ASSEMBLY LINE BALANCING

A PROJECT REPORT

Submitted in partial fulfillment for the

award of the degree of

BACHELOR OF TECHNOLOGY

in

MECHANICAL ENGINEERING

by

AMAN SHYAMSUKHA

(Registration No 1301021012)

Under the Guidance of

Mr. MANISH SINGH, Mr. A.D. SHARMA

&

Mr. ATUL DAMKE

School of Engineering

JECRC UNIVERSITY

JAIPUR, RAJASTHAN

(JULY 2017)

CERTIFICATES

This is to certify that the Project work titled "***Assembly Line Balancing***" that is being submitted by ***Aman Shyamsukha*** is in partial fulfillment of the requirements for the award of **Bachelors of Technology**, is a record of bonafide work done under our guidance. The contents of this Project work, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma.

Manish Singh
(Guide)

R. M. Tripathi and Atul Damke
(Faculty Internship Guide)

Internal Examiner

External Examiner

APPROVAL

This Project Report on **"Assembly Line Balancing"** by ***Aman Shyamsukha*** is approved for the award of the degree of Bachelors of Technology in Mechanical Engineering

Examiner (s)

Guide (s)

HOD

Date:

Place: Jaipur

CANDIDATE'S DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not mispresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

AMAN SHYAMSUKHA

Registration No. - 1301021012

ACKNOWLEDGEMENT

This project report is a part of partial fulfillment for the award of the degree of Bachelors of Technology in Mechanical Engineering at JECRC University. This Internship has been an interesting challenge and a good learning experience for me. Throughout this internship period, people have contributed either directly or by providing support and guidance in the completion of the research. This dissertation not has been possible without the help and support of my family members, and faculty members.

I would like to thank my Guide (Mr. Manish Singh), my industry Guide (Mr. A.D. Sharma and Mr. Atul Damke) and our Head of department Dr. M.S. Sodhi for their patience, knowledge, encouragement, and mentorship. They provided considerable insights to find the way of doing my project. They offered excellent advices whenever I met a problem. This journey would have been directionless and less interesting without their perspectives and guidance.

AMAN SHYAMSUKHA

ABSTRACT

Poor layout design is a major problem contribution in an industry. These problems thus affect the productivity and the line efficiency as well. Throughout the study, the aim is to propose a new layout to the company to increase their productivity. The major step is to identify a bottleneck workstation in current layout. After identify related problems, the current layout is redesign by computing the standard time and processing time in each workstation. In each workstation, the processing time is different and the longest time consumption is workstation will be identified as a bottleneck workstation. The goal of the thesis is to seek the best layout in terms of line efficiency and productivity rate hence proposed to the company.

In dealing with the situation following aspects were considered.

- Method improvement
- Time study
- Methods for line balancing

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

Chapter 1
Introduction

Line Balancing means balancing the production line, or any assembly line. The main objective of line balancing is to distribute the task evenly over the work station so that idle time of man of machine can be minimized. Line balancing aims at grouping the facilities or workers in an efficient pattern in order to obtain an optimum or most efficient balance of the capacities and flows of the production or assembly processes. Assembly Line Balancing (ALB) is the term commonly used to refer to the decision process of assigning tasks to workstations in a serial production system. The task consists of elemental operations required to convert raw material in to finished goods. Line Balancing is a classic Operations Research optimization technique which has significant industrial importance in lean system. The concept of mass production essentially involves the Line Balancing in assembly of identical or interchangeable parts or components into the final product in various stages at different workstations. With the improvement in knowledge, the refinement in the application of line balancing procedure is also a must. Task allocation of each worker was achieved by assembly line balancing to increase an assembly efficiency and productivity.

1.1 Assembly Lines

Assembly lines include single-model assembly lines, mixed-model assembly lines and multi model assembly lines. There are different layouts of the different assembly lines and different assembly lines may be operated differently.

1.1.1 Layout of assembly lines

The traditional layout of an assembly system is the serial line where stations are arranged in a straight line along a conveyor belt. Serial lines have disadvantages such as low flexibility, low-motivated operators, quality problems and large inventories. A serial flow assembly line is presented in Figure 1.1.

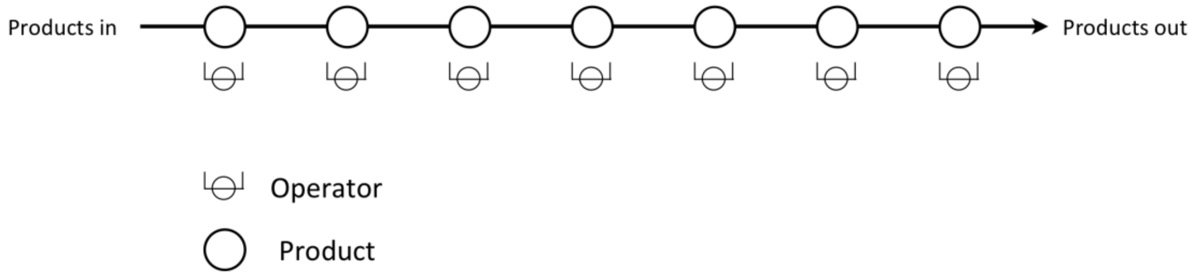

Figure 1.1 Serial flow assembly line

According to Becker & Scholl (2006) [1] the disadvantages with straight serial lines may be overcome by a U-shaped assembly line. Both ends of the line are closely together forming a rather narrow “U”. The stations can be arranged so that two work pieces can be handled at different positions during the same cycle. In Station 1, the first tasks on one work piece and the last tasks on another work piece are performed. Stations 1 and 5 are called crossover stations because they can handle the same work piece in two different cycles. U-shaped assembly lines have advantages such as job enrichment and enlargement strategies, and they might result in a better balance of station loads due to the larger number of task-station combinations. (Becker & Scholl, 2006) [1] U-shaped lines also lead to higher quality and increased flexibility. [2]

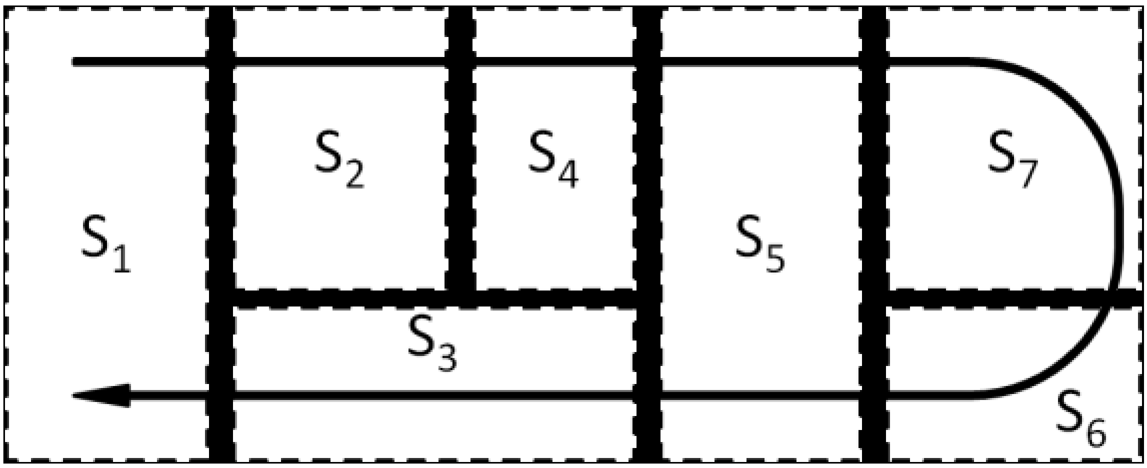

Figure 1.2 U-shaped assembly line [1]

Several parallel lines for manufacturing one or several products may lead to increased flexibility and decreased failure sensitivity of a system. Parallel lines give the management the chance to react to demand changes, due to that the number of lines can be changed, and the risk of machine breakdowns is lowered. Parallel lines also allow the enlargement of cycle times which has one advantage such as horizontal job enlargement. A strategic problem related to parallel lines is to decide how many lines to install because additional lines lead to increased capital investments. [2]

1.1.2 Single – model assembly lines

In its traditional form, assembly lines were used for high volume production of a single commodity. Now a day, products without any variation can seldom attract sufficient customers to allow for a profitable utilization of the assembly system. Advanced production technologies enable automated setup operations at a negligible setup times and costs. If more than one product is assembled on the same line, but neither setup nor significant variations in operating times occurs, the assembly system can be treated as a single model lines, as is the case in the production of compact discs or drinking cans for example. Single-model production is the standard assumption of ASLB and many generalized ABL problems and have been considered by a vast number of publications. A recent literature overview is provided by Scholl and Becker as well as Becker and Scholl.

1.1.3 Mixed-model assembly lines

An assembly line where different products are manufactured in batches is called a multi-model line. Multi-model lines are often used when there are significant differences in the production process between the products. This leads to that rearrangement of the line equipment is required. Multi-model assembly lines are also visualized in Figure. [1]

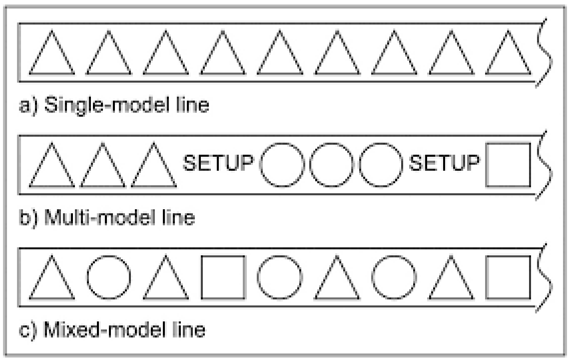

Figure 1.3 Assembly lines for single and multiple products [1]

1.1.4 Multi-model lines

Assembly lines where more than one product or model is manufactured are called mixed-model assembly lines, see Figure 1.4. The models at a mixed-model assembly line may differ from each other with respect to size, color, used material or equipment such that their production requires different tasks, task times and/or precedence relations. In mixed-model assembly line, the setup time is zero between models, and successive units coming down the line can be for different products or models. [3]

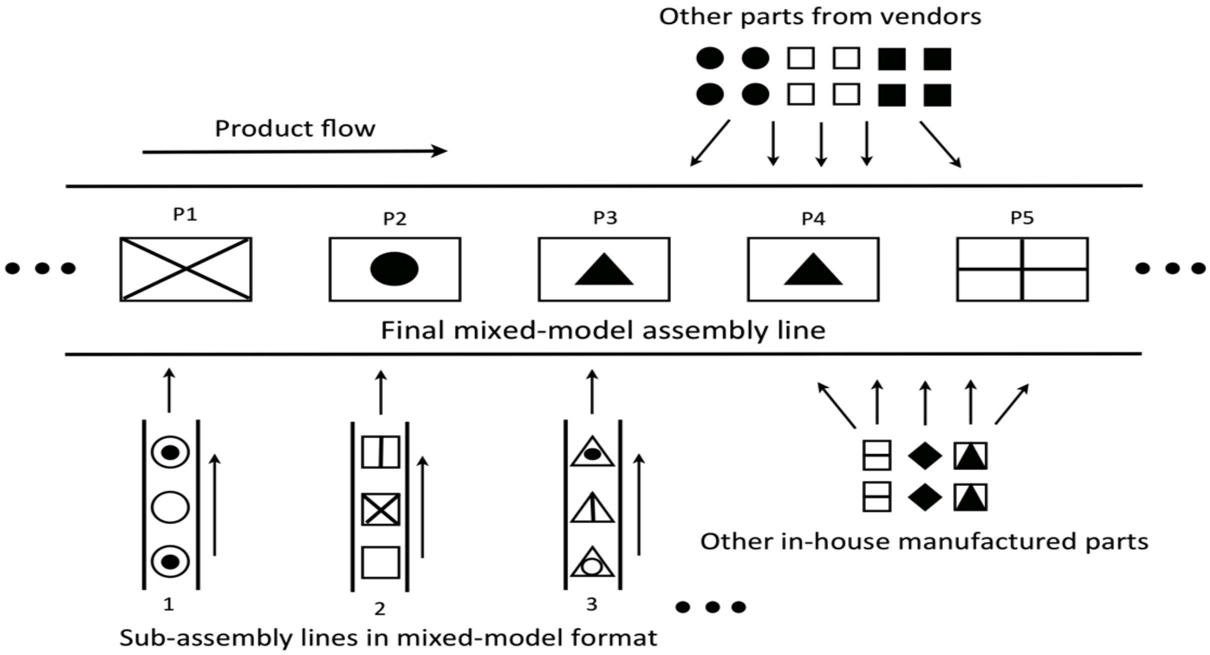

Figure 1.4 Schematic image of a mixed-model line [4]

1.2 Time constraints

The following sections describe, different time concepts that occur in a production system.

1.2.1 Operation time

The time between the start and the end of an operation at a station is known as operation time. The operation time can be measured by time studies either by stopwatch, video or image processing techniques [2], or calculated using a predetermined motion time system such as MTM.

1.2.2 Cycle time

Cycle time is a time measured from the initial moment a work-piece delivered to the station, the required time to complete all the operation of the work-piece on that station. The cycle time is a function of the total operation time and number of operators at the station [2].

1.2.3 Takt time

Takt time is defined as the time a work-piece stays at a station. It is a function of available production time and product volume [2]. In this project, it is used to understand the rate at which we need to produce the product in order to satisfy the customer demand. It can be determined with the formula:

$$\text{Takt time} = \frac{\text{Net available production}}{\text{Demand}}$$

From the definition, the takt time should not be mixed up with cycle time. Takt time is the same for all stations on an assembly line, i.e., the time for which work piece stays at a station. Cycle time is operation time of work that is completed while the work-piece is at the station.

1.2.4 Takt overdue

Takt overdue means that the takt time is not well enough to complete all the operation in a workstation.

1.2.5 Ideal Time

In general, the idle time is the difference between the cycle time and the station (takt) time. The idle time is waiting time, since the operator is idle after performing the all the operations and the work piece is not being moved to the next station. The sum of all idle times for all stations in the line is termed as balance delay time [2]. The idle time can be expressed as,

$$\text{Idle time} = \text{Takt time} - \text{Cycle time}$$

In this project, the idle time is the difference between highest cycle time and the cycle time of the respective station.

1.2.6 Tolerance time

Tolerance time is defined as the time required for work-piece to complete all operations in the current station and to be delivered to the next station [2].

1.2.7 Throughput time

The throughput time is equal to the total process and waiting times of the assembly line. Besides, it is defined as the total time required for a work piece to enter and leave the assembly line as completed product [2].

1.3 Productivity

In general, the productivity is a relationship between input and output and is usually measured in terms of:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

In this thesis work, the productivity of line is measured through OEE (overall equipment effectiveness) that identifies the how the assembly line is truly productive. The OEE is calculated from three factors: Availability (A), Performance (P) and Quality (Q). The OEE can expressed as (Braglia et al, 1986):

$$\text{OEE}=\text{Availability} \times \text{Performance} \times \text{Quality}$$

1.3.1 Availability

The availability is calculated taking account of downtime loss by dividing actual operation time by the planned production time. It can be expresses in a formula as:

$$\text{Availability} = \frac{\text{Actual operation time}}{\text{Planned production time}}$$

where, the planned production time is the time without the paid break times. The actual operation time is calculated by planned Production time minus sum of all the downtimes while operating i.e. breakdown and changeovers.

1.3.2 Performance

The performance is calculated by taking account of speed losses in the system. The performance can be expresses in the formula as:

$$\text{Performance} = \frac{\frac{\text{Total pieces}}{\text{Operating Time}}}{\text{Ideal Run rate}}$$

where, ideal run rate is the inverse of ideal cycle time.

1.3.3 Quality

The quality is calculated by taking account of quality losses in the system. It can be expressed as:

$$\text{Quality} = \frac{\text{Good Pieces}}{\text{Total Pieces}}$$

1.4 Objective of Line Balancing

Line balancing technique is used to:

i) To manage the workloads among assemblers.

ii) To identify the location of bottleneck

iii) To determine number of workstation.

iv) To reduce production cost.

1.5 Problem Statements

1.5.1 Reduced line efficiency.

In flow line production, the product moves to one workstation due to time restriction. Once it gets stuck due to accumulation in certain workstation, it exceeds the cycle time in that station. Faster station is limited by slowest station. Thus, decreasing the rate of productivity.

1.5.2 Unbalance workloads

Uneven distribution of activities on assembly line for workers lead to unbalance workload which results in increases fatigue level of operator and work stress.

1.6 Project Objectives

Two objectives are expected in the end of the project:

1. To improve productivity and efficiency of existing layout.
2. To decrease man power required in the assembly line.

Chapter 2

Company Profile

2.1 Eicher Engine, Alwar

Figure 2.1 Eicher Engine, Alwar

Office / Factory Address: Eicher Engines - A unit of TAFE Motors and Tractor Ltd, Itarana Road, Alwar – 301001, Rajasthan

Product: Automotive Engines
Stationary Engines
Agro / Industrial Engines

Year of Establishment: 1959

2.2 TMTL – TAFE Motors and Tractors Limited

TMTL - TAFE Motors and Tractors Limited, a wholly owned subsidiary of Tractors and Farm Equipment Limited (TAFE), consists of three manufacturing divisions, the Tractors Division, the Engines Division and the Transmissions Division.

The TMTL - Tractors Division caters to the dynamic market demands and needs of the modern farmers with a comprehensive range of tractors and implements. The division is perhaps the sole manufacturer of both air and water-cooled tractors across the globe. Its top-of-the-line

Research and Development facility is capable of designing and developing new tractor models with its in-house prototype development and tooling/manufacturing competencies, setting exemplary standards in the industry.

The TMTL - Engines Division manufactures specialized engines for stationary, automotive and marine applications and has a strong presence in retail, agro applications and telecom markets. Based at Alwar, Rajasthan, the unit manufactures diesel engines in the 11.7 to 160 Hp range.

The TMTL - Transmissions Division, houses an advanced manufacturing facility in Parwanoo, Himachal Pradesh, capable of producing a range of gears, shafts and housings for captive consumptions and OEMs.

2.3 TMTL Engines Division:

TMTL Engines Division is a unit of TAFE Motors and Tractors Limited (TMTL) with Alwar, Rajasthan, India, as its manufacturing base. TMTL is a wholly owned subsidiary of Tractors and Farm Equipment Limited (TAFE), part of Chennai based Amalgamations Group, which is one of India's largest light engineering conglomerates. The Amalgamations Group has a long and distinguished history of serving Indian and global markets with a pan India presence of over 41 companies and is renowned for its highest standards of integrity, ethics and values, backed by a highly skilled and competent workforce of over 15,000.

The TMTL Engines' Alwar plant at Rajasthan, India, produces a wide range of air and water cooled engines in the brand names of EICHER ENGINES (upto 45 kVA) and TMTL ENGINES (62.5 kVA & above), which cater to a wide range of automotive and stationary applications and has an existing Customer / Marketing base of over 700,000 spread across various segments.

Engines manufactured by TMTL are one of the most preferred engines for stationary applications like generators, prime mover for agro-industries, marine and other industrial applications.

In power generation segment, TMTL has a strong base of loyal customers and stands as one of the market leaders through continuous improvements in product features and product range, by using advanced technology and exceptional Customer / Marketing service that meet the global standards of quality and productivity.

TMTL envisages growing exponentially in the power generation segment by providing economic power solutions with custom built products and services catering to a wide range of institutional and retail customers ranging from banking and finance, commercial, construction and real estate, hospitality, information technology, government and public sector, small and medium enterprises, petrol pumps, educational institutes and hospitals.

2.4 EICHER ENGINES PRODUCT RANGE

- This unit of Eicher is producing one of the world's most economical tractor engines which include 24 HP, 30 HP, 35 HP, 42 HP 4-Strokes Air Cooled Diesel Engines and 49 HP 4-Strokes Water Cooled Diesel Engines.
- The assembly of engine is divided into four parts. These are known as 115, 298, 398 and Valtra assembly.
- For Valtra engines technology is developed by Valtra Inc., Finland., water cooled. Power range varies from 49 Hp to 80 Hp for Auto and Genset application.

Figure 2.2 Air Cooled Single Cylinder Engine


Figure 2.3 Air Cooled Two Cylinder Engine

Figure 2.4 Air Cooled Three Cylinder Engine

Figure 2.5 Genset -5 to 125 KVA

1.5 MODEL SPECIFICATION OF EICHER ENGINE:

Table 2.1 Model Specification of Eicher Engines Tractor

Engine Manufacturer	TAFE MOTORS AND TRACTORS LIMITED									
Engine Brand	EICHER ENGINES	EICHER ENGINES	EICHER ENGINES	EICHER ENGINES	EICHER ENGINES	EICHER ENGINES	EICHER ENGINES	TMTL ENGINES	TMTL ENGINES	TMTL ENGINES
Engine Model	198 ES	222 ES	322 ES	323 ES	422 ES	422TC	621 ES	881 ES	1121ES	1751ES
No of Cylinders	1	1	2	2	3	3	3	3	4	4
Aspiration	Natural	Natural	Natural	Natural	Natural	Turbo Charged	TCIC	TCIC	TCIC	TCIC
Engine BHP (Gross Hp)	11.7	18.7	25.1	25.7	35.5	48.2	59.1	82.2	102	160
Rated speed (RPM)	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Cubic capacity (cc)	981	1557	1963	1963	2945	2945	3298	3298	4910	4910

Chapter 3
Literature Review

Line balancing is a very vast field and is a very important aspect for an industry. Many times, in conferences this is main topic of discussion and many students and scholars also publish their work on this topic. Amen (2000) [5] presented work on an exact method for cost-oriented assembly line balancing. Characterization of the cost oriented assembly line balancing problem had been shown by without loading the stations maximally the cost-oriented optimum. According to him criterion two stations- rule had to be used. Results of an experimental investigation showed that the new method finds optimal solutions for small and medium-sized problem instances in acceptable time.

A survey on heuristic methods for cost-oriented assembly line balancing was presented by Amen (2000) [6]. In this work, main focus was on cost-oriented assembly line balancing. This problem mainly occurs in the final assembly of automotive, consumer durables or personal computers, where production is still very labor-intensive, and where the wage rates depend on the requirements and qualifications to fulfill the work. In this work a short problem description was presented along with classification of existent and new heuristic methods for solving this problem. A new priority rule called best change of idle cost was proposed. This priority rule differs from the existent priority rules because it was the only one which considers that production cost was the result of both, production time and cost rates.

A work on new heuristic method for mixed model assembly line balancing problem was published by Jin and Wu (2002) [7]. A goal chasing method was presented which is a popular algorithm in JIT system for the mixed model assembly line balancing problem. In this work, definition of good parts and good remaining sequence were provided and analyze their relationship with the optimal solutions objective function value. A new heuristic algorithm was also develop called ‘variance algorithm’ the numerical experiments showed that the new algorithm can yield better solution with little more computation overhead.

Fleszar and Hindi (2003) [8] presented a work on enumerative heuristic and reduction methods for the assembly line balancing problem. They presented a new heuristic algorithm and new reduction techniques for the type 1 assembly line balancing problem. The new heuristic was based on the Hoffmann heuristic and builds solutions from both sides of the precedence network to choose the best. The reduction techniques aimed at augmenting precedence, conjoining tasks and increasing operation times. A test was carried out on a well-known benchmark set of problem instances; testify to the efficacy of the combined algorithm, in terms of both solution quality and optimality verification, as well as to its computational efficiency.

A work on assembly line balancing in a mixed model sequencing environment with synchronous transfers was presented by Karabati and Sayin (2003) [9]. An assembly line balancing problem was under a cyclic sequencing approach. Study of the problem was done in an assembly line environment with synchronous transfer of parts between the stations.

They formulated the assembly line balancing problem with the objective of minimizing total cycle time by incorporating the cyclic sequencing information. They showed that the solution of a mathematical model that combines multiple models into a single one by adding up operation times constitutes a lower bound for this formulation. An alternative formulation was proposed that suggested minimizing the maximum sub cycle time.

A work was presented by Simaria and Vilarinho (2004) [10] on genetic algorithm based approach to the mixed-model assembly line balancing problem of type II. According to them mixed-model assembly lines allow for the simultaneous assembly of a set of similar models of a product. A mathematical programming model was presented in this work and an iterative genetic algorithm based procedure for the mixed-model assembly line balancing problem with parallel workstations, in which the goal was to maximize the production rate of the line for a predetermined number of operators.

A fuzzy logic approach to assembly line balancing work was presented by Fonseca et al. (2005) [11]. This work deals with the use of fuzzy set theory as a viable alternative method for modeling and solving the stochastic assembly line balancing problem. Variability and uncertainty in the assembly line balancing problem had traditionally been modeled through the use of statistical distributions. Fuzzy set theory allowed for the consideration of the ambiguity involved in assigning processing and cycle times and the uncertainty contained within such time variables. COMSOAL and Ran-ked Positional Weighting Technique were modified to solve the balancing problem with a fuzzy representation of the time variables. The work showed that the new fuzzy methods capabilities of producing solutions similar to, and in some cases better than, those reached by the traditional methods.

Gokcen (2005) [12] presented a work on shortest route formulation of simple U-type assembly line balancing problem. A shortest route formulation of simple U-type assembly line balancing (SULB) problem was presented. This model was based on the shortest route model developed in for the traditional single model assembly line balancing problem. Agpak and Gokcen (2005)

[13] presented their work on assembly line balancing: Two resource constrained cases. A new approach on traditional assembly line balancing problem was presented. The proposed approach was to establish balance of the assembly line with minimum number of station and resources and for this purpose, 0–1 integer-programming models were developed.

A work was presented by Bukchin and Rabinowitch (2006) [14] on branch and bound based solution approach for the mixed-model assembly line balancing problem for minimizing stations and task duplication costs. A common assumption in the literature on mixed model assembly line balancing is that a task that is common to multiple models must be assigned to a single station. In this work a common task to be assigned to different stations for different models.

The sum of costs of the stations and the task duplication was to be minimized. An optimal solution procedure based on a backtracking branch and bound algorithm was developed and evaluates its performance via a large set of experiments. For solving large-scale problems branch and bound based heuristic was developed.

Levitin et al. (2006) [15] works on genetic algorithm for robotic assembly line balancing. Flexibility and automation in assembly lines can be achieved by the use of robots. The robotic assembly line balancing (RALB) problem was defined for robotic assembly line, where different robots may be assigned to the assembly tasks, and each robot needs different assembly times to perform a given task, because of its capabilities and specialization. The solution to the RALB problem includes an attempt for optimal assignment of robots to line stations and a balanced distribution of work between different stations. It aims at maximizing the production rate of the line. Gokcen and Agpak (2006) [16] presented their work on goal programming approach to simple U-line balancing problem. A goal programming model for the simple U-line balancing (ULB) problem was developed. The proposed model which was the multi criteria decision making approach to the U-line version provides increased flexibility to the decision maker since several conflicting goals can be simultaneously considered.

A work on heuristic solution for fuzzy mixed model line balancing problem was presented by Hop (2006) [17]. This work addresses the mixed-model line balancing problem with fuzzy processing time. A fuzzy binary linear programming model was formulated for the problem. This fuzzy model was then transformed to a mixed zero one program. Due to the complexity nature in handling fuzzy computation, new approximated fuzzy arithmetic operation was presented. A fuzzy heuristic was developed to solve this problem based on the aggregating fuzzy numbers and combined precedence constraints. The general idea of our approach was to arrange the jobs in a sequence by a varying-section exchange procedure. Then jobs were allocated into workstations based on these aggregated fuzzy times with the considerations of technological constraint and cycle time limit. Promising results were obtained by experiments. Gamberini et al. (2006) [18] presented their work on a new multi-objective heuristic algorithm for solving the stochastic assembly line re-balancing problem. In this work a new heuristic for solving the assembly line rebalancing problem was presented. The decision-making procedure, named technique for order preference by similarity to ideal solution (TOPSIS), and the well-known Kottas and Lau heuristic approach. The proposed methodology was focused on rebalancing an existing line, when some changes in the input parameters (i.e. product characteristics and cycle time) occur. Hence, the algorithm deals with the assembly line balancing problem by considering the minimization of two performance criteria: (i) the unit labor and expected unit incompletion costs, & (ii) tasks reassignment.

A work was presented by Song (2006) [19] on recursive operator allocation approach for assembly line-balancing optimization problem with the consideration of operator efficiency. An optimization model was used for assembly line balancing problem in order to improve the line balance of a production line under a human centric and dynamic apparel assembly process. An approach was proposed to balance production line through optimal operator allocation with the consideration of operator efficiency. Two recursive algorithms were developed to generate all feasible solutions for operator allocation. Three objectives i.e. the lowest standard deviation of operation efficiency, the highest production line efficiency and the least total operation efficiency waste were rearranged to find out the optimal solution of operator allocation. The performance comparison demonstrated that the proposed optimization method outperforms the industry practice.

Dolgui et al. (2006) [20] works on special case of transfer lines balancing by graph approach. In their work for paced production they considered a balancing problem lines with workstations in series and blocks of parallel operations at the workstations. Operations of each workstation were partitioned into blocks. All operations of the same block were performed simultaneously by one spindle head. All blocks of the same workstation were also executed simultaneously. The operation time of the workstation was the maximal value among operation times of its blocks. The line cycle time was the maximal workstation time. A method for solving the problem was based on its transformation to a constrained shortest path problem.

A survey on problems and methods in generalized assembly line balancing was presented by Becker and Scholl (2006) [21]. Assembly lines are traditional and still attractive means of mass and large scale series production. Since the early times of Henry Ford several developments took place which changed assembly lines from strictly paced and straight single model lines to more flexible systems including, among others, lines with parallel work stations or tasks, customer oriented mixed model and multi-model lines, U-shaped lines as well as un paced lines with intermediate buffers. Assembly line balancing research had traditionally focused on the simple assembly line balancing problem which had some restricting assumptions. Recently, a lot of research work had been done in order to describe and solve more realistic generalized problems.

Kim et al. (2006) [22] presented his work on endo symbiotic evolutionary algorithm for the integration of balancing and sequencing in mixed-model U-lines. A new evolutionary approach in mixed model U-shaped lines was proposed to deal with both balancing and sequencing problems. The use of U-shaped lines was an important element in Just-In-Time production. For an efficient operation of the lines, it is important to have a proper line balancing and model sequencing. A new genetic approach was proposed to solve the two problems of line balancing and model sequencing called endosymbiotic evolutionary algorithm.

Peeters and Degraeve (2006) [23] works on linear programming based lower bound for the simple assembly line balancing problem. The simple assembly line balancing problem was a classical integer programming problem in operations research. A set of tasks, each one being an indivisible amount of work requiring a number of time units, must be assigned to workstations without exceeding the cycle time. They presented a new lower bound, namely the LP relaxation of an integer programming formulation based on Dantzig–Wolfe decomposition. A column generation algorithm was proposed to solve the formulation and a branch-and-bound algorithm also proposed to exactly solve the pricing problem.

A work on optimal piecewise-linear program for the U-line balancing problem with stochastic task times was published by Urban and Chiang (2006) [24]. The utilization of U-shaped layouts in place of the traditional straight-line configuration has become increasingly popular. This work examines the U-line balancing problem with stochastic task times. A chance constrained, piecewise linear, integer program was formulated to find the optimal solution. Various approaches were used to identify a tight lower bound. Computational results showed that the proposed method was able to solve practical sized problems.

Hirotani et al. (2006) [25] works on analysis and design of self-balancing production line. In a self-balancing production line, each worker was assigned work dynamically. In this work, they examine other less restrictive conditions that can achieve the same self-balancing effect, and furthermore, characteristics of this line were analyzed by deriving the imbalance condition and analyzing the influence of initial position. In addition, a method for designing a self-balancing line based on our results was proposed.

A work was presented by Dimitriadis (2006) [26] on assembly line balancing and group working: A heuristic procedure for worker's groups operating on the same product and workstation. In this work, they examined an assembly line balancing problem that differs from the conventional one in the sense that there were multi-manned workstations, where worker's groups simultaneously perform different assembly works on the same product and workstation. The proposed approach here results in shorter physical line length and production space utilization improvement, because the same number of workers can be allocated to fewer workstations. A heuristic assembly line balancing procedure was thus developed and illustrated. Finally, experimental results of a real-life automobile assembly plant case and well known problems from the literature indicate the effectiveness and applicability of the proposed approach in practice.

Lapierre et al. (2006) [27] presented his work on balancing assembly lines with tabu search. Balancing assembly lines is a crucial task for manufacturing companies in order to improve productivity and minimize production costs. Despite some progress in exact methods to solve large scale problems, software's implementing simple heuristics are still the most commonly used tools in industry. Here a new tabu search algorithm was presented and discussed. Its performance was then evaluated on Type I assembly line balancing problem. They discuss the flexibility of the meta-heuristic and its ability to solve real industrial cases.

For productivity improvement Gokcen et al. (2006) [28] published a work on balancing of parallel assembly lines. Productivity improvement in assembly lines is very important because it increases capacity and reduces cost. If the capacity of the line is insufficient, one possible way to increase the capacity is to construct parallel lines. In this study, new procedures and a mathematical model on the single model assembly line balancing problem with parallel lines were proposed.

Amen (2006) [29] works on cost-oriented assembly line balancing in which model formulations, solution difficulty, upper and lower bounds was also considered. Cost oriented assembly line balancing was discussed in this work. First focus was on special objective function and a formal problem statement. Then they concentrate on general model formulations that can be solved by standard optimization tools and introduce several improvements to existent models. These models were designed for either general branch-and-bound techniques with LP-relaxation or general implicit enumeration techniques. Further they discuss the solution difficulty of the problem and showed that the maximally-loaded station rule had to be replaced by the two-station rule.

Azar et al. (2006) [30] presented their work on load balancing of temporary tasks in the lp norm. In this on-line load, balancing problem has been considered on m identical machines. Jobs arrive at arbitrary times, where each job had a weight and duration. A job had to be assigned upon its arrival to exactly one of the machines. The duration of each job was known only on completion. Once a job has been assigned to a machine it cannot be reassigned to another machine. Focus was to minimize the maximum over time of the sum (over all machines) of the squares of the loads, instead of the traditional maximum load.

Chapter 4
METHODOLOGY

The methodology is used to reach out the definite goals in the project. A short description of the procedure is shown below, followed by the visualization of methodology which is given in the Figure, where each process is further described in detail.

4.1 Description of procedure

The procedure was to study the current state assembly line, make observations on line, see how the process is being performed and assembly line works. Make evaluations and study current line balancing. Make some interviews with the operators at assembly line who have a task to perform as the know all the basics required for the project.
The procedure was to collect the time studies, then analyzing the work tasks by isolating the value adding, the non-value adding and the waiting time to identify the losses. The time studies used video analysis and onsite evaluation was done for identifying the risks. The results were used to evade those losses the assembly line.

4.2 Visualization of methodology

The first section of the project introduces the essential things of the project that includes the focus of the project. The second section shows the current evaluation of the project that is the things that have to do before the designing the new assembly. The third section is the main focus objectives of the project for the reliable results, and the final section is evaluation of the final results and recommendation for the future.

Introduction	Current State Analysis	Future State Mapping	Verification and validation of the system.
• Project initiation • Problem definition • Area of focus • Observation at line	• Observation at stations • Evaluation of current line balance • Theoretical study • Interview	• Data mining • Time study • Determination and elimination of wastes • Line balancing • Operator planning • Layout planning • Theoretical study • Interview	• Evaluation of proposed system • Recommendation for future • Project conclusion

Figure 4.1 Project steps and flows

4.3 Data Gathering

The parts regarding the data gathering will be described more in detail in the following chapter:

4.3.1 Time studies

The times studies of the assembly process were undertaken in terms of video analysis with the help of a company supervisor and operators. In those case, that video analysis is used to analysis the task times and ergonomics standards, and to enhance it.

4.3.2 Interview

The most vital information that was collected during the interview was the adjustment time took for a specific task and the frequency of errors at the section.

4.3.3 Error collection

From the interviews and studies the screw related errors are common and frequently occurs in the assembly line. Thus, the screws related errors are classified into categories:

- Not performed – screw tasks have not been performed
- Performed incorrectly – screw tasks were performed in the wrong place
- Removal of dropped screws – Screws fallen over the mirror and not been removed

4.4 Line balancing

In order to level the workload and achieve a well-balanced assembly line, the factors that cause losses and; wastes have to be eliminated. The production system was analyzed to define wastes and factors that cause losses before performing the balancing procedure.

4.5 Evaluating the assembly conditions

The evaluation of the assembly complexity can be performed by either directly on the sight or by a film. For this study, it was decided to film the work tasks to get an explicit condition of every task and respective movements for the assessments. Filming the assembly task for the assessments has a numerous benefit:

- The film can be reviewed for infinite times for the assessment.
- Filming the work tasks assists to get an unambiguous view of the working position.
- The evaluated assessments can be shown.
- For the future examination, the film can be stockpiled.

4.6 Statement of Approach

With the aim of balancing the assembly line, it is required to all know all knowledge of the assemblies their sequence, precedence and operation times.

Single cylinder engine assembly line was analyzed where three types of engines were assembled (Auto, ESG and NC engines). Even though, the operations are similar, there is some process change in assembling and operation times for these different models. For this reason, it was significant to clarify and consider these reasons before balancing was done. The method applied to balance the line are stated below:

1. All stations of single cylinder engine assembly line were determined.
2. Operation time and number of operators in all process of each station were calculated. This was done by the stopwatch and video analysis studies.
3. Interviews with the line team leader, process engineer and line operators had been done to identify the problems in the existing line.
4. In order to achieve a well-balanced line, the source of wastes risk was determined.
5. Improvement potential to removal of waste and quality problems was created and analyzed with line team leader and engineers.
6. Data of fixtures and tools were created.
7. A new time study analysis was done for eliminating the balance and system losses. Then the cycle times, idle time etc., are calculated. A few Kaizen workshops has been done to optimize the line as well-balanced.
8. Yamaguchi chart were prepared for graphical representation.
9. Change in activities of operators was done to balance the line and also to complete the objective of reducing man power and increasing assembly line efficiency and productivity.
10. Proposed system was then sent for evaluation.

4.7 Structuring the balanced assembly line

With the data of precedence, operation and known operation times, the desired balance assembly line has to be designed. For this purpose, the number of workstations, expected number of operators in the line, organizing the tool, fixture and material handling setup was considered.

To achieve a better efficient assembly line more data are required. To collect all assembly line data, several performance and workstation indexes are considered as shown in table.

Table 4.2 Performance and workstation indexes for assembly line layout

Performance Index	Workstation Index
• Variance of time among product versions • Cycle time • Number of stations • Station space • Traffic problems • Task complexity • Reliability	• Operator skill, motivation • Tool/fixture required • Tool/fixture change necessary • Material allocation • Setup time • Ease of assembly • Working place • Need of storage

4.8 Operator planning

The efficiency of the assembly line was based on assigning the assembly operators to the assembly stations. While planning the required number of operators to complete entire operations, balancing of the line was considered for avoiding system losses.

In order to eliminate the idle times of the operators at the stations, the number of operators required should be kept minimum. This would cause Takt overdue that can be overcome by having maximum number of operators at the stations. In this perception, the best approach in terms of efficiency of line would be having an optimum number of operators which would not create a Takt overdue.

Chapter 5
Observation and Calculation

In this chapter, the data gathered from the time study, interviews and previous work will be evaluated. And from the data gathered, calculations will be performed to for completion of our objective of our study to reduce man power and to increase line efficiency and productivity of the assembly line.

5.1 Time study

In single cylinder engine assembly, there are three types of engines to be assembled, namely:

1. Auto engine
2. NC engine
3. ESG engine

For assembling the parts of these engines, different activities are performed at different stages for different engines.

A stop watch and a video camera were used for gathering the data so that precise timing can be obtained. Then the processes and the time taken in them were listed in an excel sheet.

Due to rules of the company and as data is confidential, all the data of time study cannot be shown into the report.

Below is the sample data of 2L stage for all the engines which include the processes and the time taken to complete them.

5.1.1 Auto Engine – Time Study Data

Table 5.1 Time study data of auto engine

2L STAGE - AUTO ENGINE DATA		
S. No.	**Processes**	**Time(sec.)**
1	Bring hose	7
2	Connect hose with crank shaft	5
3	Lift crank shaft to engine	11
4	Put crank shaft in engine	20

5	Bring two bolts	4
6	Hand tight bolts into crank shaft	6
7	Unlock crank shaft with hose	6
8	Put hose back	4
9	Take one bolt	2
10	Hand tight bolt into crank shaft	2
11	Take another bolt	2
12	Hand tight bolt into crank shaft	2
13	Take another bolt	2
14	Hand tight bolt into crank shaft	2
15	Take another bolt	2
16	Hand tight bolt into crank shaft	2
17	Take another bolt	2
18	Hand tight bolt into crank shaft	2
19	Take another bolt	2
20	Hand tight bolt into crank shaft	2
21	Pull down DC tool	3
22	Apply torque on 1st bolt	4
23	Apply torque on 2nd bolt	4
24	Apply torque on 3rd bolt	4
25	Apply torque on 4th bolt	4
26	Apply torque on 5th bolt	4
27	Apply torque on 6th bolt	4
28	Apply torque on 7th bolt	4
29	Apply torque on 8th bolt	4
30	Apply torque on bearing cover plate bolts	12
31	Push DC tool back	1
32	Take pilot tube	2
33	Bring hand gun	2
34	Fit pilot tube in crank shaft	3
35	Put hand gun back	2
36	Bring crank shaft calibrator	2

37	Check and adjust crank shaft	19
38	Put calibrator back	2
39	Bring marker	2
40	Put inspection marks	8
41	Pull engine number card out	1
42	Mark in it	2
43	Put engine number card back	1
44	Put marker back	2
45	Rotate engine to 180 degrees	3
46	Take crank gear	2
47	Put gear on shaft	6
48	Lift fixture	1
49	Put fixture on gear	2
50	Pull pressure gun down	3
51	Put it on fixture	2
52	Tighten the pressure gun	14
53	Press button	1
54	Work of gun	12
55	Loose pressure gun	8
56	Push pressure gun back	2
57	Put fixture back	2
58	Take idler shaft	2
59	Hold fixture	1
60	Fir idler shaft using fixture	3
61	Put fixture back	1
62	Take idler gear and fit it	5
63	Take oil pump gear and fir it	4
64	Take hex nut	1
65	Fix hex nut on oil pump gear	4
66	Take hex bolt	2
67	Take washer & put it in hex bolt	2
68	Take anabond	1

69	Apply on threads of hex bolt	2
70	Put anabond back	1
71	Fit bolt in idler shaft	4
72	Take anabond	1
73	Apply on threads of other gears	3
74	Put anabond back	1
75	Take hand gun	2
76	Take fixture	2
77	Tight hex nut of oil pump gear	2
78	Put fixture back	1
79	Take another fixture	1
80	Tight hex bolt of idler gear	3
81	Put fixture back	1
82	Put hand gun back	2
83	Put fixture to fix rotation of gears	3
84	Bring governor flange	4
85	Fit it on crank shaft	8
Total Time (seconds)		**308**

5.1.2 NC Engine – Time Study Data

Table 5.2 Time study data of NC engine

2L STAGE – NC ENGINE DATA		
S. No.	**Processes**	**Time(sec.)**
1	Bring hose	7
2	Connect hose with crank shaft	5
3	Lift crank shaft to engine	11
4	Put crank shaft in engine	20
5	Bring two bolts	4
6	Hand tight bolts into crank shaft	6
7	Unlock crank shaft with hose	6
8	Put hose back	4
9	Take one bolt	2

10	Hand tight bolt into crank shaft	2
11	Take another bolt	2
12	Hand tight bolt into crank shaft	2
13	Take another bolt	2
14	Hand tight bolt into crank shaft	2
15	Take another bolt	2
16	Hand tight bolt into crank shaft	2
17	Take another bolt	2
18	Hand tight bolt into crank shaft	2
19	Take another bolt	2
20	Hand tight bolt into crank shaft	2
21	Pull down DC tool	3
22	Apply torque on 1st bolt	4
23	Apply torque on 2nd bolt	4
24	Apply torque on 3rd bolt	4
25	Apply torque on 4th bolt	4
26	Apply torque on 5th bolt	4
27	Apply torque on 6th bolt	4
28	Apply torque on 7th bolt	4
29	Apply torque on 8th bolt	4
30	Apply torque on bearing cover plate bolts	12
31	Push DC tool back	1
32	Bring crank shaft calibrator	2
33	Check and adjust crank shaft	19
34	Put calibrator back	2
35	Bring marker	2
36	Put inspection marks	8
37	Pull engine number card out	1
38	Mark in it	2
39	Put engine number card back	1
40	Put marker back	2
41	Rotate engine to 180 degrees	3

42	Take crank gear	2
43	Put gear on shaft	6
44	Lift fixture	1
45	Put fixture on gear	2
46	Pull pressure gun down	3
47	Put it on fixture	2
48	Tighten the pressure gun	12
49	Press button	1
50	Work of gun	12
51	Loose pressure gun	8
52	Push pressure gun back	2
53	Put fixture back	2
54	Take PD gear	3
55	Fit PD gear on LOF pump	5
56	Take one washer	2
57	Take one nut	2
58	Put washer on LOF pump	1
59	Hand tight nut on LOF pump	2
60	Take anabond	2
61	Apply anabond	3
62	Put anabond back	2
63	Take hand gun	3
64	Take a socket	3
65	Tight nut through handgun	3
66	Put hand gun back	3
67	Put socket back	2
68	Take gear fixing fixture	3
69	Fit fixture on carter	4
70	Take marker	2
71	Make inspection marks	2
72	Put marker back	2
73	Take oil ring	5

74	Fit oil ring on crank shaft	3
75	Take governor flange	4
76	Fit governor flange on crank shaft	18
Total Time (Seconds)		**309**

5.1.3 ESG Engine – Time Study Data

Table 5.3 Time study data of ESG engine

2L STAGE - ESG ENGINE DATA		
S. No.	**Processes**	**Time(sec.)**
1	Bring hose	7
2	Connect hose with crank shaft	5
3	Lift crank shaft to engine	11
4	Put crank shaft in engine	20
5	Bring two bolts	4
6	Hand tight bolts into crank shaft	6
7	Unlock crank shaft with hose	6
8	Put hose back	4
9	Take one bolt	2
10	Hand tight bolt into crank shaft	2
11	Take another bolt	2
12	Hand tight bolt into crank shaft	2
13	Take another bolt	2
14	Hand tight bolt into crank shaft	2
15	Take another bolt	2
16	Hand tight bolt into crank shaft	2
17	Take another bolt	2
18	Hand tight bolt into crank shaft	2
19	Take another bolt	2
20	Hand tight bolt into crank shaft	2
21	Pull down DC tool	3
22	Apply torque on 1st bolt	4
23	Apply torque on 2nd bolt	4

24	Apply torque on 3rd bolt	4
25	Apply torque on 4th bolt	4
26	Apply torque on 5th bolt	4
27	Apply torque on 6th bolt	4
28	Apply torque on 7th bolt	4
29	Apply torque on 8th bolt	4
30	Apply torque on bearing cover plate bolts	12
31	Push DC tool back	1
32	Bring crank shaft calibrator	2
33	Check and adjust crank shaft	19
34	Put calibrator back	2
35	Bring marker	2
36	Put inspection marks	8
37	Pull engine number card out	1
38	Mark in it	2
39	Put engine number card back	1
40	Put marker back	2
41	Rotate engine to 180 degrees	3
42	Take crank gear	2
43	Put gear on shaft	6
44	Lift fixture	1
45	Put fixture on gear	2
46	Pull pressure gun down	3
47	Put it on fixture	2
48	Tighten the pressure gun	14
49	Press button	1
50	Work of gun	12
51	Loose pressure gun	8
52	Push pressure gun back	2
53	Put fixture back	2
54	Take idler shaft	2
55	Hold fixture	1

56	Fir idler shaft using fixture	3
57	Put fixture back	1
58	Take idler gear and fit it	5
59	Take oil pump gear and fir it	4
60	Take hex nut	1
61	Fix hex nut on oil pump gear	4
62	Take hex bolt	2
63	Take washer & put it in hex bolt	2
64	Take anabond	1
65	Apply on threads of hex bolt	2
66	Put anabond back	1
67	Fit bolt in idler shaft	4
68	Take anabond	1
69	Apply on threads of other gears	3
70	Put anabond back	1
71	Take hand gun	2
72	Take fixture	2
73	Tight hex nut of oil pump gear	2
74	Put fixture back	1
75	Take another fixture	1
76	Tight hex bolt of idler gear	3
77	Put fixture back	1
78	Put hand gun back	2
79	Put fixture to fix rotation of gears	3
80	Bring governor flange	4
81	Fit it on crank shaft	8
Total Time (Seconds)		**299**

Above shown data is then summarized into some group of activities for an operator to perform so that during line balancing, some of activities can be transferred to other operator to reduce time of a particular stage and to reduce fatigue level of the operator.

Below is the summarized data or the activities that an operator has to perform on 2L stage.

5.1.4 AUTO Engine – Activity List

Table 5.4 Activity list of auto engine

Processes	Time
Put crank shaft in engine	43
Fit crank shaft in engine	92
Calibrate crank shaft & fill engine card	51
Fit crank gear	55
Fit idler and oil pump gear	48
Fit governor flange	12
Total Time (Seconds)	**301**

5.1.5 NC Engine – Activity List

Table 5.5 Activity list of NC engine

Processes	Time
Put crank shaft in engine	43
Fit crank shaft in engine	92
Calibrate crank shaft & fill engine card	42
Fit crank gear	53
Fit PD gear	49
Fit oil ring & governor flange	30
Total Time (Seconds)	**309**

5.1.6 ESG Engine – Activity List

Table 5.6 Activity list of ESG engine

Processes	Time
Put crank shaft in engine	43
Fit crank shaft in engine	92
Calibrate crank shaft & fill engine card	42
Fit crank gear	55
Fit idler and oil pump gear	55

Fit governor flange	12
Total Time (Seconds)	**299**

5.2 Yamazumi chart

5.2.1 Introduction

Yamazumi is a Japanese word that literally means to stack up.

Process tasks are individually represented in a stacked bar chart, these can be categorized as either Value Added, Non-Value Added or Waste. The mean duration time of each task is recorded and displayed within the bar chart. Each process task is stacked to represent the entire process step.

The axes of the Yamazumi chart are as follow:

- y axis represents cycle time.
- x axis represents each process step.

5.2.2 Benifits

Often, a target cycle time (mean cycle time) will be plotted to aid line balancing activities.

The Yamazumi board provides a mechanism to quickly rebalance a process when takt changes, and allows a visual indication of which operations are overloaded (beyond takt), and which are underutilized.

The Yamazumi chart is a great visual tool to show where delays, wastage and blocks are happening.

Yamazumi charts for all three engines were plotted to check the current state of the assembly line. In all the three graphs, there is a black horizontal line showing the takt time is drawn. Processes having cycle time above this line are undesirable and have a need to bring under the tank time line.

Takt time > Cycle time

5.2.3 Yamazumi chart for current state assembly line.

5.2.3.1 Yamazumi chart for Auto Engine is plotted below.

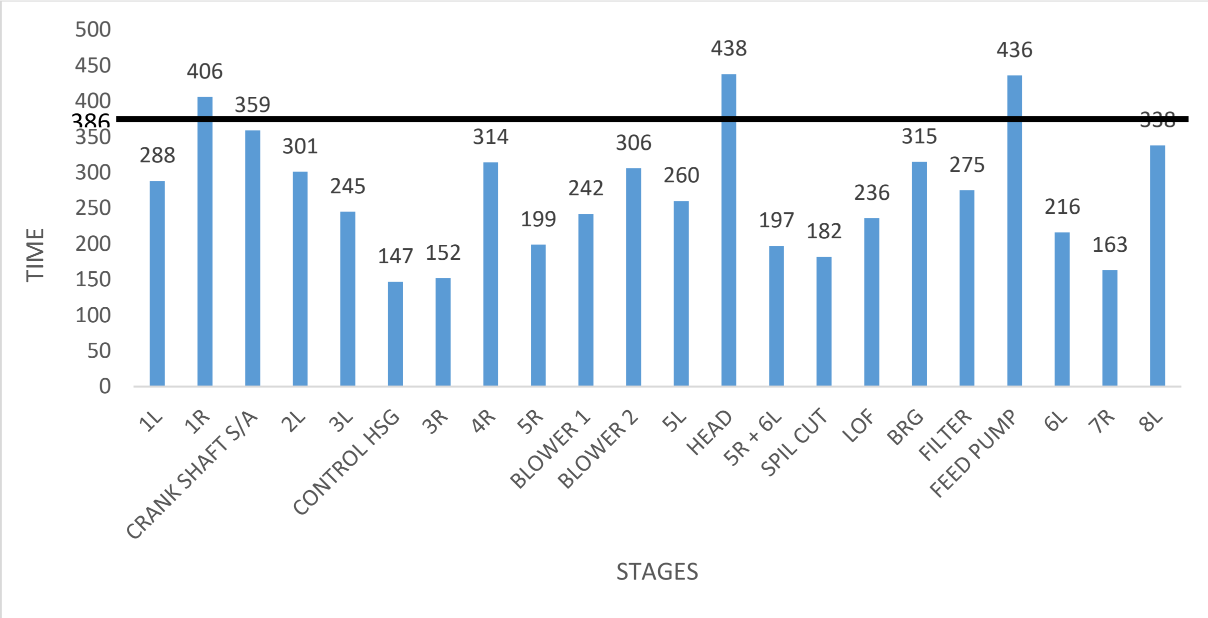

Figure 5.1 Yamazumi chart for auto engine

Yamazumi chart for Auto Engine contains a total of 22 stages including sub-assemblies.

Takt time = 386 seconds

Cycle time = 438 seconds

5.2.3.2 Yamazumi chart for ESG Engine is plotted below.

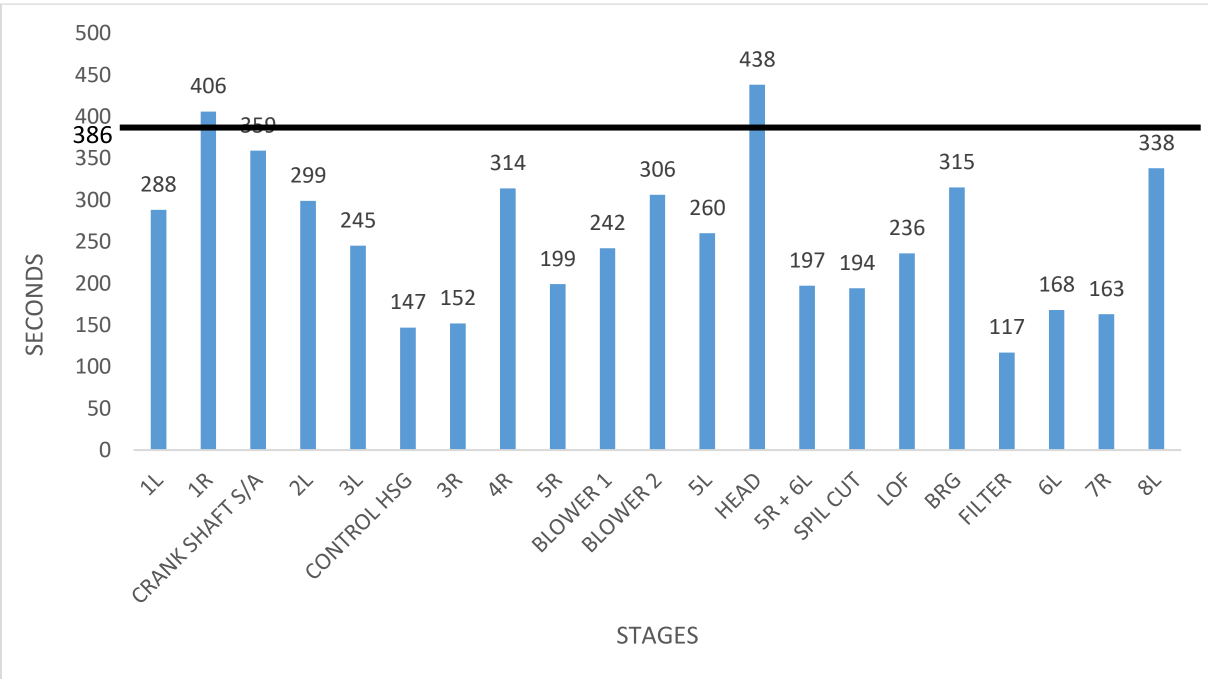

Figure 5.2 Yamazumi chart for ESG engine

Yamazumi chart for ESG Engine contains a total of 21 stages including sub-assemblies.

Takt time = 386 seconds

Cycle time = 438 seconds

5.2.3.3 Yamazumi chart for NC Engine is plotted below.

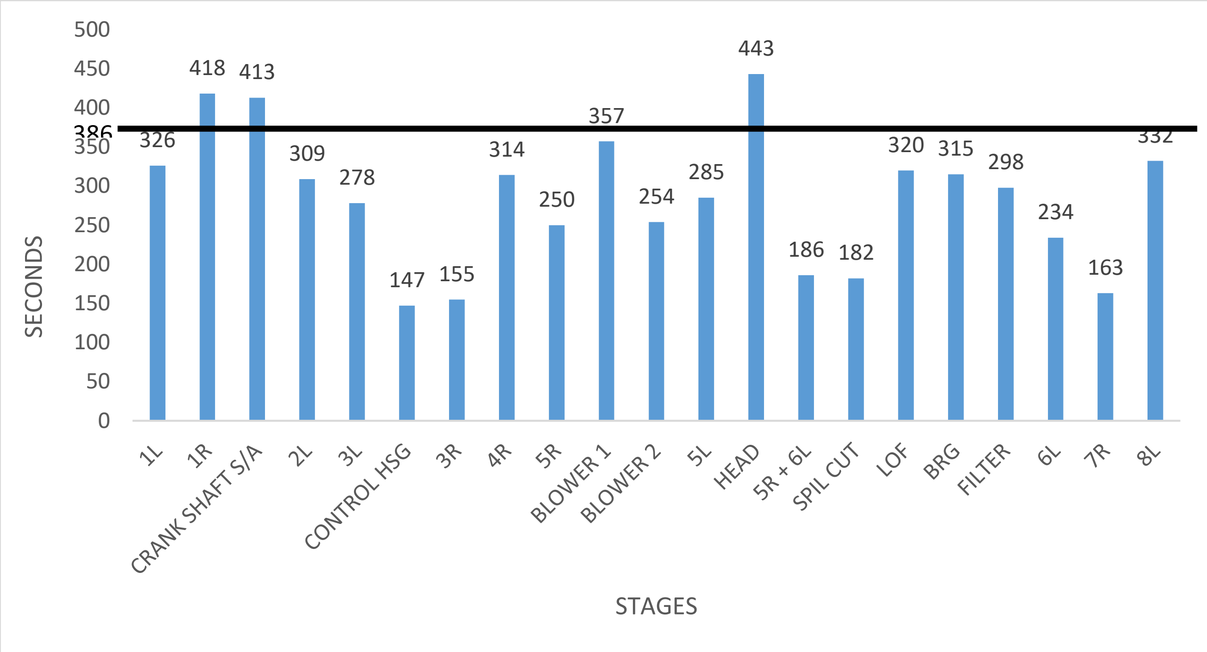

Figure 5.3 Yamazumi chart for NC engine

Yamazumi chart for NC Engine contains a total of 21 stages including sub-assemblies.

Takt time = 386 seconds

Cycle time = 443 seconds

5.2.4 Yamazumi chart for proposed assembly line

5.2.4.1 Yamazumi chart for Auto Engine is plotted below.

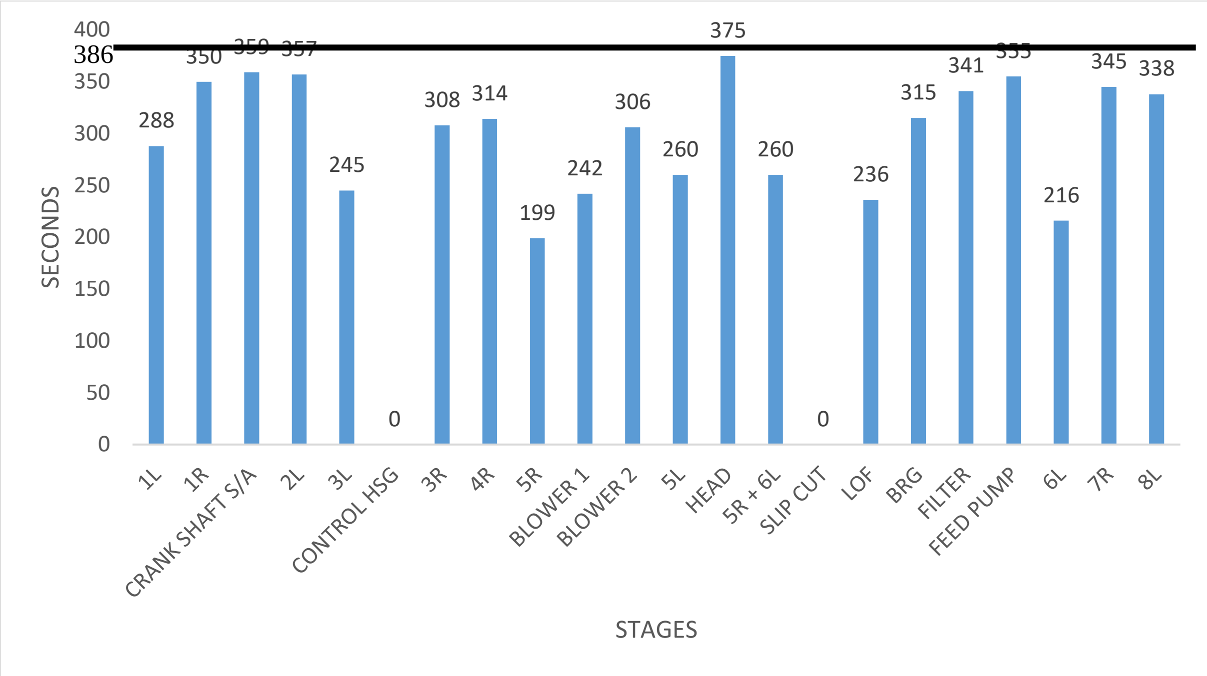

Figure 5.4 Yamazumi chart for Auto engine of new line

Yamazumi chart for Auto Engine contains a total of 22 stages including sub-assemblies.

Takt time = 386 seconds

Cycle time = 375 seconds

5.2.4.2 Yamazumi chart for ESG Engine is plotted below.

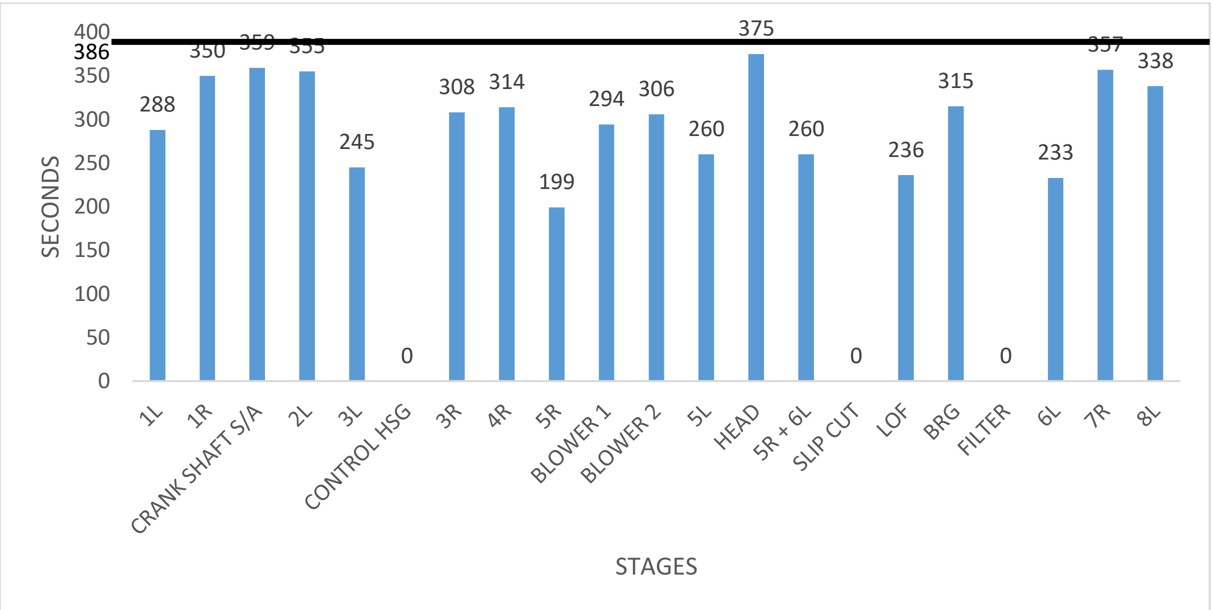

Figure 5.5 Yamazumi chart for ESG engine of new line

Yamazumi chart for ESG Engine contains a total of 21 stages including sub-assemblies.

Takt time = 386 seconds

Cycle time = 375 seconds

5.2.4.3 Yamazumi chart for NC Engine is plotted below.

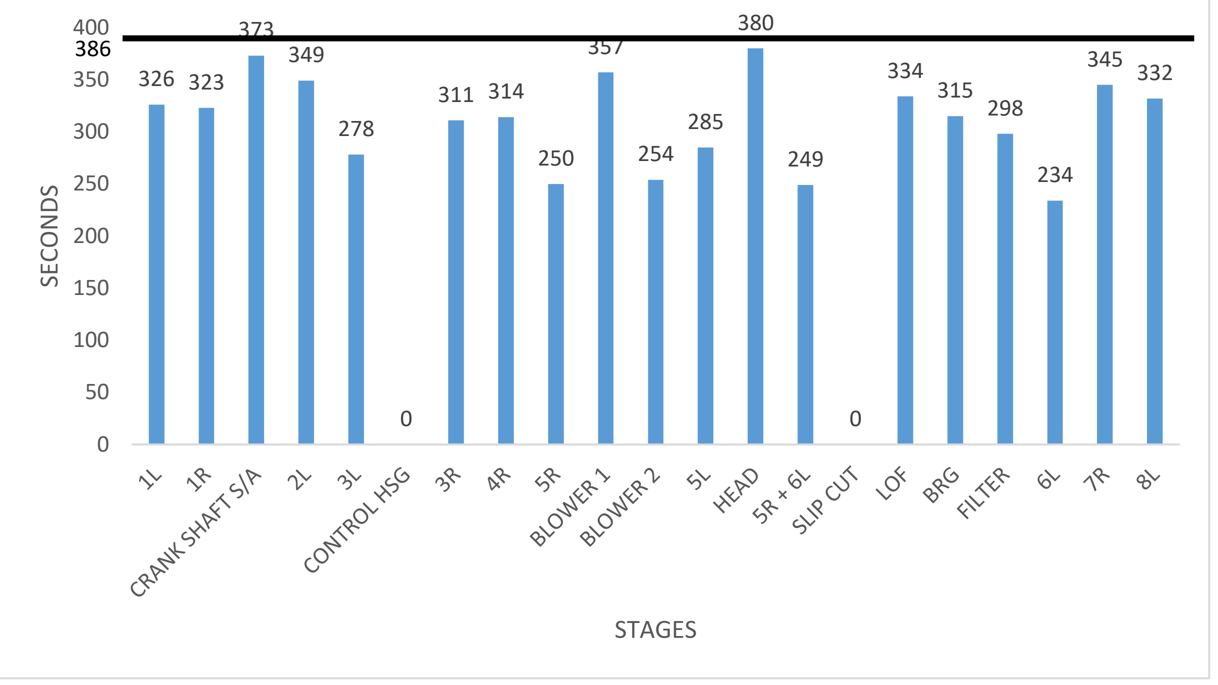

Figure 5.6 Yamazumi chart for NC engine of new line

Yamazumi chart for NC Engine contains a total of 21 stages including sub-assemblies.

Takt time = 386 seconds

Cycle time = 380 seconds

5.3 Calculations

5.3.1 Calculation for existing assembly line:

5.3.1.1 Auto engine:

Cycle time (C) = 438 seconds

Demand Rate = 70 units / shift

Assembly line operates 2 shift / day = 8.5 hours / shift

Total Operational Time = 8.5 hours – 1 hour = 450 minutes

Number of workstations (m) = 22

Sum of station time (STi) = 6015 seconds

$$\text{Takt time} = \frac{\text{Available Time for production}}{\text{Required Units of Production}}$$

$$= \frac{450 \text{ X } 60}{70} = 386 \text{ seconds}$$

$$\text{Line Efficiency} = \frac{\sum_{i=1}^{N} \text{STi}}{\text{m x C}} \text{ x } 100$$

$$= \frac{6015}{22 \text{ x } 438} \text{ x } 100 = 62.42 \%$$

$$\text{Smoothness Index} = \sqrt{\sum_{i=1}^{N} (C - STi)^2}$$

$$= \sqrt{(438 - STi)^2} = 867.93$$

5.3.1.2 ESG engine:

Cycle time (C) = 438 seconds

Demand Rate = 70 units / shift

Assembly line operates 2 shift / day = 8.5 hours / shift

Total Operational Time = 8.5 hours – 1 hour = 450 minutes

Number of workstations (m) = 21

Sum of station time (STi) = 5383 seconds

$$\text{Takt time} = \frac{\text{Available Time for production}}{\text{Required Units of Production}}$$

$$= \frac{450 \text{ X } 60}{70} = 386 \text{ seconds}$$

$$\text{Line Efficiency} = \frac{\sum_{i=1}^{N} \text{STi}}{\text{m x C}} \text{ x } 100$$

$$= \frac{5383}{21 \text{ x } 438} \text{ x } 100 = 58.52 \%$$

$$\text{Smoothness Index} = \sqrt{\sum_{i=1}^{N} (C - STi)^2}$$

$$= \sqrt{(438 - STi)^2} = 920.81$$

5.3.1.3 NC engine:

Cycle time (C) = 443 seconds

Demand Rate = 70 units / shift

Assembly line operates 2 shift / day = 8.5 hours / shift

Total Operational Time = 8.5 hours – 1 hour = 450 minutes

Number of workstations (m) = 21

Sum of station time (STi) = 5979 seconds

$$\text{Takt time} = \frac{\text{Available Time for production}}{\text{Required Units of Production}}$$

$$= \frac{450 \text{ X } 60}{70} = 386 \text{ seconds}$$

$$\text{Line Efficiency} = \frac{\sum_{i=1}^{N} \text{STi}}{\text{m x C}} \text{ x } 100$$

$$= \frac{5979}{21 \text{ x } 443} \text{ x } 100 \quad = \quad 64.27\ \%$$

$$\text{Smoothness Index} = \sqrt{\sum_{i=1}^{N} (\,C - STi)^2}$$

$$= \sqrt{(\,443 - STi\,)^2} \quad = \quad 821.36$$

5.3.2 Calculations for proposed assembly line:

5.3.2.1 Auto engine:

Cycle time (C) = 375 seconds

Demand Rate = 70 units / shift

Assembly line operates 2 shift / day = 8.5 hours / shift

Total Operational Time = 8.5 hours – 1 hour = 450 minutes

Number of workstations (m) = 22

Sum of station time (STi) = 6009 seconds

$$\text{Takt time} = \frac{\text{Available Time for production}}{\text{Required Units of Production}}$$

$$= \frac{450 \text{ X } 60}{70} = 386 \text{ seconds}$$

$$\text{Line Efficiency} = \frac{\sum_{i=1}^{N} \text{STi}}{\text{m x C}} \text{ x } 100$$

$$= \frac{6009}{22 \text{ x } 375} \text{ x } 100 \quad = \quad 72.73\ \%$$

$$\text{Smoothness Index} = \sqrt{\sum_{i=1}^{N} (\,C - STi)^2}$$

$$= \sqrt{(\,375 - STi\,)^2} \quad = 407.24$$

5.3.2.2 ESG engine:

Cycle time (C) = 375 seconds

Demand Rate = 70 units / shift

Assembly line operates 2 shift / day = 8.5 hours / shift

Total Operational Time = 8.5 hours – 1 hour = 450 minutes

Number of workstations (m) = 21

Sum of station time (STi) = 5392 seconds

$$\text{Takt time} = \frac{\text{Available Time for production}}{\text{Required Units of Production}}$$

$$= \frac{450 \text{ X } 60}{70} = 386 \text{ seconds}$$

$$\text{Line Efficiency} = \frac{\sum_{i=1}^{N} \text{STi}}{\text{m x C}} \text{ x } 100$$

$$= \frac{5392}{21 \text{ x } 375} \text{ x } 100 \quad = \quad 68.47\ \%$$

$$\text{Smoothness Index} = \sqrt{\sum_{i=1}^{N} (\,C - STi)^2}$$

$$= \sqrt{(\,375 - STi\,)^2} \quad = \quad 382.25$$

5.3.2.3 NC engine:

Cycle time (C) = 380 seconds

Demand Rate = 70 units / shift

Assembly line operates 2 shift / day = 8.5 hours / shift

Total Operational Time = 8.5 hours – 1 hour = 450 minutes

Number of workstations (m) = 21

Sum of station time (STi) = 5907 seconds

$$\text{Takt time} = \frac{\text{Available Time for production}}{\text{Required Units of Production}}$$

$$= \frac{450 \text{ X } 60}{70} = 386 \text{ seconds}$$

$$\text{Line Efficiency} = \frac{\sum_{i=1}^{N} \text{STi}}{\text{m x C}} \text{ x } 100$$

$$= \frac{5907}{21 \text{ x } 380} \text{ x } 100 \quad = \quad 74.02\%$$

Smoothness Index = $\sqrt{\sum_{i=1}^{N}(C - STi)^2}$

$$= \sqrt{(380 - STi)^2} \quad = \quad 352.27$$

Chapter 6

Result and Conclusion

6.1 Cycle Time

For proper functioning of assembly line,

Takt Time > Cycle Time

For all the three engine models, it was found that cycle time was way much higher than takt time. And to complete the production, operator have to work very fast which could result in fatigue on operator and he could miss a process activity.

To control the cycle time, some activity of a stage was transferred to another stage to reduce time at a particular stage.

6.1.1 Reduction in cycle time of AUTO Engine:

Cycle time of newly proposed assembly line after line balancing is 375 seconds.

Cycle time is reduced by (438 – 375) seconds = 63 seconds.

6.1.2 Reduction in cycle time of ESG Engine:

Cycle time of newly proposed assembly line after line balancing is 375 seconds.

Cycle time is reduced by (438 – 375) seconds = 63 seconds.

6.1.3 Reduction in cycle time of NC Engine:

Cycle time of newly proposed assembly line after line balancing is 380 seconds.

Cycle time is reduced by (443 – 380) seconds = 63 seconds.

6.2 Line Efficiency

6.2.1 Increment in line efficiency of AUTO Engine:

Line efficiency of newly proposed assembly line after line balancing is 72.73%

Increase in line efficiency = (72.73 – 62.42) %

= 10.31%

6.2.2 Increment in line efficiency of ESG Engine:

Line efficiency of newly proposed assembly line after line balancing is 68.47%

Increase in line efficiency = (68.47 – 58.52) %

= 9.95%

6.2.3 Increment in line efficiency of NC Engine:

Line efficiency of newly proposed assembly line after line balancing is 74.02%

Increase in line efficiency = (74.02 – 64.27) %

= 9.75%

6.3 Smoothness Index

Lower the smoothness index, better will be the balancing of the assembly line. To lower the smoothness index, time difference between processes was reduced as low as possible. Manpower reduction was also a great factor in lowering smoothness index.

6.3.1 Smoothness Index for AUTO Engine:

Smoothness index for current state assembly line = 867.93

Smoothness index for proposed assembly line = 407.24

Percentage improvement in Smoothness Index = 53.08%

6.3.2 Smoothness Index for ESG Engine:

Smoothness index for current state assembly line = 920.81

Smoothness index for proposed assembly line = 382.25

Percentage Improvement in Smoothness Index = 58.49%

6.3.3 Smoothness Index for NC Engine:

Smoothness index for current state assembly line = 821.36

Smoothness index for proposed assembly line = 352.27

Percentage improvement in Smoothness Index = 57.11%

6.4 Man-power

Reduction in man-power in production is viewed as one of the most desirable aspect for the company. Reducing man-power increases the productivity of the assembly line and company can save extra cost spent on operators. Some operators have very less activities to perform, so those activities were then transferred to others operators which then can perform easily under takt time.

6.4.1 Man-power for AUTO Engine:

Current state assembly line has 22 operators for different operations.

In newly proposed balanced assembly line, there is requirement of 20 operators only as activities of ‘Spil Cut’ and ‘Control housing’ stage was transferred to other operators.

Productivity Increase = 10%

6.4.2 Man-power for ESG Engine:

Current state assembly line has 21 operators for different operations.

In newly proposed balanced assembly line, there is requirement of 18 operators only as activities of ‘Spil Cut’ and ‘Control housing’ stage was transferred to other operators.

Productivity Increase = 14.29%

6.4.3 Man-power for NC Engine:

Current state assembly line has 21 operators for different operations.

In newly proposed balanced assembly line, there is requirement of 19 operators only as activities of ‘Spil Cut’ and ‘Control housing’ stage was transferred to other operators.

Productivity Increase = 10.53%

6.5 Conclusion

Systematic design and balancing of Assembly line is somewhat complicated, especially for the large-scale product customization due to uneven nature of tasks time of different models. But, in terms of not finding a good balancing structure supported by a proper sequencing of the models, the performances of the line will be poor which obstruct the overall assembly line based production scenario.

The research carried out in this report helps to identify the critical design parameter associated to assembly line balancing and sequencing. The methodology for assembly line balancing and sequencing addressed in this work distributes workloads of mixed-models to predefined workstations considering smoothed station assignment load. This results in optimizing the shift timing of assembly line for any combination of various models and defines a repetitive production lot planning from model sequencing.

The end result can be summarized as:

- Decrease in man power by 2 for AUTO engine, 2 for NC engine and 3 for ESG engine.
- Line efficiency increased by for 10.31% AUTO engine, for 9.75% NC engine and 9.95% for ESG engine.
- Smoothness index is improved by for 53.08% AUTO engine, for 57.11% NC engine and 58.49% for ESG engine.

6.6 Future Work

In a more complex assembly environment, there might be several constrains like equipment restrictions, facility layout restrictions, buffer allocation and stations length which essentially differ from plant to plant. For an overall understating of performances of assembly line balancing and sequencing, all those plant and line oriented constraints should be taken into account within the balancing methodology and this is considered to be the future extension of this work.

REFERENCES

1. Becker, C., & Scholl, A. (2006). A survey on problems and methods in generalized assembly line balancing. European Journal of Operational Research, 694-715.

2. Scholl, A. (1999) Balancing and Sequencing of Assembly Lines. 2nd Edition, Physical Verlag, Heidelberg, ISBN 3 – 7908-1180-7

3. Baudin, M. (2004). Lean Logistics: The Nuts and Bolts of Delivering Materials and Goods. New York: Productivity Press.

4. Aigbedo, H., & Monden, Y. M. (1997). A Parametric Procedure for Multi-Criterion Sequence Scheduling for Just-In-Time Mixed-Model Assembly Lines. International Journal of Production Research, 35 (9), 2543-2564.

5. Matthias Amen (2000)” An exact method for costoriented assembly line balancing”. International Journal of Production Economics, Vol. 64, pp. 187-195.

6. Matthias Amen Int. (2000) “Heuristic methods for cost-oriented assembly line balancing: A survey”. International Journal of Production Economics, Vol. 68, pp. 1-14.

7. Mingzhou Jina, S. David Wub (2002) “A new heuristic method for mixed model assembly line balancing problem”. Computers & Industrial Engineering, Vol. 44, pp.159–169.

8. Krzysztof Fleszar, Khalil S. Hindi (2003) “An enumerative heuristic and reduction methods for the assembly line balancing problem”. European Journal of Operational Research Vol. 145, pp. 606–620.

9. Selcuk Karabati, Serpil Sayin (2003) “Assembly line balancing in a mixed-model sequencing environment with synchronous transfers”. European Journal of Operational Research, Vol. 149, pp. 417–429.

10. Ana Sofia Simaria, Pedro M. Vilarinho (2004) “A genetic algorithm based approach to the mixed model assembly line balancing problem of type II”. Computers & Industrial Engineering, Vol. 47, 391–407.

11. J. Fonseca, C.L. Guest, M. Elam, and C.L. Karr (2005) “A Fuzzy Logic Approach to Assembly Line Balancing”. Mathware & Soft Computing, Vol.12, pp. 57-74.

12. Hadi Gokcen, Kursat Agpak, Cevriye Gencer, Emel Kizilkaya (2005) “A shortest route formulation of simple U-type assembly line balancing problem”. Applied Mathematical Modelling Vol.29, pp. 373–380.

13. Kursad Agpak, Hadi Gokcen (2005) “Assembly line balancing: Two resource constrained cases”. Int. J. Production Economics Vol.96, pp.129–140.

14. Yossi Bukchin, Ithai Rabinowitch (2006) “Production, Manufacturing and Logistics A branch-and-bound based solution approach for the mixed-model assembly line-balancing problem for minimizing stations and task duplication costs”. European Journal of Operational Research Vol.174, pp. 492–508.

15. Gregory Levitin, Jacob Rubinovitz, Boris Shnits (2006) “A genetic algorithm for robotic assembly line balancing”. European Journal of Operational Research Vol.168, pp.811–825.

16. Hadi Gokcen, Kursat Agpak (2006) “A goal programming approach to simple U-line balancing problem”. European Journal of Operational Research Vol.171, pp.577–585.

17. Nguyen Van Hop (2006) “A heuristic solution for fuzzy mixed-model line balancing problem”. European Journal of Operational Research Vol.168, pp.798–810.

18. Rita Gamberini, Andrea Grassi, Bianca Rimini (2006) “A new multi-objective heuristic algorithm for solving the stochastic assembly line re-balancing problem”. Int. J. Production Economics Vol.102, pp.226–243.

19. B.L. Song, W.K. Wong, J.T. Fan, S.F. Chan (2006) “A recursive operator allocation approach for assembly line-balancing optimization problem with the consideration of operator efficiency”. Computers & Industrial Engineering Vol.51, pp.585–608.

20. Alexandre Dolgui, Nikolai Guschinsky, Genrikh Levin (2006) a special case of transfer lines balancing by graph approach. European Journal of Operational Research 168, 732–746.

21. Christian Becker, Armin Scholl Invited review (2006) “A survey on problems and methods in generalized assembly line balancing”. European Journal of Operational Research Vol.168, pp.694–715.

22. Yeo Keun Kim, Jae Yun Kim, Yeongho Kim (2006) “An endosymbiotic evolutionary algorithm for the integration of balancing and sequencing in mixedmodel U-lines”. European Journal of Operational Research Vol.168, pp.838–852.

23. Marc Peeters, Zeger Degraeve (2006) “A linear programming based lower bound for the simple assembly line balancing problem”. European Journal of Operational Research Vol.168, pp. 716–731.

24. Timothy L. Urban, Wen-Chyuan Chiang (2006) “An optimal piecewise-linear program for the U-line balancing problem with stochastic task times”. European Journal of Operational Research Vol.168, pp.771–782.

25. Daisuke Hirotani, Myreshka, Katsumi Morikawa, Katsuhiko Takahashi (2006), “Analysis and design of self-balancing production line”. Computers & Industrial Engineering Vol.50, pp.488–502.

26. Sotirios G. Dimitriadis (2006) "Assembly line balancing and group working: A heuristic procedure for workers' groups operating on the same product and workstation". Computers & Operations Research Vol.33, pp.2757–2774 from www.elsevier.com/locate/cor.
27. Sophie D. Lapierre, Angel Ruiz, Patrick Soriano (2006) "Balancing assembly lines with tabu search". European Journal of Operational Research Vol.168, pp.826–837.
28. Hadi Gokcen, Kursad Agpak, Recep Benzera (2006) Balancing of parallel assembly lines. Int. J. Production Economics 103, 600–609.
29. Matthias Amen (2006), "Cost-oriented assembly line balancing: Model formulations, solution difficulty, upper and lower bounds". European Journal of Operational Research Vol.168, pp.747–770.
30. Yossi Azar, Amir Epstein, Leah Epstein (2006) "Load balancing of temporary tasks in the lp-norm". Theoretical Computer Science Vol.361, pp. 314 – 328 from www.elsevier.com/locate/tcs