

Problem of scheduling occur when different jobs are to be processed on one or more machines. Various actors supporting the scheduling range from production planning of parts and services, development of shop floor to maintenance, acquisition to storage, material management to dispatch, accounts department to marketing department, profits of parts to selling in scrap, operations management to manpower, technical to non technical are essential part of organization.

The following are elements essential for scheduling:

1. Resources
   (a) Limited Machines
   (b) Employees at work
   (c) Mega Kitchens
   (d) Teleconference
2. Tasks
   (a) production operations
   (b) Assigning task to employees
   (c) Cooking stages
3. objectives
   (a) Makespan
   (b) Tardiness
   (c) completion time
   (d) flow time
   (e) Lateness time

2.2 Models of Scheduling

2.2.1 Performance criteria

The performance of production scheduling be evaluated with some objectives in the system related to anything towards time, cost, efficiency, lateness, earliness criteria. The criteria differs from organization to organization. Below are some objective functions often found in the literature both in academics and industry. This section gives basic information regarding most commonly used terms in day-to-day life activities of manufacturing.

1. **Makespan**:

   Makespan is the most used parameter of production scheduling. It refers to the total time required for all jobs to be completed. The total time in which all operations for jobs are completed is generally referred to as makespan.

2. **Tardiness**:

   Tardiness of jobs refers to the job which has delayed their respective due dates.

3. **Longest processing time** :

   This refers to the longest time taken for a job to be processed at the machine. The objective will be to minimize the longest processing time of a job

4. **Critical Ratio**

   The ratio of time left to work to the time remaining by the jobs to be manufactured

5. **Earlier Due date**:

   Production Jobs are sequenced for manufacturing in the order of their due date delivery

2.2.2 Three field Notation : $\alpha \setminus \beta \setminus \gamma$

Scheduling is not limited to one sector or a company. It represents the complexity of management decisions and scope of improvement. This results in increased attention to both academicians and industrial professionals. The idle conditions in which the task of implementation referred in many academic research articles are bound to debate. Where as industrial professionals, due to stress from competitors, keeps it a closed secret in the way the tasks are implemented. The long arguments on the topic of scheduling is resolved by structuring the general scheduling problem. In scheduling literature the machine environment, problem constraint and performance measure are structured into a tuple $\alpha \setminus \beta \setminus \gamma$. The functionality of the terms are as follows.

- **α:** Represent the system environment. This involves single machine to multiple parallel machines depending on the nature and size of the organization.
- **β:** Represents the constraint of the scheduling problem. It represents sequence dependent or independent involving family of parts in some cases.
- **γ:** Represents the performance measure of the organization which suits their way of business objective.

The complete description of the notation is explained from the following fig 2.1

Description of α, β, γ fields.

α		β		γ	
Notation	Description	Notation	Description	Notation	Description
1	Single machine	ST_{si}	Sequence-independent setup time	C_{max}	Makespan
P	Parallel machines (identical)	SC_{sd}	Sequence-dependent setup cost	E_{max}	Maximum earliness
Q	Parallel machines (uniform)	ST_{sd}	Sequence-dependent setup time	L_{max}	Maximum lateness
R	Parallel machines (unrelated)	$ST_{si,f}$	Sequence-independent family setup time	T_{max}	Maximum tardiness
Fm	m-stage flowshop	$ST_{sd,f}$	Sequence-dependent family setup time	D_{max}	Maximum delivery time
FFm	m-stage flexible (hybrid) flowshop	$SC_{sd,f}$	Sequence-dependent family setup cost	TSC	Total setup/changeover cost
AFm	m-stage assembly flowshop	ST_{psd}	Past-sequence-dependent setup time	TST	Total setup/changeover time
J	Job shop	$Prec$	Precedence constraints	TNS	Total number of setups
FJ	Flexible job shop	r_j	Non-zero release date	ΣF_j	Total flowtime
O	Open shop			ΣC_j	Total completion time
				ΣE_j	Total earliness
				ΣT_j	Total tardiness
				ΣW_j	Total waiting time
				ΣU_j	Number of tardy (late) jobs
				Σw_jC_j	Total weighted completion time
				Σw_jF_j	Total weighted flowtime
				Σw_jU_j	Weighted number of tardy jobs
				Σw_jE_j	Total weighted earliness
				Σw_jT_j	Total weighted tardiness
				Σw_jW_j	Total weighted waiting time
				$\Sigma h(E_j)$	Total earliness penalties
				$\Sigma h(T_j)$	Total tardiness penalties
				$TADC$	Total absolute differences in completion times

Fig. 2.1 Description of $\alpha \setminus \beta \setminus \gamma$

2.2.3 **Brief review of Literature**

The books on scheduling by authors (Pinedo 2012), (Blazewicz 2007) put together the concepts of scheduling , algorithms in various environments with single, parallel to multiple machines. The survey of various algorithms with objective to tardy jobs in a single machine environment are discussed by (Koulamas 2010),(Muminu O. Adamu 2014) and (Skylab R. Gupta 2006). In the surveys the authors refers concepts of minimizing the number of jobs missing due dates with considerations towards the sequence dependent setups of single machine. The scheduling problems and dispatching rules related to setup times and some times setup costs are extensively surveyed by authors (Allahverdi 2015) , (Christoph W.Pickardt 2012). The survey articles comprise of more than 300 journals published by authors of similar interest.

The concept of reducing wastage of time, resources is termed as Lean. The lean philosophy adds value to the time spend on resources by methods suggested by six sigma to improve process of task. The scheduling concepts also find its importance into the lean philosophy and its implementation in reducing time and add value keeping due date for the customers. The authors (Ajit Kumar Sahoo 2008),(Mohamed K. Omar 2013) have suggested methods of lean philosophy adding value in the forging company using single minute tool and die cast changing. The scheduling problems using lean six sigma implementation and concepts can find more articles in coming future.

In real time Scheduling problems with setups need time to arrange the requirements of next job after finishing the current job. The setups are registered either by time based or cost based. To avoid the problem of repeated setups the shop floor managers prefer to make more parts in the current setup. The total parts produced in a single run is termed as batch size / lot size. Large Lot sizing is a problem which delays jobs of other customers and small batch size leads to increased setup times or costs. The shop floor management needs to make good judgments in minimizing both the problems. Making of parts by optimized lot sizing depends on the lead time of customer and the variable demand. The concept of batching related issues are discussed by authors (Alessandro Agnetisa 2004), (Cheng 2010), (Cheng 2006), (Rui Xu 2012), (Subhash C. Sarin 2012), (Chen 2010)

Sequencing refers to the order in which jobs are processed over machines/resources. The time taken to job change over from current job to the next depends on the job which is coming next. The situation under which the job changeover depends on the current and next jobs is termed as scheduling with sequence dependent setup times/ cost. Single machine environment with sequence dependent setups problem cannot be solved in polynomial time. (Janez Kusar 2010),(Velsquez 2008) discussed the issues under sequence dependent setup time in a single machine environment with objective to reduce the setup time.

Batching of jobs with sequence dependent setup times in single machine environment answers many key issues related to minimizing the setup time / cost. The other improvement to this problem is to consider the family setup time rather than the parts setup time. Multiple parts with different designs are made of a single raw material. Sorting of jobs based on family helps the shop floor management to minimize the movement of jobs in and out of the group. The articles by authors (Feng Jin 2009), (Veronique Sels 2012*a*), (Ananta Praveen Kumar MVR 2017), emphasize the need of family setup over part setup.

Scheduling algorithms for single machine environment, batching, sequence dependent setup, family setup related issues are listed by authors (Davide Anghinolfi 2009), (Lai 2011), (Pape 2005).

The scheduling and sequencing problems are not complete without the availability of raw materials. Inventory control dealing with supply of raw materials and its consumptions are vital for the organization because it deals with purchase cost and interest paid on holding inventory. Inventory constrained issues on single machine are discussed by (Dirk Briskorn 2013).

Table 2.1 Scheduling Algorithms

Type	Description	Reference
Branch and bound	Integer Optimization method	(Radhouan Bouabda 2011) (Cheng 2006)
Simulated anealing	Reaching global optimum by probabilistic method	(Lai 2011) (Dirk Briskorn 2013)
MIP	Mixed Integer Programming	(Chen 2010) (Feng Jin 2009)
Tabu search	Metaheuristic approach	(Kailiang Xu 2010) (Ajit Kumar Sahoo 2008)
Heuristic Algorithms	Quicker solution compared to classical operations research methods	(Chen 2010) (Lai 2011) (Cheng 2006)
Genetic Algorithm	Most popularly used constrained optimization with repeatedly modifying individual solutions	(Xavior 2014) (Wang 2003) (Veronique Sels 2012*b*) (Kodaganallur 2014) (Lai 2011) (Cheng 2006) (Wang 2014)

The release times of jobs into shop floor is based on the readiness of raw material for processing. The issues of release dates into the environment are discussed by (Wang 2014), (Ananta Praveen Kumar MVR 2017),(Veronique Sels 2012*a*).

The following tables gives the literature review related to scheduling problems based on algorithms, categories and priority rules. Table 2.1 gives most commonly used algorithms for solving single machine scheduling problems. Table 2.2 represents the various priority rules most commonly used by industries to evaluate their methods.

Table 2.2 Priority Rules Table

Type	Description	Reference
FCFS	First come first served	(Pinedo 2012) (Christoph W.Pickardt 2012)
EDD Rule	Earliest Due date first	(Chen 2010) (Lai 2011) (Cheng 2006) citepMohamed2013 (Ananta Praveen Kumar MVR 2017) (Alessandro Agnetisa 2004) (Veronique Sels 2012*a*) (Feng Jin 2009)
SPT	Shortest Processing time First rule	(Janez Kusar 2010) (Ajit Kumar Sahoo 2008) (Chen 2010) (Cheng 2010) (Pape 2005) (Feng Jin 2009) (Subhash C. Sarin 2012) (Davide Anghinolfi 2009) (Skylab R. Gupta 2006) (Cheng 2006) (Lai 2011)
LPT	Longest processing time first rule	(Cheng 2010) (Velsquez 2008) (Koulamas 2010) (Dirk Briskorn 2013) (Rui Xu 2012) (Pape 2005) (Chen 2010) (Lai 2011) (Cheng 2006) (Wang 2014) (Chen 2010) (Lai 2011) (Cheng 2006)
PCO	Preferred customer order rule	(Chen 2010) (Lai 2011) (Cheng 2006)
MDD	Modified due date Rule	(Veronique Sels 2012*a*) (Feng Jin 2009) (Subhash C. Sarin 2012) (Davide Anghinolfi 2009) (Skylab R. Gupta 2006) (Cheng 2010) (Velsquez 2008) (Koulamas 2010) (Chen 2010) (Lai 2011) (Cheng 2006)
Smallest SLACK ratio	Smallest ratio rule in smallest CR ratio	citepAlessandro2004 (Veronique Sels 2012*a*) (Feng Jin 2009) (Subhash C. Sarin 2012)
SRT / OP	Slack time remaining per operations in a multi stage manufacturing environment	(Allahverdi 2015) (Muminu O. Adamu 2014) (Janez Kusar 2010) (Ajit Kumar Sahoo 2008) (Mohamed K. Omar 2013) (Ananta Praveen Kumar MVR 2017) (Alessandro Agnetisa 2004) (Veronique Sels 2012*a*) (Feng Jin 2009) (Subhash C. Sarin 2012) (Davide Anghinolfi 2009) (Skylab R. Gupta 2006) (Chen 2010) (Lai 2011) (Cheng 2006)

Table 2.3 Priority Rules Table conti..

Type	Description	Reference
Hybrid	Mixture of some few priority rules like PCO and EDD etc	(Koulamas 2010) (Dirk Briskorn 2013) (Rui Xu 2012)
Regular objective	Minimization of total duration of project is most commonly used under this rule	(Davide Anghinolfi 2009) (Skylab R. Gupta 2006) (Cheng 2010) (Velsquez 2008) (Koulamas 2010) (Chen 2010)

Table 2.4 Scheduling Categories

Type	Description	Reference
Job Shop	Every job has a sequence with unequal processing times	(Ajit Kumar Sahoo 2008) (Mohamed K. Omar 2013) (Cheng 2006)
Flow Shop	Under Flow shop scheduling there is strict order of all operations to be performed on all jobs	(Baki 2003) (Pape 2005) (Chen 2010)
Open shop	A given set of jobs be processed at a given set of machines, in an arbitrary order over a time period	(Baki 2003) (Lai 2011) (Cheng 2006)
Group Technology	A single solution is formed by grouping similar problems	(Lai 2011) (Cheng 2006)
Cellular manufacturing	Just in time manufacturing + lean manufacturing	(Chen 2010) (Lai 2011) (Cheng 2006) (Cheng 2006)
Dynamic scheduling	Multi agent , meta heuristic, AI techniques	(A. S. Xanthopoulosa and Ioannidis 2016) (V. Vinod 2008) (Davide Anghinolfi 2009) (Koulamas 2010)
Just in time scheduling	Availability of resources and raw material ready at its scheduled time. No waiting time	(Ang 2007) (Lai 2011) (Cheng 2006)
Assembly Line	Assembling of parts to make cars, planes, mobile etc. Production is done elsewhere	(Ajit Kumar Sahoo 2008) (Mohamed K. Omar 2013) (Ananta Praveen Kumar MVR 2017) (Alessandro Agnetisa 2004) (Veronique Sels 2012*a*) (Feng Jin 2009) (Subhash C. Sarin 2012) (Davide Anghinolfi 2009)
Stochastic scheduling	Just in time manufacturing + lean manufacturing	(Chen 2010) (Lai 2011) (Cheng 2006)
Flexible Job shop scheduling	Just in time manufacturing + lean manufacturing	(Chen 2010) (Lai 2011) (Cheng 2006)

2.3 Summary of Literature

Scheduling on a single machine environment in real time is operated with variable demand from customers, maintaining quality, delivering parts on time, continuous supply of raw materials, maintaining tight inventory, overhead charges, risks of machine breakdown, availability of operators, making of profits from sales, sales improvement by marketing teams. The study on scheduling needs to take into consideration the above facts and is assumed to be a continuous supporting the shop floor. Based on the assumes, in the current study the following issues are reviewed.

- Various types of Scheduling
- Scheduling with setup time
- Sequence dependent family setup time
- Batching and batch size
- Release time of jobs
- Inventory management

CHAPTER 3

Data Analysis

3.1 Production related data - Its Importance

One of the key production related functions of every SMEs involving machines is data collection and monitoring. Every day machine related activities are very essential to improve production quality, yield / output, reduce wastage, improve operations, process optimization, identify sudden machine breakdown etc. Big companies make use of costly software solution to monitor the production process, material management, client with on time delivery, reducing work in progress, operations management, demand forecasting, order handling and sales, monitoring suppliers, monitoring vendors and other tasks in the system. The advanced cloud based IT solutions benefits the big companies to instantly access all the activities from anywhere, anytime and even with a small hand held device. SMEs dont need all the features the costly software provide. High spending on software solutions by SMEs will not service the purpose of both software and the SMEs. Hence the SMEs collect the shop floor data manually.

Collecting and processing data and maintain it continuously is a tedious job. Data plays a vital role to improve quality, efficiency, output and overall growth of the organization. Initially the data should be collected by the organization and the most important issue is sharing of the data for academic interest. Due to heavy competition, the data related to product manufacturing is very crucial for the growth of the company. Hence most companies dont share their data outside the organization. First it is very tedious job to maintain data and second it should be guarded from competitors.

3.1.1 **Raw Materials Used**

The raw materials used are metals either in the wire-form or the bar-form. The products manufactured are normally Ferrous and other Ferrous alloys and hence the wires and bars used are normally of this kind. Non Ferrous items like, copper, brass etc.., may also be used to forge. The alloys are standard alloys, both High density alloys and mild steel alloys. The raw materials answer to universal standards which vary in composition depending on the application of the final product. The raw materials also come in various diameters depending upon the products produced. In general, Chromium, Boron, Sulphur, Nickel, Molybdenum -are some of the elements used to make alloy steel. The alloy steel, by virtue of its superior ductile property helps in the easy usage of this material for this process. There are various processes the wire is subjected to with a view to obtaining a smooth and a flawless product. These processes are Cold drawing, pickling and phosphating, annealing, spherodized annealing, Normalising, hardening and tempering etc. These processes alter the material to the required softness/hardness, suitable ductility, and to the desired strength.

Some of the Standard Cold Forging alloy steels and mild steels used are

1. SAE4140
2. SAE4145
3. SAE1045
4. EN8
5. EN19
6. 16MnCr5
7. SAE1010/1015/1018
8. 15B25
9. 10B21
10. CK45

3.1.2 Characteristics of Parts

Each part has a unique identity based on the following characteristics

- **Diameter:** Each Part is made of a specific material standard and diameter. After the raw material goes through the 3-5 stations of the machine, the raw material changes to the desired shape. If the client needs 15mm size part, the company cannot buy exactly 15mm diameter wire. Rather it comes in 15.60 / 15.65 mm size wire. The tools and die moulds will change the final product to 15mm.

- **Sale:** Based on the demand from customers, the company manufactures the parts. Some portion of it will goes to inventory based on the lead time. The monthly demand alone will be billed for sale. The company manufactures the parts once in 2-3 months.

- **Weight:** Each part has a specific weight generally in grams. Number of parts per minute will be less for heavier parts and will be more for lighter parts. Sale is made by multiplying weight with the rate per piece. Heavier parts are always profitable.

- **Speed:** The machine produces parts with number of pieces per minute generally 45 pieces per minute. More the weight of the part lesser is the speed. For heavier parts due to hammering the tools and die may open up and have more chance of wear and tear.

3.2 Insights to Production Data

The data shared by Madras cold forming Pvt ltd is a real time production information. For the sake of anonymity the names of parts and customers are given dummy names and the remaining production related information is real and accurate. This is not a simulated / assumed information. Thanks to the company for maintaining the daily information. The one year historic data is a result of fine tuning the process over more than 5 years and keeping in the standards of six sigma.

Six Sigma considerations: As per the six sigma concepts, every activity needs to be recorded it terms of time. The time taken to setup is divided into activities, each activity is given 30 min and is recorded. Every time an operator works near the machine, he records the information in a well formated record data sheet. The data sheet which contain the hourly activities of machine related information is maintained by the shop floor operators. Later the information sheets are filed and a entry into Microsoft excel is made of the same daily.

Lean philosophy : The concept of lean philosophy is to add value for each activity to its total time taken. The time in which an operator spends in arrange the setup has to add value to the total time taken to setup the machine. In order to reduce the wastage of time, the tools and dies will be arranged well in advance before the finish of current job. The tools and die will be ready as soon as the current job is completed and ready to mounting. A special room in which the operator arranges tools and die is well arranged based on size and weights of the tools. The accessories also are near to the place of work in a very systematically arranged manner.

The organization have taken enough care in modifying the process over years. The data sheet is a resultant of process improvements. Over eight hours shift time, the organization is able to keep up the demand without missing the due dates and also without any shortages in inventory control.

A screen shot of raw data from April to August is available in appendix B.

One year financial production data is collected and analyzed. R programming Language is used for data analysis. The data has the following details.

1. **Production shift and activity** :

   The company works in the shift hours as shown in the Fig. 3.1. production shifts suits the demand and time spend on job change time. The company keeps up demand in their single regular shift hours. The following are the types of activities.

   (a) **Manufacturing** :

   Manufacturing activity denotes with making of already done parts in the past. Under this category the company buys the raw materials, performs the desired operations, maintains in inventory and sells them as per the monthly demand. Both material and operations are done by the organization.

   (b) **Development**:

   Dev activity deals with a new product and design. The operators need to try new combination of tools and die for setup of new parts.

   (c) **Job** :

   Job activity refers for machine related operations alone. The material belongs to the client. The role of the organization under job category is to take the material from client, perform a particular operation and dispatch the finished goods. The organization will not keep the finished goods in their inventory.

   (d) **Maintenance**:

   Annual machine Maintenance is a very important activity to avoid unexpected machine break down. The SME's generally have enough time in a year for annual maintenance. This activity is scheduled based on demand and without production delay.

2. **Product details** :

   The list of products are listed in Fig.3.3. The important characteristics of a product are

   (a) Product Weight

   (b) Quantity Manufactured

(c) Customer details

(d) Operator Name

(e) raw material information

3. **Job Change Information**:

   The data lists out the job change time between two parts. Job change over activity time involving removing previous job tools and die and mounting the tools and die for new job.This generally takes more than 2-4 hours.

4. **Customer information**:

   The data gives information related to who are the list of customers and the frequency of times the job is done for a particular customer. Based on the monthly demand, the production is performed.

5. **Machine Related Information**:

   A part from product name, customer details, raw material details, tools and die , the machine need the speed in which the parts are made per minute, for Eg. 45 pieces/ min.

6. **Various time details**:

   The following are the various columns in the excel sheet. The meaning of each column represent the task performed / time taken to perform the task.

- Raw Material
- Produced Numbers
- Quantity Accepted Numbers
- Quantity Rejected Numbers
- Setting Sample Numbers
- Production weight per unit in Kgs
- Job Change in Minutes
- Production time in minutes

- Coil Change time in Minutes
- Tool Breakage / Rework time in Minutes
- Waiting time for tools in minutes
- Waiting for Tools in minutes
- Waiting for Raw materials
- Waiting for Manpower in minutes
- Waiting for approval in minutes
- Raw Material problem in minutes
- Forging problem in Minutes
- Power outage in minutes
- Main Machine down time in minutes
- Other machine down time in machine
- Maintenance time in minutes
- Development time in minutes
- idle time in minutes
- Other minutes
- Total Minutes
- Trim progress scrap per unit in Kgs
- Total Trim progress scrap per unit in kgs
- Other Scrap in kgs
- setting sample in kgs

- Cut off scrap in kgs
- rejected pieces in kgs
- tool scrap kgs
- End bit in kgs
- Total scrap in kgs
- Total input weight
- Scrap of the total production volume

3.3 Data Particulars

To have a detailed study on single machine scheduling problem with setup times to improve the machine utilization. The details of various parts, clients, raw materials, time details are extracted from the data for analysis. The use of release times of job into the system will make sure the parts are manufactured only after the required raw material is available for production. The current work not only deals with scheduling but also the inventory management of raw material and finished good inventory control. The heuristic methodology applied helps in effective scheduling in a multi-part environment and also improve the availability of parts for the clients.

	Customer	Freq
1	Arco Wind energies	8
2	Balakrishna Industries	17
3	Bridge Forgers	2
4	Chennai Reprographics	34
5	Continental Pressings	9
6	Hi Beam Electricals	42
7	Hydraulics & Engineering	25
8	IMTC Pvt Ltd	6
9	Jwarner Industries Pvt Ltd	72
10	Paroca Fasteners Pvt Ltd	6
11	PayGay Industries	17
12	Perfect Engg Pvt Ltd	8
13	Pivot Engineers	20
14	Precision Indusries Pvt Ltd	23
15	Ray Tools & Dies P Ltd	29
16	Ray Tools & Dies Pvt LTd	12
17	RK Engg	5
18	Shastra Engg Pvt LTd	32
19	SIMCO Industrial Engg Pvt Ltd	38
20	Zenith Industries Pvt Ltd	34

	Shift Timings	No. times Annually
1	06:00 hrs - 14:30 hrs	1
2	06:00 hrs - 17:30 hrs	2
3	06:00 hrs - 19:00 hrs	1
4	07:30 hrs - 11:30 hrs	1
5	09:00 hrs - 10:30 hrs	1
6	09:00 hrs - 13:00 hrs	1
7	09:00 hrs - 13:30 hrs	1
8	09:00 hrs - 17:30 hrs	336
9	09:00 hrs - 18:00 hrs	7
10	09:00 hrs - 18:30 hrs	42
11	09:00 hrs - 19:00 hrs	5
12	09:00 hrs - 19:30 hrs	26
13	09:00 hrs - 20:00 hrs	9
14	09:00 hrs - 20:30 hrs	7
15	09:00 hrs - 21:30 hrs	1
16	09:00 hrs - 2100 hrs	1
17	09:00 hrs -18:30 hrs	1
18	14:00 hrs - 19:30 hrs	1

Fig. 3.1 List of Customer and Shift Timings

	Product	Freq
1	15mm Shaft	25
2	Ace PIN	7
3	ALL20-16203	4
4	ALV20-16203	1
5	Bolt 12mm	3
6	Bolt Lock	13
7	Capstain Screw	9
8	Collar Screw 1/2"	3
9	Collar Screw 3/8"	6
10	Collar Screw 5/8 X 1.25	3
11	Collar Screw 5/8"	8
12	Cot Gear Pin	12
13	Free Wheel Joint	6
14	Gee Bolt- 25	3
15	Gen Shaft 13684	13
16	Link Bolt	17
17	M12 Coach Bolt	6
18	M12X1.25X30HHB	34
19	M12X1.25X35HHB	4
20	M16 Bolt	8

	Product	Freq
21	M8X15X1.5 Screw	3
22	Machine Maintenance	3
23	P3270-Pin	4
24	PAC-183526	34
25	Peg Retainer	6
26	Pick Rod	34
27	PIN-20051	29
28	Pinion Rod	16
29	Pip Screw	31
30	Plain Shaft	16
31	Plain Shaft 1007	2
32	Plug Engg	5
33	Push Stroke Rod	8
34	Release Screw	4
35	Rivet 16mm	2
36	S00-2100 Shaft	32
37	Shaft Del	2
38	Stopper	3
39	Stud 18mm	15
40	Trowel Stud	8

Fig. 3.2 List of all Product

	Raw Material	Freq
1	10B21-10.60/10.65mm	2
2	10B21-9.70/9.75mm	20
3	10B35-9.70/9.75mm	14
4	15B25-10.60/10.65mm	35
5	15B25-13.70/13.75mm	19
6	16MnCr5H-17.80/17.85mm	28
7	16MnCr5H-18.85/18.90mm	19
8	16MnCr5H-21.70/21.75mm	8
9	EN8-15.60/15.65mm	19
10	EN8D-10.60/10.65mm	5
11	EN8D-13.50/13.55mm	9
12	EN8D-13.70/13.75mm	12
13	EN8D-15.50/15.55mm	11
14	EN8D-15.60/15.65mm	2
15	SAE1010-13.70/13.75mm	3

	Raw Material	Freq
16	SAE1010-15.60/15.65mm	3
17	SAE1010-19.90/19.95mm	6
18	SAE1010-21.70/21.75mm	19
19	SAE1010-7.80/7.85mm	11
20	SAE1010-9.95/9.98mm	24
21	SAE1018-13.70/13.75mm	50
22	SAE1018-15.60/15.65mm	3
23	SAE1018-9.95/9.98mm	2
24	SAE4135-10.60/10.65mm	22
25	SAE4140-10.60/10.65mm	2
26	SAE4140-12.60mm	3
27	SAE4140-13.70/13.75mm	26
28	SAE4140-15.60/15.65mm	22
29	SAE4140-9.70/9.75mm	17

Fig. 3.3 List of all Raw Materials

Month	Job Change (Mins)	Prodn Time (Mins)	Coil Change Time (Mins)	Tool Breakage/Rework Time (Mins)	Wating for Tools (Mins)	Waiting for RM (Mins)	Waiting for Manpower (Mins)	Wating for Approval (Mins)	RM Problem (Mins)	FG Problem (Mins)	Power Outage (Mins)	Main Machine Down time (Mins)	Other Machine Down time (Mins)	Maint Time (Mins)	Dev Time (Mins)	Idle Time (Mins)	Others (Mins)	Total Time (Mins)	Prodn In units	Prodn in Kgs	Prodn speed per min	Prodn per tot time avl (nos)	No : Setups
Apr	5025	2817	660	1586	0	0	240	245	150	360	240	0	60	690	0	0	196	12269	136958	10,203	49	11	13
May	4453	2872	755	2850	60	0	60	260	150	60	300	0	0	0	0	0	292	12112	132077	12,625	46	11	9
Jun	5190	2077	420	2386	60	534	30	397	352	510	210	0	0	30	0	0	459	12655	95652	7,222	46	8	13
Jul	3855	951	210	1260	0	5490	0	135	180	210	0	90	0	0	0	0	127	12508	42572	4,495	45	3	10
Aug	4740	2668	615	2145	0	480	0	969	180	210	0	52	0	0	0	22	355	12436	124506	10,275	47	10	14
Sep	5520	3554	719	2165	0	0	0	404	60	0	90	330	0	0	0	0	267	13109	159732	17,247	45	12	15
Oct	4155	3099	510	3460	0	0	0	201	180	90	60	0	0	0	0	0	220	11975	136471	15,093	44	11	10
Nov	4433	2542	555	3720	0	180	0	324	660	90	360	450	0	0	0	30	253	13597	114406	13,878	45	8	14
Dec	3630	1898	450	930	0	600	0	150	0	0	3510	480	390	450	183	0	68	12739	89582	7,798	47	7	11
Jan	2670	845	225	1755	0	870	0	80	0	30	0	0	0	150	3483	270	832	11210	35853	4,994	42	3	9
Feb	4433	2542	555	3720	0	180	0	324	660	90	360	450	0	0	0	30	253	13597	114406	13,878	45	8	14
Mar	3855	951	210	1260	0	5490	0	135	180	210	0	90	0	0	0	0	127	12508	42572	4,495	45	3	10
TOTAL	43671	23323	5119	22257	120	8154	330	3165	1912	1560	4770	1402	450	1320	3666	322	3069	124610	1067809	1,03,830	46	9	118

Fig. 3.4 Overview of Monthly data

Month	Job Change (%)	Prodn Time (%)	Coil Change Time (%)	Tool Breakage/Rework Time (%)	Wating for Tools (%)	Waiting for RM (%)	Waiting for Manpower (%)	Wating for Approval (%)	RM Problem (%)	FG Problem (%)	Power Outage (%)	Main Machine Down time (%)	Other Machine Down time (%)	Maint Time (%)	Dev Time (%)	Idle Time (%)	Others (%)	Total Time (%)
Apr	40.96%	22.96%	5.38%	12.93%	0.00%	0.00%	1.96%	2.00%	1.22%	2.93%	1.96%	0.00%	0.49%	5.62%	0.00%	0.00%	1.60%	100%
May	36.77%	23.71%	6.23%	23.53%	0.50%	0.00%	0.50%	2.15%	1.24%	0.50%	2.48%	0.00%	0.00%	0.00%	0.00%	0.00%	2.41%	100%
Jun	41.01%	16.41%	3.32%	18.85%	0.47%	4.22%	0.24%	3.14%	2.78%	4.03%	1.66%	0.00%	0.00%	0.24%	0.00%	0.00%	3.63%	100%
Jul	30.82%	7.60%	1.68%	10.07%	0.00%	43.89%	0.00%	1.08%	1.44%	1.68%	0.00%	0.72%	0.00%	0.00%	0.00%	0.00%	1.02%	100%
Aug	38.12%	21.45%	4.95%	17.25%	0.00%	3.86%	0.00%	7.79%	1.45%	1.69%	0.00%	0.42%	0.00%	0.00%	0.00%	0.18%	2.85%	100%
Sep	42.11%	27.11%	5.48%	16.52%	0.00%	0.00%	0.00%	3.08%	0.46%	0.00%	0.69%	2.52%	0.00%	0.00%	0.00%	0.00%	2.04%	100%
Oct	34.70%	25.88%	4.26%	28.89%	0.00%	0.00%	0.00%	1.68%	1.50%	0.75%	0.50%	0.00%	0.00%	0.00%	0.00%	0.00%	1.84%	100%
Nov	37.02%	21.23%	4.63%	31.06%	0.00%	1.50%	0.00%	2.71%	5.51%	0.75%	3.01%	3.76%	0.00%	0.00%	0.00%	0.25%	2.11%	114%
Dec	30.31%	15.85%	3.76%	7.77%	0.00%	5.01%	0.00%	1.25%	0.00%	0.00%	0.00%	4.01%	3.26%	3.76%	1.53%	0.00%	0.57%	106%
Jan	22.30%	7.06%	1.88%	14.66%	0.00%	7.27%	0.00%	0.67%	0.00%	0.25%	0.00%	0.00%	0.00%	1.25%	0.00%	2.25%	6.95%	94%
Feb	42.11%	27.11%	5.48%	16.52%	0.00%	0.00%	0.00%	3.08%	0.46%	0.00%	0.69%	2.52%	0.00%	0.00%	0.00%	0.00%	2.04%	100%
Mar	42.11%	27.11%	5.48%	16.52%	0.00%	0.00%	0.00%	3.08%	0.46%	0.00%	0.69%	2.52%	0.00%	0.00%	0.00%	0.00%	2.04%	100%
TOTAL	35.05%	18.72%	4.11%	17.86%	0.10%	6.54%	0.26%	2.54%	1.53%	1.25%	3.83%	1.13%	0.36%	1.06%	2.94%	0.26%	2.46%	100%

Fig. 3.5 Percentage view of monthly data

CHAPTER 4

Methodology

4.1 Need for Scheduling Improvements

In long term the primary objectives of business are mainly to expand customer base and profit by increasing productivity. Due to competitiveness and variable demand, SMEs expected to produce quality parts and deliver them in shorter time duration. The following improvements in the shop floor control brings a huge change to the machine efficiency.

4.2 Reducing Setup time

Setup time is the important factor for improving the production. Setup time is very often considered the significant unit of completion time. On an average half day or more is needed to setup the machine for a new job. The job changeover is essential as the parts depend on tools and dies, raw material and design of part. The following approach helps the organization to minimize the setup related time

4.2.1 Sequence dependent setup time

The parts manufactured are made of raw material with a specific diameter of the metal rod. The job changeover from part-A to part-B needs to change quill cutter and its respective activities. Hence the sequence of jobs depend on the previous setup and current setup. The situation under which the job changeover depends on the current and next jobs is termed as scheduling with sequence dependent setup times/ cost.

Sequence dependent setup time on machines takes the time to setup a new part acts on the part of machine which is processing the current part. The setup time can be improved by considering the parts and the order in which they processed. By setting up parts based on the sequence dependent setup time will not only arrange the order of processing but also helps the operators to complete one set of jobs belonging to the group before moving to other groups.

4.2.2 **Rearrange jobs by family**

The grouping of parts according to the shape of the raw material is termed as family of parts. Based on the diameter of the metal raw material the parts are grouped and is termed as family of parts. The data shows parts are produced without considering the time taken to setup the family. The family setup time gives us minimum time when doing multiple parts of the same family in long run.

4.2.3 **Setup matrix method**

The setup matrix for part changeover gives us the time duration of setup change from one part to the other part. In the **fig 4.1** the changeover matrix is extracted from the historic data. The matrix is formed by the 40 parts manufactured. The resultant matrix is a sparse matrix with many values zeros. The part changeover matrix is not very informative about the order in which the parts move in the sequence. The following information be inferred from the sparse matrix

- Setup swap between parts is not the same at different times.
- The longest and smallest times each time the changeover occurs cannot be recorded.
- Different instance of time gives random changeover for the same part
- The selection of parts in sequence in a month cannot assist the decision making by the organization.

4.2.4 **Modified setup matrix**

The setup matrix based on family type gives the modified setup matrix which deals with the diameter of the raw material used. The modified matrix answers the time spend on changing the setup related task by operators. The matrix is a resultant of 22 family of raw materials used in the organization In **fig 4.2** the modified setup matrix gives the following information

- The Changeover between the family of parts gives the highest and lowest time changes between the families

- The decision to choose the order of parts can use the setup matrix which gives the time required to setup the family
- Grouping of parts into family is easier than looking at individual parts
- The cause and effect of choosing a part for production on the overall time to complete production can be made simple by the family setup matrix

4.3 Decisions in Planning and Scheduling

The study on scheduling is a decision making task to assist the organization in improving the efficiency of the machine. The following enhancements / considerations suggested to improve the sequencing problem but also to improve the inventory consumption. The following sections are dedicated to the improvements to the production planning division of the organization.

4.3.1 Make to order / Make to stock strategies

The SME's depend on orders from customers. On receiving orders they start manufacturing. If the customer gives orders on a regular basis, the SME's try to minimize the setups by making the part and keeps in inventory for short period of time. On a regular basis the stock is consumed and again manufactured according to the lead times and reorder points of the stock. Even thought the strategy looks like make to stock but it is actually for make to order.

4.3.2 Improved Lot sizing

The scheduling parts by family setup matrix and sequence dependent approach gives an understanding of when to manufacture the parts. Then the question raises is how much to manufacture. The lot sizing issue leads to increased number of setups, if not taken care of. The modified lot sizing formula is as follows.

Production batch size = Closing stock + Current Sales - opening sales

Closing stock for current month (will be opening stock for next month)= 50% *of Current sale.*

4.4 Increase the availability of parts

The one year production data of parts has to deal with make to stock strategies based on the inventory levels of the stock. The finished goods inventory consumption and ordering of supply for raw material are vital for any SME's to continuously perform the production line. The following are the terminologies related to inventory control and **fig 4.3** shows the inventory breakdown

1. **Lead Time** : The time period between two orders of a customer.
2. **Safety Stock** : The minimum quantity of number of parts needs to be maintained at any point of time.
3. **Reorder point** : The reorder point is a trigger, that is generated when the stock is consumed below the safety stock.

4.4.1 Reduce Number of setup's for Complementary parts

Each part is made of a raw material and many parts are made of the same raw material. Such parts are termed as complementary parts. If 4 tons of a raw material is used for 2 parts part-a and part-b each 2 tons and are made every month leads to 12 setups each and 24 setups annually for the parts.

Whereas using 4 ton raw material to make part-a this month and another 4 ton raw material to make part-b next month leads to 6 setups annually and 12 setups for the parts.

The **fig 4.4** shows the details regarding the parts made of same raw material. A R programming code is used to extract the combination of raw material to its respective parts.

4.4.2 Release times

From the historic data there are instances where a part is setup twice or sometimes trice in a month. The primary reason behind such repeated setup time is non availability of raw materials. This prompted the use of release time of jobs into the system which represents the availability of raw material. The raw material to be supplied

4.4.3 **Heuristic Algorithm**

The heuristic algorithm presented in the study is given in the **fig.4.5**. The focus of the algorithm is on sequencing of jobs / order of production of jobs.

1. The Production planning department plans the parts, monthly demand, priority of customers, quantity of parts to be manufactured in the month.
2. The shop floor manager takes stock of available raw material and the arrival dates of the stock into system.
3. Based on the available dates, sorts the parts into families.
4. The products parts where the reorder point he less than safety stock include the part in the sequence.
5. The families are first sorted based on release dates of raw material.
6. Inside the families the parts move according to the priority of the customers.
7. Once the parts are made, the name is removed from the list.

	Pip Screw	PIN-20051	AC-18352	15mm Shaf	Pick Rod	K15X1.5 Sc	pstain Scre	Plain Shaft	0-2100 Sh	ot Gear Pin	n Shaft 136	P3270-Pin	lease Scre	2X1.25X30	Stopper	Ace PIN	Stud 18mm	Pinion Rod	ne Mainte	Shaft Del	Link Bolt	Bolt 12mm	ar Screw 3	Bolt 8mm	ar Scre
Pip Screw	0	120	540	420	810	0	0	0	0	0	570	0	270	0	0	0	0	300	0	0	0	0	690	0	
PIN-20051	0	0	210	0	360	0	0	0	330	270	0	0	0	0	0	0	0	300	0	0	480	0	0	300	
PAC-183526	150	600	0	810	0	0	0	510	480	0	720	0	0	0	0	570	0	0	0	0	0	0	0	0	
15mm Shaft	1140	390	0	0	1020	0	0	0	330	0	630	0	0	0	0	0	0	0	0	0	0	0	0	0	
Pick Rod	1020	0	0	0	0	690	720	390	360	0	380	0	0	750	0	0	0	0	0	0	0	0	0	0	
M8X15X1.5 Screw	0	0	0	0	0	0	540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Capstain Screw	0	420	0	0	540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	840	
Plain Shaft	0	210	0	0	0	0	0	0	225	270	0	0	0	0	0	0	0	270	0	0	0	0	0	0	
S00-2100 Shaft	0	0	270	0	240	0	330	210	0	433	330	0	0	360	0	0	0	0	390	30	0	0	0	300	
Cot Gear Pin	300	0	0	240	0	0	0	270	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Gen Shaft 13684	0	0	303	0	0	0	0	240	0	270	0	360	0	0	0	0	60	0	0	240	0	0	0	0	
P3270-Pin	420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Release Screw	0	0	0	0	0	0	0	720	0	0	0	0	0	330	0	0	0	0	0	0	0	0	0	0	
M12X1.25X30HHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	330	0	0	0	0	0	0	0	0	30	
Stopper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	270	0	0	0	0	0	0	0	0	
Ace PIN	0	360	0	0	0	0	0	0	240	0	0	0	0	0	0	0	240	255	0	0	0	0	0	0	
Stud 18mm	0	0	0	0	0	0	0	0	0	0	0	0	1050	0	0	420	0	0	0	0	360	0	0	0	
Pinion Rod	750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	360	0	0	0	
lachine Maintenanc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Shaft Del	0	0	0	0	0	0	0	0	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	
Link Bolt	0	0	0	0	0	0	0	0	0	720	0	0	0	420	0	865	0	1140	0	0	0	510	0	0	
Bolt 12mm	0	0	0	0	660	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Fig. 4.1 Part Changeover Matrix

		TO																					
	Family	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22
FROM	F1	X	60	60	60	60	20	60	60	60	60	60	60	60	40	40	40	40	40	40	60	60	60
	F2	0	X	22	22	22	22	22	60	60	60	60	60	60	40	40	40	40	40	40	60	22	60
	F3	22	22	X	22	22	22	22	60	60	60	60	60	60	40	40	40	40	40	40	60	60	60
	F4	22	22	22	X	20	20	60	60	60	60	60	60	60	40	40	40	40	40	40	60	22	60
	F5	22	22	22	22	X	0	22	60	60	60	60	60	60	40	40	40	40	40	40	60	22	60
	F6	22	60	60	60	60	X	60	60	60	60	60	60	60	40	40	40	40	40	40	60	60	60
	F7	22	22	22	22	20	20	X	60	60	60	60	60	60	40	40	40	40	40	40	60	60	60
	F8	60	60	60	60	60	60	60	X	60	60	60	60	60	40	40	40	40	40	40	22	60	22
	F9	60	60	60	60	60	60	60	60	X	60	60	60	60	40	40	40	40	40	40	60	60	60
	F10	60	60	60	60	60	60	60	60	60	X	60	60	60	40	40	40	40	40	40	60	60	60
	F11	22	22	22	22	22	22	22	22	22	22	X	22	22	40	40	40	40	40	40	22	22	22
	F12	22	22	22	22	22	22	22	22	22	22	22	X	22	40	40	40	40	40	40	22	22	22
	F13	22	22	22	22	22	22	22	22	22	22	22	22	X	40	40	40	40	40	40	22	22	22
	F14	40	40	40	40	40	40	40	40	40	40	40	40	40	X	20	20	20	20	22	40	40	40
	F15	40	40	40	40	40	40	40	40	40	40	40	40	40	20	X	20	20	20	22	40	40	40
	F16	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	X	20	20	22	40	40	40
	F17	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	X	20	22	40	40	40
	F18	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	X	22	40	40	40
	F19	40	40	40	40	40	40	40	40	40	40	40	40	40	60	60	60	60	60	X	40	40	40
	F20	60	60	60	60	60	60	60	60	60	60	60	60	60	40	40	40	40	40	40	X	60	22
	F21	60	60	60	60	60	60	60	60	60	60	60	60	60	40	40	40	40	40	40	60	X	60
	F22	60	60	60	60	60	60	60	60	60	60	60	60	60	40	40	40	40	40	40	60	60	X

Fig. 4.2 Part Family Setup Matrix

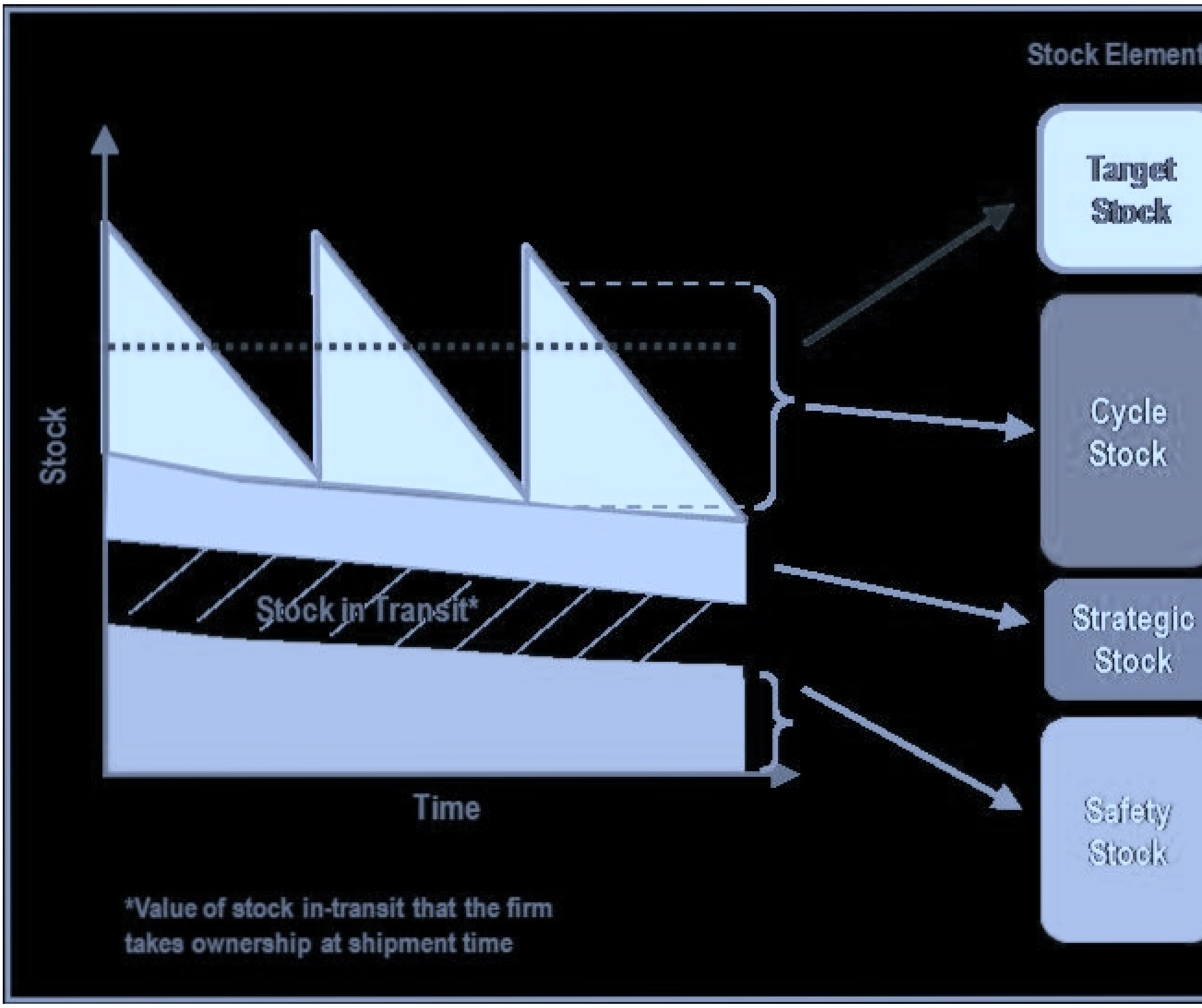

Fig. 4.3 Inventory Breakdown

Raw Material	Product
10B21-10.60/10.65mm	[u'M12X1.25X30HHB']
10B21-9.70/9.75mm	[u'Pip Screw' u'PAC-183526']
10B35-9.70/9.75mm	[u'Pip Screw' u'PAC-183526']
15B25-10.60/10.65mm	[u'M12X1.25X30HHB' u'Bolt 8mm' u'Gee Bolt- 25' u'M12 Coach Bolt' u'Capstain Screw' u'M12 Bolt GEE']
15B25-13.70/13.75mm	[u'Capstain Screw' u'Pick Rod']
16MnCr5H-17.80/17.85mm	[u'Plain Shaft' u'Cot Gear Pin']
16MnCr5H-18.85/18.90mm	[u'Gen Shaft 13684' u'Shaft Del' u'ALL20-16203']
16MnCr5H-21.70/21.75mm	[u'PS7001' u'Plug Engg']
EN8-15.60/15.65mm	[u'S00-2100 Shaft']
EN8D-10.60/10.65mm	[u'M12 Coach Bolt' u'M12X1.25X30HHB']
EN8D-13.50/13.55mm	[u'Pick Rod']
EN8D-13.70/13.75mm	[u'Pick Rod']
EN8D-15.50/15.55mm	[u'S00-2100 Shaft']
EN8D-15.60/15.65mm	[u'S00-2100 Shaft']
SAE1010-13.70/13.75mm	[u'Pinion Rod']
SAE1010-15.60/15.65mm	[u'Free Wheel Joint']
SAE1010-19.90/19.95mm	[u'15mm Shaft']
SAE1010-21.70/21.75mm	[u'15mm Shaft']
SAE1010-7.80/7.85mm	[u'P3270-Pin' u'Pip Screw' u'Peg Retainer']
SAE1010-9.95/9.98mm	[u'PAC-183526']
SAE1018-13.70/13.75mm	[u'Stopper' u'Ace PIN' u'Pinion Rod' u'Link Bolt' u'Trowel Stud' u'Rivet 16mm']
SAE1018-15.60/15.65mm	[u'Free Wheel Joint']
SAE1018-9.95/9.98mm	[u'PAC-183526']
SAE4135-10.60/10.65mm	[u'Bolt 12mm' u'Bolt Lock' u'M12X1.25X35HHB' u'M12X1.25X30HHB']
SAE4140-10.60/10.65mm	[u'Bolt Lock']
SAE4140-13.70/13.75mm	[u'PIN-20051' u'Collar Screw 1/2"']
SAE4140-15.60/15.65mm	[u'Collar Screw 5/8"' u'PIN-20051' u'M16 Bolt' u'Collar Screw 5/8 X 1.25' u'Collar Screw 5/8 UNC -1.5' u'Collar Screw 5/8 UNC -1.25' u'PAC-183526']
SAE4140-9.70/9.75mm	[u'M8X15X1.5 Screw' u'Release Screw' u'Collar Screw 3/8"' u'Pip Screw']

Fig. 4.4 Parts made by same Raw Material

```
Take input for Product[], Raw_Mat[], Qty[], priority[]
Groupby(priority).['Product','Raw_Mat','Qty'].sorted()
i = 1
j = 1
cur_date = sys.current_date()
While Product not empty:
        While Family_Type not empty:
                If Product[i] in Family_Type[j]:
                        if Prodn_Date[Product[i]] >= Release_Date[Product[i]]:
                                For cur_prod in Family_Type[j]:

                For part in Parts[Product[i]]:
                        If Reorder_Pt[part] < 0.20

                j++
    If Release_Date[Raw_Mat[i]] < cur_date
        START production[Product[i]]
        cur_date += Prodn_Time[Product[i]]
        Product[i].remove(), Raw_Mat[i].remove(), Qty[i].remove(), priority[i].remove()
    Else:
        i++
```

Fig. 4.5 Heuristic Algorithm for current work

CHAPTER 5

Implementation and Results

5.1 Objectives of the Exercise

The study of scheduling with setup time and release time for the cold forging organization has the following objectives

1. Minimize time
2. Maximize output
3. Minimize number of setups both monthly and annually
4. Release dates
5. Improved lot sizing

The study of machine scheduling in the organization can reduce the setup time not by any algorithm. There are many variables like cost of buying the raw materials, overhead charges, competitive selling price, making charges, investment on tools and die, weight of the part, burden of setup time and number of setups, delay in payment by customers, delay of arrival of raw material from suppliers etc.

The setup time reduction depends on multiple factors and the implementation of suggestions given in chapter-4 helps the reduce the annual setups.

5.2 Implementation of Modified Lot sizing

Modified Lot sizing formula for the organization helps in keeping a tight inventory. The total setups are reduced and the total average inventory units are increased. The change lot size of parts are also attributed to the monthly demand and lead times of the parts.

The customer are given priority as P1,P2,P3,P4 given in **fig.5.2**. The customer who places demand every month are placed in P1. The customers who places orders once in 2-3 months are given P2. The customers who place orders once in six months are considered P3. The customers P4 category are very rare and place orders once in a year or may not turn back again.

5.3 Reducing the annual setups

The parts are chosen according to family of raw materials. The complementary parts are identified and the number of setups annually are brought to half.

The setup times are directly proportional to the number of times its done monthly / annually.

The chart fig. 5.3 shows the number of setups reduced for the parts. For some parts who belong to P3 are not possible to reduce the annual setups. The inventory will be burdened if the modified lot size formula is applied for P3 and P4 category.

5.4 Softwares for production

- SAP
- Oracle Corporation
- SAP for SME's
- R for Data Analysis and statistics
- Phython for Data Analysis

5.5 Conclusion

The study on scheduling with setup and release time is based on sequence dependent family setup time. The current machine utilization of machine is improved by reducing the setup time. The factors related to setup time are analyzed along with inventory control.

The study results in improving the overall availability of parts and reduce the number of setups annually. The finished goods inventory consumption value is less than 3 which justifies that the parts produced in one batch are consumed in the same quarter. The parts availability is improved and machine utilization is increased to 10 percentage.

5.6 Future Study

The study at the SME for fasteners manufacturing has lot of scope for improvement. There are many variables like weight of product, demand forecasting, selling price, profit etc with objective to find the optimal number of setups and lot sizing. The work can be made into a Linear Programming Problem and the results will be compared to real time implementation.

Product	Customer	Batch Size	ImprovedBatch Size
15mm Shaft	['Hydraulics & Engineering']	16710	284070
ALL20-16203	['SIMCO Industrial Engg Pvt Ltd']	710	12070
Ace PIN	['Jwarner Industries Pvt Ltd']	28670	487390
Bolt 12mm	['Jwarner Industries Pvt Ltd']	140	2380
Bolt 8mm	['Jwarner Industries Pvt Ltd']	105860	1799620
Bolt Lock	['Jwarner Industries Pvt Ltd']	36240	616080
Capstain Screw	['KK Press' , 'Continental Pressings']	37670	640390
Collar Screw 1/2"	['Pivot Engineers']	14170	240890
Collar Screw 3/8"	['Pivot Engineers']	14060	239020
Collar Screw 5/8 UNC -1.25	['Pivot Engineers']	2080	35360
Collar Screw 5/8 UNC -1.5	['Pivot Engineers']	3330	56610
Collar Screw 5/8 X 1.25	['Pivot Engineers']	1280	21760
Collar Screw 5/8"	['Pivot Engineers']	6340	107780
Cot Gear Pin	['Ray Tools & Dies Pvt LTd']	42650	725050
Free Wheel Joint	['IMTC Pvt Ltd']	690	11730
Gee Bolt- 25	['PayGay Industries']	12710	216070
Gen Shaft 13684	['SIMCO Industrial Engg Pvt Ltd']	37570	638690
Link Bolt	['Jwarner Industries Pvt Ltd']	0	0
M12 Bolt GEE	['PayGay Industries']	4210	71570
M12 Coach Bolt	['Paroca Fasteners Pvt Ltd']	10090	171530
M12X1.25X30HHB	['PayGay Industries', 'Arco Wind energies	101030	1717510

Fig. 5.1 Modified lot sizing

SL NO	Product	New Company	Wire Grade	Wrie Size	No: Stations	Annual Prodn Qty	Monthly Consumption	Likely No Production Batches in the year	Lead time for Purchase (days)	Purchase Rate per ton (Rs)		Carry Cost p orde
1	PSE Bolt	M S Exports	SAE4140	10.60/10.65mm	4	20000		1	45	72,800	72.80	
2	Push Stroke Rod	Hi Beam Electricals			5	120000	10000	12	45	65,000	65.00	
3	M12X1.25X30HHE	PayGay Indust	10B21	10.60/10.65mm	5	180000	15000	12	30	67,000	67.00	
4	1/2 UNC X 1" Flan	Pivot Engineer	SAE4140	12.60/12.65mm	5	120000	10000	4	45	72,800	72.80	
5	1/2 UNC X 1.25" F	Pivot Engineer	SAE4140	12.60/12.65mm	5	80000	7000	3	45	72,800	72.80	
6	Collar Screw 1/2"	Pivot Engineer	SAE4140	12.60/12.65mm	5	NA			45	72,800	72.80	
7	1/2" Flange Screw	Pivot Engineer	SAE4140	12.60/12.65mm	5	120000	10000	4	45	72,800	72.80	
8	Rivet 16mm	Bridge Forgers	SAE1018	13.70/13.75mm	2	60000	5000	3	30	57,000	57.00	
9	15mm Shaft	Hydraulics & E	SAE1010	19.90/19.95mm	4	NA			30	57,000	57.00	
10	Collar Screw 3/8"	Pivot Engineer	SAE4140	9.70/9.75mm	5	30000	2500	3	45	72,800	72.80	
11	Collar Screw 5/8"	Pivot Engineer	SAE4140	15.60/15.65mm	5	NA			45	72,800	72.80	
12	Collar Screw 5/8 U	Pivot Engineer	SAE4140	15.60/15.65mm	5	24000	2000	3	45	72,800	72.80	
13	Collar Screw 5/8 X	Pivot Engineer	SAE4140	15.60/15.65mm	5	NA			45	72,800	72.80	
14	5/8"UNFX35HHS	Fit Tight Indus	EN8D	15.60/15.65mm	4	NA			35	67,000	67.00	
15	S00-2100 Shaft	Shastra Engg P	EN8D	15.60/15.65mm	4	NA			35	67,000	67.00	
16	S00-2100 - HL Sha	Shastra Engg P	EN8D	15.60/15.65mm	4	120000	10000	6	35	67,000	67.00	
17	AL Stag	Kovai Automot	16MnCr5H	21.70/21.75mm	4	100000	8000	4	35	65,900	65.90	1
18	ALV20-16203	SIMCO Industr	16MnCr5H	21.70/21.75mm	4	72000	6000	12	35	65,900	65.90	
19	ALL20-16203	SIMCO Industr	16MnCr5H	18.85/18.90mm	4	72000	6000	12	35	65,900	65.90	
20	PAC-183526	Zenith Industri	SAE1010	9.95/9.98mm	4	120000	10000	7	30	57,000	57.00	
21	Release Screw	Perfect Engg P	SAE4140	9.70/9.75mm	4	60000	5000	6	45	72,800	72.80	

Fig. 5.2 Part Analysis

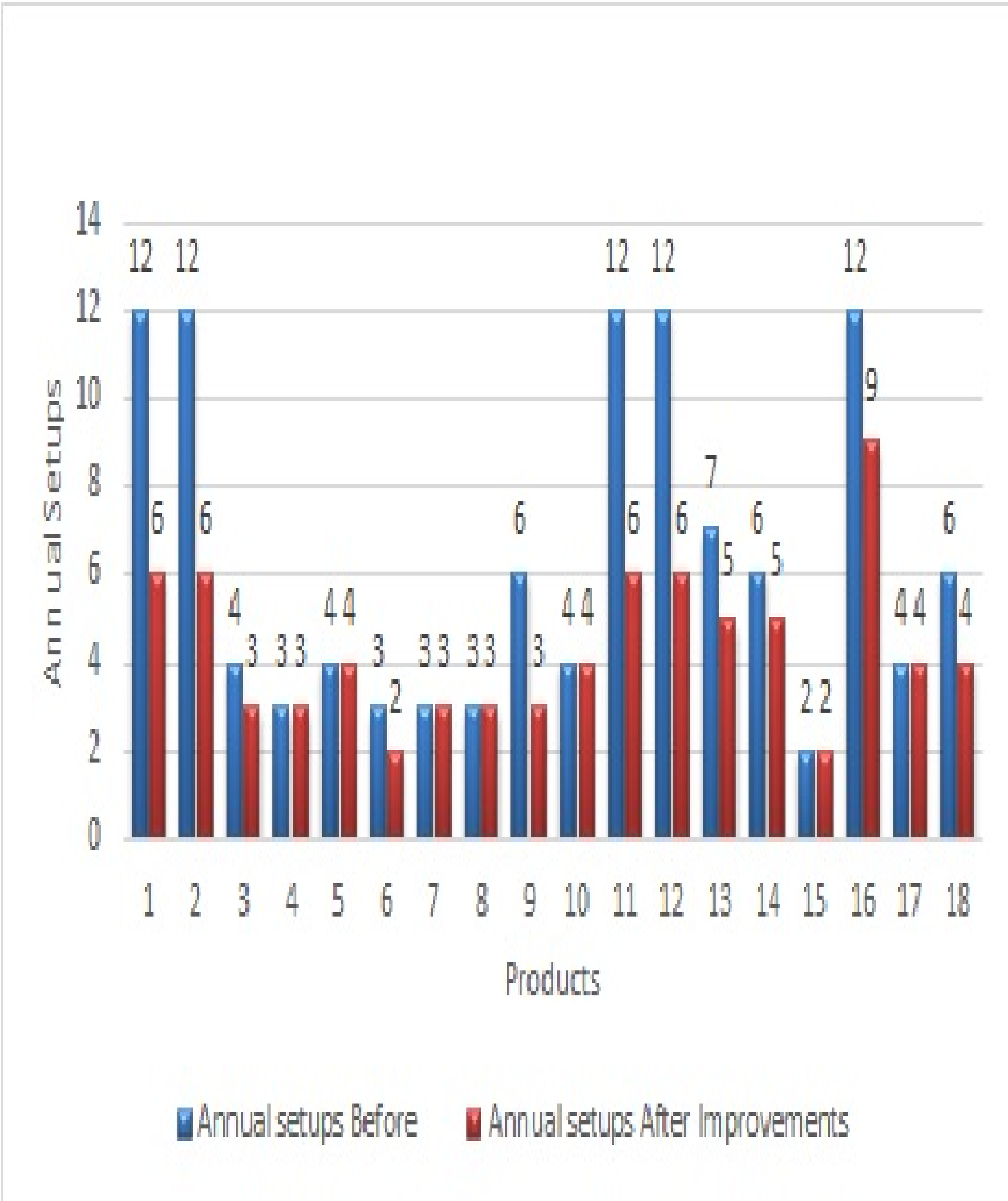

Fig. 5.3 Chart for Number of Annual Setups

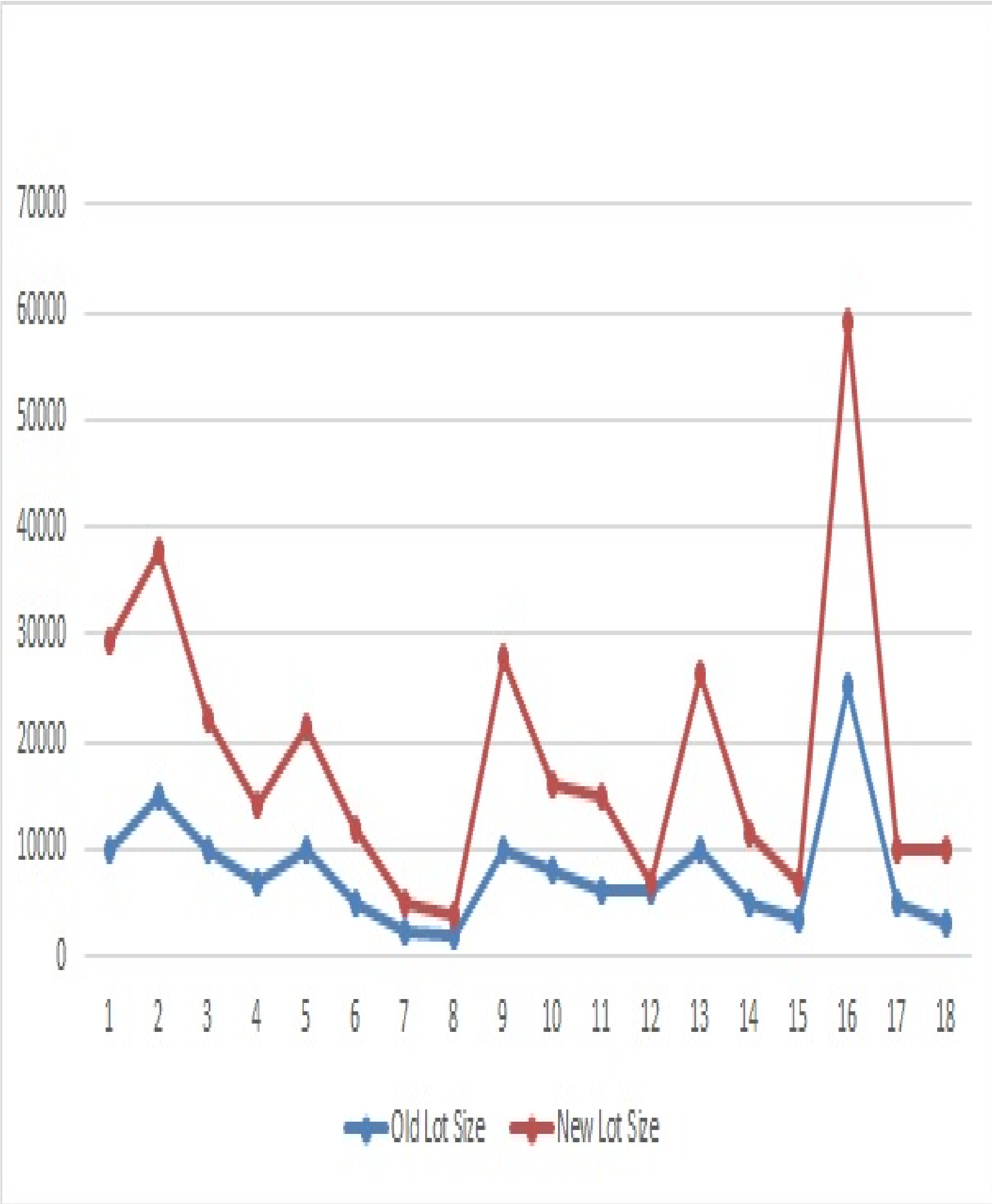

Fig. 5.4 Chart of Lot sizing

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LIST OF PUBLICATIONS

1. (Ananta Praveen Kumar MVR 2017) Ananta Praveen Kumar MVR,David Maxim Gururaj, S.Hariharan. SINGLE-MACHINE SCHEDULING WITH RELEASE DATES AND FAMILY SETUP TIMES. International Journal of Pure and Applied Mathematics, Volume 114 No. 6, 2017, 235 - 239

Appendices

Appendix A

Sample Python and R Code

Sample Python Code for Data Manipulation

```
import pandas as pd


df = pd.read_excel("D:\job_scheduling\data.xlsx")

df = df.iloc[:,[0,1,5,6,7,9,10,11,12,13,15,16,17,18,19,20,21,22,23,2

#df = df[:10]

df.fillna(0, inplace = True)

df = df[df.Product != 0]

df = df.reset_index(drop=True)

products = df.Product.unique()

products = [str(x) for x in products if str(x) != ’nan’]

i = 0

df1 = pd.DataFrame()

job_ctime = 0

prodn_time = 0

coil_ctime = 0

break_time = 0

qty = 0

prodn_wt = 0
```

```
for index, row in df.iterrows():
#print row['Product']
if index != (len(df)-1):
#print df.Product[index+1]
prod1 = row['Product']
prod2 = df.Product[index+1]
if prod1 == prod2:
job_ctime += row['Job Change (mins)']
prodn_time += row['Prodn Time (Mins)']
coil_ctime += row['Coil Change Time (Mins)']
break_time += row['Tool Breakage/Rework Time (Mins)']
qty += row['Qty Produced (Nos)']
prodn_wt += row['Total Production Weight (kgs)']
else:
df1.loc[i,'Finishing Date'] = row['Date']
df1.loc[i,'Product'] = prod1
df1.loc[i,'Raw Material'] = row['Raw Material']
df1.loc[i,'Setup'] = row['Setup']
df1.loc[i,'Customer'] = row['Customer']
qty += row['Qty Produced (Nos)']
job_ctime += row['Job Change (mins)']
prodn_time += row['Prodn Time (Mins)']
coil_ctime += row['Coil Change Time (Mins)']
break_time += row['Tool Breakage/Rework Time (Mins)']
```

```
prodn_wt += row['Total Production Weight (kgs)']

df1.loc[i,'Qty Produced (Nos)'] = qty

df1.loc[i,'Job Change (mins)'] = job_ctime

df1.loc[i,'Prodn Time (Mins)'] = prodn_time

df1.loc[i,'Coil Change Time (Mins)'] = coil_ctime

df1.loc[i,'Tool Breakage/Rework Time (Mins)'] = break_time

df1.loc[i,'Total Production Weight (kgs)'] = prodn_wt

df1.loc[i,'Qty Produced (Nos)'] = qty

df1.loc[i,'Job Change (mins)'] = job_ctime

df1.loc[i,'Prodn Time (Mins)'] = prodn_time

df1.loc[i,'Coil Change Time (Mins)'] = coil_ctime

df1.loc[i,'Tool Breakage/Rework Time (Mins)'] = break_time

df1.loc[i,'Total Production Weight (kgs)'] = prodn_wt

df1.loc[i,'Qty Produced (Nos)'] = qty

df1.loc[i,'Job Change (mins)'] = job_ctime

df1.loc[i,'Prodn Time (Mins)'] = prodn_time

df1.loc[i,'Coil Change Time (Mins)'] = coil_ctime

df1.loc[i,'Tool Breakage/Rework Time (Mins)'] = break_time

df1.loc[i,'Total Production Weight (kgs)'] = prodn_wt

df1.loc[i,'Qty Produced (Nos)'] = qty

df1.loc[i,'Job Change (mins)'] = job_ctime

df1.loc[i,'Prodn Time (Mins)'] = prodn_time

df1.loc[i,'Coil Change Time (Mins)'] = coil_ctime

df1.loc[i,'Tool Breakage/Rework Time (Mins)'] = break_time
```

```
df1.loc[i,'Total Production Weight (kgs)'] = prodn_wt
job_ctime = 0
prodn_time = 0
coil_ctime = 0
break_time = 0
qty = 0
i += 1
df1.loc[i,'Product'] = prod1
df1.loc[i,'Raw Material'] = row['Raw Material']
df1.loc[i,'Setup'] = row['Setup']
df1.loc[i,'Finishing Date'] = row['Date']
df1.loc[i,'Customer'] = row['Customer']
qty += row['Qty Produced (Nos)']
job_ctime += row['Job Change (mins)']
prodn_time += row['Prodn Time (Mins)']
coil_ctime += row['Coil Change Time (Mins)']
break_time += row['Tool Breakage/Rework Time (Mins)']
prodn_wt += row['Total Production Weight (kgs)']
df1.loc[i,'Qty Produced (Nos)'] = qty
df1.loc[i,'Job Change (mins)'] = job_ctime
df1.loc[i,'Prodn Time (Mins)'] = prodn_time
df1.loc[i,'Coil Change Time (Mins)'] = coil_ctime
df1.loc[i,'Tool Breakage/Rework Time (Mins)'] = break_time
df1.loc[i,'Total Production Weight (kgs)'] = prodn_wt
```

```
df1.loc[i,'Product'] = prod1
df1.loc[i,'Raw Material'] = row['Raw Material']
df1.loc[i,'Setup'] = row['Setup']
df1.loc[i,'Finishing Date'] = row['Date']
df1.loc[i,'Customer'] = row['Customer']
qty += row['Qty Produced (Nos)']
job_ctime += row['Job Change (mins)']
prodn_time += row['Prodn Time (Mins)']
coil_ctime += row['Coil Change Time (Mins)']
break_time += row['Tool Breakage/Rework Time (Mins)']
prodn_wt += row['Total Production Weight (kgs)']
df1.loc[i,'Qty Produced (Nos)'] = qty
df1.loc[i,'Job Change (mins)'] = job_ctime
df1.loc[i,'Prodn Time (Mins)'] = prodn_time
df1.loc[i,'Coil Change Time (Mins)'] = coil_ctime
df1.loc[i,'Tool Breakage/Rework Time (Mins)'] = break_time
df1.loc[i,'Total Production Weight (kgs)'] = prodn_wt
writer = pd.ExcelWriter("D:/job_scheduling/combine_data.xlsx")
df1.to_excel(writer)
```

Sample R code for Data Extraction

```
df_parts=read.csv(file.choose(),header = TRUE)

View(df_parts)

df_family=table(df_parts$Wrie.Size)

View(df_family)

savehistory("~/his_5-13-2017.Rhistory")

write.csv(df_family,df_family.csv)

write.csv(df_family,file="df_family.csv")

df_parts=read.csv(file.choose(),header = TRUE)

View(final_data)


sort_parts=final_data[order(final_data$Product),]

View(sort_parts)

write.csv(file="sort_parts.csv")

write.csv(sort_parts,file="sort_parts.csv",row.names = TRUE)

final_data=read.csv(file.choose(),header=true)

final_data=read.csv(file.choose(),header = TRUE)

sort_parts=final_data[order(final_data$Product),]

wire_size=table(final_data$WireSize)

View(wire_size)

shift_df=table(final_data$Shift)

View(shift_df)

final_data=final_data[-c("Deepavali Holiday","Sunday Holiday"),]

final_data=final_data['Sunday Holiday',]
```

```
final_data=read.csv(file.choose(), header = TRUE)
View(final_data)
pro_qty=final_data[Product, Setup,"QtyProducedNos"]
pro_qty=final_data["Product", "Setup","QtyProducedNos"]
pro_qty=final_data[,"Product", "Setup","QtyProducedNos"]
sort_parts=final_data[order(final_data$Product),]
View(sort_parts)
write.csv(file="sort_parts.csv")
write.csv(sort_parts,file="sort_parts.csv",row.names = TRUE)
final_data=read.csv(file.choose(),header=true)
final_data=read.csv(file.choose(),header = TRUE)
sort_parts=final_data[order(final_data$Product),]
wire_size=table(final_data$WireSize)
View(wire_size)
shift_df=table(final_data$Shift)
View(shift_df)
sort_parts=final_data[order(final_data$Product),]
View(sort_parts)
write.csv(file="sort_parts.csv")
write.csv(sort_parts,file="sort_parts.csv",row.names = TRUE)
final_data=read.csv(file.choose(),header=true)
final_data=read.csv(file.choose(),header = TRUE)
sort_parts=final_data[order(final_data$Product),]
wire_size=table(final_data$WireSize)
```

```
View(wire_size)

shift_df=table(final_data$Shift)

View(shift_df)

final_data=final_data[-c("Deepavali Holiday","Sunday Holiday"),]

final_data=final_data['Sunday Holiday',]

final_data=read.csv(file.choose(), header = TRUE)

View(final_data)

pro_qty=final_data[Product, Setup,"QtyProducedNos"]

pro_qty=final_data["Product", "Setup","QtyProducedNos"]

pro_qty=final_data[,"Product", "Setup","QtyProducedNos"]

final_data=final_data[-c("Deepavali Holiday","Sunday Holiday"),]

final_data=final_data['Sunday Holiday',]

final_data=read.csv(file.choose(), header = TRUE)

View(final_data)

pro_qty=final_data[Product, Setup,"QtyProducedNos"]

pro_qty=final_data["Product", "Setup","QtyProducedNos"]

pro_qty=final_data[,"Product", "Setup","QtyProducedNos"]

write.csv(shift_df,file="shift_df.csv",row.names = TRUE)

View(df1516)

shift_df=table(df1516$Shift)

View(shift_df)

wirte.csv(shift_df,file="shift_df.csv",row.names=TRUE)

wrIte.csv(shift_df,file="shift_df.csv",row.names=TRUE)

write.csv(shift_df,file="shift_df.csv",row.names=TRUE)
```

```
pro=df1516(,c("Product","Customer","Raw.Material,"Qty.Produced(Nos)"
pro=df1516(,c("Product","Customer","Raw.Material,"Qty.Produced(Nos)"
pro=df1516(,c("Product","Customer","Raw.Material","Qty.Produced(Nos)
View(df1516)
pro=df1516(,c("Product","Customer","Raw.Material","Qty.Produced(Nos)
pro=df1516[],c("Product","Customer","Raw.Material","Qty.Produced(Nos
pro=df1516[,c("Product","Customer","Raw.Material","Qty.Produced(Nos)
pro=df1516[,c("Product","Customer","Raw.Material","Qty.Produced(Nos)
pro=subset(df1516,select = ("Product","Customer","Raw.Material","Qty
prod=data.frame(df1516$Product,df1516$Setup,df1516$Customer,df1516$R
prod=data.frame(df1516$Product,df1516$Setup,df1516$Customer,df1516$R
write.csv(prod,file = "prod_df.csv",row.names = TRUE)
prod_all=table(df1516$Product)
View(prod_all)
write.csv(prod_all,file="prod_all.csv",row.names = TRUE)
cust_all=table(df1516$Customer)
write.csv(cust_all,file="cust_all.csv",row.names = TRUE)
raw_all=table(df1516$Raw.Material)
write.csv(raw_all,file="raw_all.csv",row.names = TRUE)
colnames(df1516)
colna_df=colnames(df1516)
View(colna_df)
```

Appendix B

Snapshot of Raw Data from Excel sheet

Date	Day	Month	Activity	Shift	Operator	Product	Setup	Customer	Speed d/min	Raw Material	Qty Produced (Nos)	Qty Accepted (Nos)	Qty Rejected (Nos)	Setting Sample	Prodn Weight per unit (kgs)	Total Production Weight (kgs)	Job Change (mins)	Prod n Time (Mins)	Coil Change Time (Min	Tool Breakage/Rework Time	Waiting for Tools (Min	Waiting for RM (Mi	Waiting for Manpower (Mins)
1-Apr-15	Wed	Apr	Mfg	09:00 hrs - 18	Dhanas	PIN-20051	PIN-20051 Set	Ray Tools	50	SAE414	0	0	0	0	**0.0728**	-	60	-	-	-	-	-	-
1-Apr-15	Wed	Apr	Mfg	09:00 hrs - 18	Dhanas	Pip Screw	Pip Screw Set	Hi Beam E	45	10B21-!	3750	3730	20	27	**0.0112**	**42.00**	120	83	-	30	-	-	-
2-Apr-15	Thu	Apr	Mfg	09:00 hrs - 19	Dhanas	PIN-20051	PIN-20051 Set	Ray Tools	50	SAE414	8020	8000	20	0	**0.0728**	**583.86**	150	160	-	180	-	-	-
3-Apr-15	Fri	Apr	Mfg	09:00 hrs - 19	Muruge	PAC-183526	PAC-183526 S	Zenith Inc	50	SAE101	0	0	0	0	**0.0712**	-	360	-	-	-	-	-	-
3-Apr-15	Fri	Apr	Mfg	09:00 hrs - 19	Muruge	PIN-20051	PIN-20051 Set	Ray Tools	46	SAE414	10210	10200	10	0	**0.0728**	**743.29**		222	30	-	-	-	-
4-Apr-15	Sat	Apr	Mfg	09:00 hrs - 18	Muruge	15mm Shaft	15mm Shaft S	Hydraulics & En		SAE101	0	0	0				210		-	-	-	-	-
4-Apr-15	Sat	Apr	Mfg	09:00 hrs - 18	Muruge	PAC-183526	PAC-183526 S	Zenith Inc	50	SAE101	14457	14457	0	0	**0.0710**	**1,026.45**	30	289	60	-	-	-	-
5-Apr-15	Sun	Apr		Sunday Holiday														-					
6-Apr-15	Mon	Apr	Dev	09:00 hrs - 19	Muruge	15mm Shaft	15mm Shaft S	Hydraulics & En		SAE101	50	50	0	15	**0.2380**	**11.90**	390	-	-	120	-	-	-
7-Apr-15	Tue	Apr	Dev	09:00 hrs - 19	Muruge	15mm Shaft	15mm Shaft S	Hydraulics & En		SAE101	30	30	0	10	**0.2380**	**7.14**	30	-					
8-Apr-15	Wed	Apr	Dev	09:00 hrs - 19	Muruge	15mm Shaft	15mm Shaft S	Hydraulic	35	SAE101	625	625	0	0	**0.2380**	**148.75**	120	18	30	150			
8-Apr-15	Wed	Apr	Dev	09:00 hrs - 19	Muruge	15mm Shaft	15mm Shaft S	Hydraulics & En		SAE1010-21.70/21.75mm							180						
9-Apr-15	Thu	Apr	Dev	09:00 hrs - 19	Muruge	15mm Shaft	15mm Shaft S	Hydraulic	35	SAE101	3805	3805	0	10	**0.2450**	**932.23**	90	109	60	90			
9-Apr-15	Thu	Apr	Mfg	09:00 hrs - 19	Muruge	Pick Rod	Pick Rod Setu	Chennai Reprog		EN8D-1	0	0	0			-	240						
10-Apr-15	Fri	Apr	Mfg	09:00 hrs - 18	Muruge	Pick Rod	Pick Rod Setu	Chennai Reprog		EN8D-1	0	0	0	50	**0.0880**	-	180		-	90	-	-	-
11-Apr-15	Sat	Apr	Mfg	09:00 hrs - 19	Muruge	M8X15X1.5 Screw	M8X15X1.5 Sc	Balakrishi	55	SAE414	0	0	0	20	**0.0134**	-	300	-	-	-	-	-	-
11-Apr-15	Sat	Apr	Mfg	09:00 hrs - 19	Muruge	Pick Rod	Pick Rod Setu	Chennai Reprog		EN8D-1	0	0	0	130	**0.0880**	-	270		-	-	-	-	-
12-Apr-15	Sun	Apr	Mfg	09:00 hrs - 18	Muruge	M8X15X1.5 Screw	M8X15X1.5 Sc	Balakrishi	55	SAE414	1250	1250	0	15	**0.0134**	**16.75**	210	23	-	270	-	-	-

Fig. B.1 Data screen shot for April Month

Date	Day	Month	Activity	Shift	Operator	Product	Setup	Customer	Speed/mi	Raw Material	Qty Produced (Nos)	Qty Accepted (Nos)	Qty Rejected (Nos)	Setting Sample (Nos)	Prodn Weight per unit (kgs)	Total Production Weight (kgs)	Job Change (mins)	Prodn Time (Mins)
1-May-15	Fri	May		May day Holiday														
2-May-15	Sat	May	Mfg	06:00 hrs - 17:30	Murugesan	Stopper	Stopper Se	Hi Beam El	50	SAE1018-13.70/13.75mm	13670	13670	0	0	**0.0670**	**915.89**		273
3-May-15	Sun	May		Sunday Holiday														
4-May-15	Mon	May	Dev	06:00 hrs - 19:00	Murugesan	Ace PIN	Ace PIN Se	Jwarner In	50	SAE1018-13.70/13.75mm	5850	5850	0	10	**0.0470**	**274.95**	240	117
5-May-15	Tue	May	Mfg	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work					**0.0580**	-	480	-
6-May-15	Wed	May	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	0	0	0	20	**0.0580**	-	480	-
7-May-15	Thu	May	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	9200	9200	0	40	**0.0580**	**533.60**	90	184
8-May-15	Fri	May	Job	09:00 hrs - 18:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	21900	21900	0	10	**0.0580**	**1,270.20**		438
9-May-15	Sat	May	Dev	09:00 hrs - 17:30	Murugesan	Release Scre	Release Sc	Perfect En	45	SAE4140-9.70/9.75mm	0	0	0	15	**0.0470**	-	360	-
10-May-15	Sun	May		Sunday Holiday														
11-May-15	Mon	May	Dev	09:00 hrs - 17:30	Murugesan	Release Scre	Release Sc	Perfect En	45	SAE4140-9.70/9.75mm	0	0	0	20	**0.0470**	-	270	
12-May-15	Tue	May	Dev	09:00 hrs - 17:30	Murugesan	Release Scre	Release Sc	Perfect En	45	SAE4140-9.70/9.75mm	170	160	10	0	**0.0470**	**7.99**	90	4
12-May-15	Tue	May	Mfg	09:00 hrs - 17:30	Murugesan	Plain Shaft	Plain Shaft	SIMCO Ind	45	16MnCr5H-17.80/17.85mn	0	0	0	0	**0.1860**	-	120	-
13-May-15	Wed	May	Mfg	09:00 hrs - 17:30	Murugesan	Plain Shaft	Plain Shaft	SIMCO Ind	45	16MnCr5H-17.80/17.85mn	9210	9200	10	0	**0.1860**	**1,713.06**	150	205
13-May-15	Wed	May	Dev	09:00 hrs - 17:30	Murugesan	Pinion Rod	Pinion Roc	Jwarner In	45	SAE1010-13.70/13.75mm	0	0	0	0	**0.0695**	-	90	
14-May-15	Thu	May	Dev	09:00 hrs - 17:30	Murugesan	Pinion Rod	Pinion Roc	Jwarner In	45	SAE1010-13.70/13.75mm	0	0	0	0	**0.0695**	-	360	-
15-May-15	Fri	May	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	Hi Beam El	40	10B21-9.70/9.75mm					-	-	120	-
15-May-15	Fri	May	Dev	09:00 hrs - 17:30	Murugesan	Pinion Rod	Pinion Roc	Jwarner In	45	SAE1010-13.70/13.75mm	150	150	0	60	**0.0695**	**10.43**	300	3

Fig. B.2 Data screen shot for May Month

Date	Day	Month	Activity	Shift	Operator	Product	Setup	Customer	Speed/mi	Raw Material	Qty Produced (Nos)	Qty Accepted (Nos)	Qty Rejected (Nos)	Setting Sample (Nos)	Prodn Weight per unit (kgs)	Total Production Weight (kgs)	Job Change (mins)	Prodn Time (Mins)
1-Jun-15	Mon	Jun	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	300	300	0	25	**0.0575**	**17.25**	210	6
2-Jun-15	Tue	Jun	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	3600	3600	0	20	**0.0575**	**207.00**	210	72
3-Jun-15	Wed	Jun	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	19100	19100	0	0	**0.0575**	**1,098.25**	-	382
4-Jun-15	Thu	Jun	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	18500	18500	0	0	**0.0575**	**1,063.75**		370
5-Jun-15	Fri	Jun	Mfg	09:00 hrs - 17:30	Murugesan	Ace PIN	Ace PIN Se	Jwarner In	50	SAE1018-13.70/13.75mm	0	0	0	0	**0.0470**	**-**	300	-
5-Jun-15	Fri	Jun	Job	09:00 hrs - 17:30	Murugesan	Stud 18mm	Stud 18mn	Precision I	50	Job Work	3000	3000	0	0	**0.0575**	**172.50**		60
6-Jun-15	Sat	Jun	Mfg	09:00 hrs - 17:30	Murugesan	Ace PIN	Ace PIN Se	Jwarner In	50	SAE1018-13.70/13.75mm	10850	10850	0	20	**0.0470**	**509.95**	60	217
6-Jun-15	Sat	Jun	Mfg	09:00 hrs - 17:30	Murugesan	PIN-20051	PIN-20051	Ray Tools (	50	SAE4140-13.70/13.75mm			0			**-**	180	-
8-Jun-15	Mon	Jun	Mfg	09:00 hrs - 17:30	Murugesan	PIN-20051	PIN-20051	Ray Tools (	45	SAE4140-13.70/13.75mm	150	150	0	17	**0.0735**	**11.03**	120	3
9-Jun-15	Tue	Jun	Mfg	09:00 hrs - 17:30	Murugesan	PIN-20051	PIN-20051	Ray Tools (	50	SAE4140-13.70/13.75mm	14550	14550	0	5	**0.0735**	**1,069.43**		291
10-Jun-15	Wed	Jun	Mfg	09:00 hrs - 17:30	Murugesan	PIN-20051	PIN-20051	Ray Tools (	50	SAE4140-13.70/13.75mm	5968	5968	0	0	**0.0735**	**438.65**		119
10-Jun-15	Wed	Jun	Mfg	09:00 hrs - 17:30	Murugesan	Pinion Rod	Pinion Roc	Jwarner In	45	SAE1018-13.70/13.75mm	320	300	20	0	**0.0700**	**22.40**	330	7
11-Jun-15	Thu	Jun	Dev	09:00 hrs - 17:30	Dhanasekar	Link Bolt	Link Bolt S	Jwarner Indus		SAE1018-13.70/13.75mm	0	0	0	0	**0.0800**	**-**	90	
11-Jun-15	Thu	Jun	Dev	09:00 hrs - 17:30	Dhanasekar	Pinion Rod	Pinion Roc	Jwarner In	45	SAE1018-13.70/13.75mm	830	810	20	0	**0.0700**	**58.10**	90	18
12-Jun-15	Fri	Jun	Dev	09:00 hrs - 17:30	Dhanasekar	Link Bolt	Link Bolt S	Jwarner Indus		SAE1018-13.70/13.75mm	0	0	0	20	**0.0800**	**-**	420	
13-Jun-15	Sat	Jun	Dev	09:00 hrs - 17:30	Dhanasekar	Bolt 12mm	Bolt 12mm	Jwarner Indus		SAE4135-10.60/10.65mm	0	0	0	15	**0.0280**	**-**	210	
14-Jun-15	Sun	Jun		Sunday Holiday														
15-Jun-15	Mon	Jun	Dev	09:00 hrs - 17:30	Murugesan	Bolt 12mm	Bolt 12mm	Jwarner Indus		SAE4135-10.60/10.65mm	0	0	0	40	**0.0280**	**-**	240	

Fig. B.3 Data screen shot for June Month

Date	Day	Month	Activity	Shift	Operator	Product	Setup	Setting Sample (Nos)	Prodn Weight per unit (kgs)	Total Production Weight (kgs)	Job Change (mins)	Prodn Time (Mins)	Coil Change Time (Mins)	Tool Breakage /Rework Time (Mins)	Wating for Tools (Mins)	Waiting for RM (Mins)	Waiting for Manpower (Mins)	Wating for Approval (Mins)	RM Problem (Mins)
1-Jul-15	Wed	Jul	Mfg	09:00 hrs - 18:30	Murugesan	Collar Screw	Collar Scre	7	**0.0745**	**7.67**	270	3		120	30				
2-Jul-15	Thu	Jul	Mfg	09:00 hrs - 18:00	Murugesan	Collar Screw	Collar Scre	27	**0.0745**	**558.75**	180	188		150	-				
3-Jul-15	Fri	Jul	Dev	09:00 hrs - 17:30	Murugesan	15mm Shaft	15mm Sha	9	**0.2420**	-	300	-	30	-					
3-Jul-15	Fri	Jul	Mfg	09:00 hrs - 17:30	Murugesan	Collar Screw	Collar Scre	27	**0.0745**	-		-			60				
4-Jul-15	Sat	Jul	Dev	09:00 hrs - 17:30	Murugesan	15mm Shaft	15mm Sha	20	**0.2420**	**58.08**	300	6		120				30	
5-Jul-15	Sun	Jul		Sunday Holiday															
6-Jul-15	Mon	Jul		Power Holiday															
7-Jul-15	Tue	Jul	Dev	09:00 hrs - 17:30	Murugesan	15mm Shaft	15mm Sha	20	**0.2420**	**21.78**	180	2	30	210					
8-Jul-15	Wed	Jul	Dev	09:00 hrs - 17:30	Murugesan	15mm Shaft	15mm Sha	20	**0.2420**	**101.64**	150	11	30	150					
9-Jul-15	Thu	Jul	Dev	09:00 hrs - 17:30	Murugesan	15mm Shaft	15mm Sha	20	**0.2400**	**388.80**	180	41		120					30
10-Jul-15	Fri	Jul	Dev	09:00 hrs - 17:30	Murugesan	15mm Shaft	15mm Sha	10	**0.2400**	**482.40**	30	50		90					
10-Jul-15	Fri	Jul	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	0	**0.0112**	-	120	-							
11-Jul-15	Sat	Jul	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	40	**0.0112**	-	300	-	-	150	-	-	-	-	-
12-Jul-15	Sun	Jul	Dev	Sunday Holiday						-		-							
13-Jul-15	Mon	Jul	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	53	**0.0112**	**15.12**	30	30		480					
14-Jul-15	Tue	Jul	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	23	**0.0112**	**40.54**		80		310	60				
15-Jul-15	Wed	Jul	Mfg	09:00 hrs - 17:30	Murugesan	PAC-183526	PAC-18352		**0.0712**	-	30	-	30						
15-Jul-15	Wed	Jul	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	7	**0.0112**	**118.05**		234		120					

Fig. B.4 Data screen shot for July Month

Date	Day	Month	Activity	Shift	Operator	Product	Setup	Prodn Time (Mins)	Coil Change Time (Mins)	Tool Breakage /Rework Time (Mins	Wating for Tools (Mins)	Waiting for RM (Mins)	Waiting for Manpower (Mins	Wating for Approval (Mins)	RM Problem (Mins)	FG Problem (Mins)	Power Outage (Mins)	Main Machine Down time (Mins	Other Machine Down time (Mins
1-Aug-15	Sat	Aug	Mfg	Power Holiday															
2-Aug-15	Sun	Aug	Mfg	06:00 hrs - 14:30	Murugesan	Pick Rod	Pick Rod S	76	30	270					90				
3-Aug-15	Mon	Aug	Mfg	09:00 hrs - 17:30	Murugesan	Pick Rod	Pick Rod S	-		240									
3-Aug-15	Mon	Aug	Mfg	09:00 hrs - 17:30	Murugesan	S00-2100 Sha	S00-2100 S	-	30										
4-Aug-15	Tue	Aug	Mfg	09:00 hrs - 17:30	Murugesan	S00-2100 Sha	S00-2100 S	160	30	120									
5-Aug-15	Wed	Aug	Mfg	09:00 hrs - 17:30	Murugesan	M12 Coach B	M12 Coach	-											
5-Aug-15	Wed	Aug	Mfg	09:00 hrs - 17:30	Murugesan	S00-2100 Sha	S00-2100 S	164	60	90									
6-Aug-15	Thu	Aug	Mfg	09:00 hrs - 17:30	Murugesan	M12 Coach B	M12 Coach	4						30	210				
6-Aug-15	Thu	Aug	Mfg	09:00 hrs - 17:30	Murugesan	M12 Coach B	M12 Coach	73	30										
7-Aug-15	Fri	Aug	Mfg	09:00 hrs - 17:30	Murugesan	M12 Coach B	M12 Coach	89									90		
7-Aug-15	Fri	Aug	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw		60		30								
8-Aug-15	Sat	Aug	Dev	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw			30									
8-Aug-15	Sat	Aug	Dev	09:00 hrs - 17:30	Murugesan	Pinion Rod	Pinion Roc	-											
9-Aug-15	Sun	Aug		Sunday Holiday															
10-Aug-15	Mon	Aug	Dev	09:00 hrs - 17:30	Murugesan	Link Bolt	Link Bolt S			90									
10-Aug-15	Mon	Aug	Dev	09:00 hrs - 17:30	Murugesan	Pinion Rod	Pinion Roc	121	30										
11-Aug-15	Tue	Aug	Dev	09:00 hrs - 17:30	Murugesan	Bolt Lock	Bolt Lock S	-											
11-Aug-15	Tue	Aug	Dev	09:00 hrs - 17:30	Murugesan	Link Bolt	Link Bolt S			240						60			

Fig. B.5 Data screen shot for August Month

Date	Day	Month	Activity	Shift	Operator	Product	Setup	Prodn Time (Mins)	Coil Change Time (Mins)	Tool Breakage /Rework Time (Mins	Wating for Tools (Mins)	Waiting for RM (Mins)	Waiting for Manpower (Mins	Wating for Approval (Mins)	RM Problem (Mins)	FG Problem (Mins)	Power Outage (Mins)	Main Machine Down time (Mins	Other Machine Down time (Mins
1-Sep-15	Tue	Sep	Mfg	09:00 hrs - 17:30	Murugesan	M12 Coach B	M12 Coach	76											
1-Sep-15	Tue	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	-											
2-Sep-15	Wed	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	-		180						30			
3-Sep-15	Thu	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	140		180					30				
4-Sep-15	Fri	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	330		120						30			
5-Sep-15	Sat	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	337	0	150	0								
6-Sep-15	Sun	Sep		Sunday Holiday															
7-Sep-15	Mon	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	7		120								240	
8-Sep-15	Tue	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pick Rod	Pick Rod S	-											
8-Sep-15	Tue	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pip Screw	Pip Screw	9		60									
9-Sep-15	Wed	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pick Rod	Pick Rod S	-		300									
10-Sep-15	Thu	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pick Rod	Pick Rod S	2		240									
11-Sep-15	Fri	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pick Rod	Pick Rod S	100		60								180	
12-Sep-15	Sat	Sep	Dev	09:00 hrs - 17:30	Murugesan	Trowel Stud	Trowel Stu		30										
12-Sep-15	Sat	Sep	Mfg	09:00 hrs - 17:30	Murugesan	Pick Rod	Pick Rod S	187	30	30									
13-Sep-15	Sun	Sep	Dev	Sunday Holiday															
14-Sep-15	Mon	Sep	Dev	09:00 hrs - 17:30	Murugesan	Trowel Stud	Trowel Stu			240	30								
15-Sep-15	Tue	Sep	Dev	09:00 hrs - 17:30	Murugesan	Trowel Stud	Trowel Stu	6						30					

Fig. B.6 Data screen shot for September Month