FACILITY LAYOUT OPTIMIZATION OF EXHAUST MUFFLER MANUFACTURING USING ARENA DISCRETE-EVENT SIMULATION

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DECLARATION

I hereby declare that the research work titled "Facility Layout Optimization of Exhaust Muffler Manufacturing using Arena Discrete-Event Simulation" and / or any of its contents have not been submitted in support of any application for any other degree / certification to any other university or institute. It is my own work based on my research and has been submitted only to PNEC-NUST in partial fulfillment of the requirements of the degree of Master of Science (MS) in Manufacturing Engineering & Management.

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DEDICATION

This thesis report is dedicated to my beloved parents, all family members and faculty members for their dedicated support and encouragement.

ACKNOWLEDGEMENT

I would like to thank the ALMIGHTY ALLAH for providing me the strength to carry out this research. I also express my gratitude for my family, specially my parents for providing me the required support throughout the duration of this thesis.

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LETTER OF ACKNOWLEDGEMENT

January 7, 2018

TO WHOM IT MAY CONCERN

Subject: Letter of acknowledgement for Engineering Research done by MS (ME&M) student from NUST

This is to certify and acknowledge that Mr. Mansoor Ahmed Khan, who is MS student at National University of Science and Technology (NUST), Pakistan Navy Engineering College (PNEC), Industrial and Manufacturing Engineering (IME) department having registration number NUST201463725MPNEC45414F has conducted an engineering research in our company in exhaust muffler shop for the purpose of optimizing its facility layout and improvement of productivity using Arena Discrete Event Simulation software.

We found the outcomes of this research work as quite promising in improving the facility layout of the exhaust muffler shop and would definitely consider applying them at some suitable time in future.

We would like to express our appreciation for the work and dedication that have been put in by Mr. Mansoor Ahmed Khan and other members of the research in achieving the objectives.

Thank you very much.

Sincerely,

Mr. Iftikhar Ahmed

Senior General Manager Production

Loads Limited

Exhaust Systems manufactured under Licence from

FUTABA INDUSTRIAL CO. LTD, Japan

ABSTRACT

The facility layout of any manufacturing organization is one of the main factors that determine its overall operational effectiveness and performance. A facility layout that is not optimally planned cannot contribute to the growth of the company. This study was aimed at optimizing the facility layout of exhaust muffler assembly at Loads Limited, a leading manufacturer of automotive parts to renowned customers. The principles of Facility Layout Problem (FLP) were applied in conjunction with Discrete Event Simulation. The framework of this study is applicable to any manufacturing facility layout having product layout. Moreover, it can also be applied to the operation of service-based organization after slight modifications. The study is based on primary data collected by means of direct observations made on the shop floor which was then used to develop simulation models. Key Performance Indicators (KPIs) related to manufacturing systems were addressed including lead time, cycle time and material handling costs. After analyzing the current facility layout, two improved layouts were proposed. The study concluded that the lead time improved by 26.3% & 73.4%, cycle time by 16.6% & 33.4% and material handling costs by 20% and 68% for the two proposed layouts respectively.

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LIST OF ABBREVIATIONS

FLP: Facility Layout Planning

DES: Discrete Event Simulation

VSM: Value Stream Mapping

WIP: Work In Progress

SIMAN: Simulation Analysis

GUI: Graphical User Interface

SLP: Systematic Layout Planning

QAP: Quadratic Assignment Problem

CRAFT: Computerized Relative Allocation of Facilities Technique

GBT: Graph Based Theory

SA: Simulated Annealing

DFLP: Dynamic Facility Layout Problem

MMF: Modified Material Flow

TOC: Total Operating Cost

LP: Linear Programming

KPI: Key Performance Indicator

MSR: Manufacturing Space Ratio

MIP: Mixed Integer Programming

CHAPTER 1

INTRODUCTION

1.1 Overview of the Company

Loads Limited was formed in 1979 as a private limited company with the objective of manufacturing exhaust systems, radiators, and sheet metal components for the automotive industry. The Company was converted to public limited company on January 12, 1994. Since its formation, the company has seen continuous growth due to the quality of its products with its clientele consisting mainly of multi-national assemblers of passenger cars, light commercial vehicles, heavy commercial vehicles (trucks & buses), tractors and motor cycles. The Company has three wholly owned subsidiaries, namely, Specialized Autoparts Industries (Private) Limited, Multiple Autoparts Industries (Private) Limited and Specialized Motorcycles (Private) Limited. Currently, the key customers of the company are Toyota, Honda, Suzuki, Hino, Nissan, Isuzu, Massey-Ferguson, Mitsubishi, Yamaha, etc. The Company has acquired ISO-9001 and ISO-14001 certifications to enhance and maintain highest levels of quality standards. The company has shown significant dedication to quality improvement as reflected by its numerous technical collaborations with leading Japanese firms like Toyo Radiator Company, Futaba Industrial Company, Sankei Giken Kogyo, Yutaka Giken, Hamamatsu Pipe & Futaba to acquire latest technology and equipment. Moreover, besides manufacturing of automotive parts, the company also houses a die-designing and manufacturing facility comprising of CNC automatic die manufacturing machines. The Group’s head office and manufacturing facility is located at Korangi Industrial Area, Karachi. The remaining manufacturing facilities are housed in the two wholly owned subsidiaries, situated in Bin Qasim, Karachi.

1.2 Manufacturing Process of the Exhaust Muffler System

The sequence of stages for the production of exhaust systems is as follows:

1. Shell forming
2. Shell flanging
3. Shell ovaling
4. Neck spotting
5. Partition inserting
6. Partition spotting
7. Seaming
8. Welding (Final Assembly)
9. Air leak testing
10. Cleaning & final inspection

The production of the exhaust muffler systems is based on a sequential flow. Pieces of metal sheet that are cut to size arrive at the first station, i.e. shell forming station, where they are rolled to form a shell. Once this process is done, it moves on to the next station in the sequence mentioned above until it reaches the final station and converted to finished product. These various stages of production are represented in figure 1.

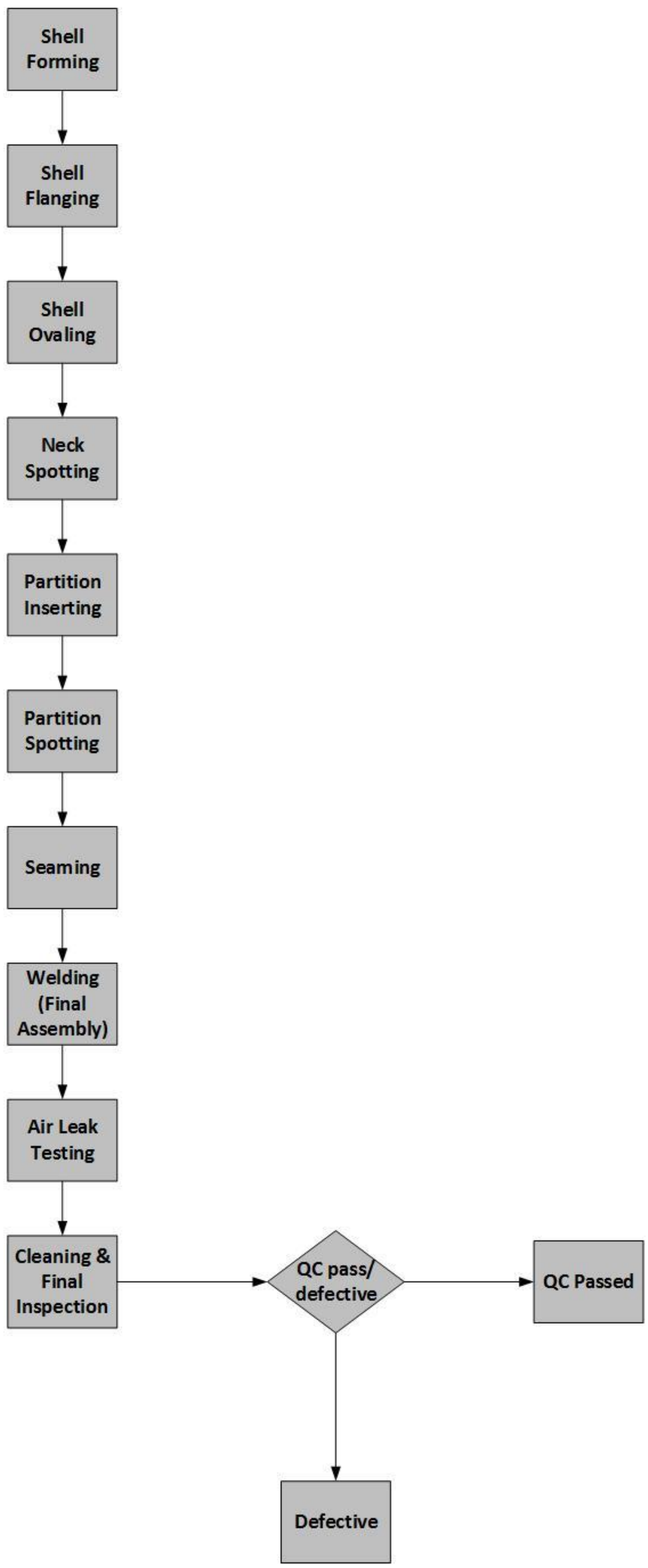


Figure 1. *Flow chart of various processes of exhaust muffler manufacturing*

1.3 Research Rationale

Designing of an efficient facility layout is one of the most significant factors when it comes to the capability and competence of a manufacturing industry. A production facility with poorly designed arrangement of workstations / equipment cannot compete with the market forces in terms of lead times and costs. To design a sound facility layout, or to optimize an existing layout, there are a number of tools that available that can help increase productivity. One of such tools is Facility Layout Planning (FLP) which enables a manufacturing organization to increase its productivity by streamlining the work flow within the facility.

The objective of this study is to utilize Facility Layout Planning through simulation to enable the company to increase its productivity and eliminate wastes at the same time by optimizing the flow of work within the facility. This study will contribute towards the reduction of lead times, costs, inventory levels and improvement of the facility's productivity.

1.4 Problem Statement

The company has been facing tough competition from other market forces, and thus needs to be on a continuous improvement course. It currently needs to reduce its manufacturing lead time (which is currently around 6 minutes / muffler) for its exhaust muffler production line in order to deliver customer orders quickly. The reason behind this need for improvement is that its competitors, mainly, Atlas Engineering, Thal Engineering, Crown engineering and Landhi Engineering present a serious competition in the business.

At present, the daily production demand of the facility is approximately 90 exhaust mufflers that is expected to go up to around 110mufflers per day in future. However, this demand is seldom met on a per day basis and therefore, the company has to operate additional shifts and overtimes that result in additional costs. An increase in the production capability of the facility by means of improvement would eliminate the need for overtimes/additional shifts, resulting in cost saving as well as lead time reduction.

1.5 Objectives of the Study

The objectives of this research are as follows:

a) Reduction of unnecessary movements of the material

One of the foremost objectives of this research was to eliminate unnecessary movement of the material that contributes towards waste. There was zigzag as well as back tracked movements of the material that resulted in unnecessary movement which is a type of waste. Both the distances travelled and the time consumed due to unnecessary movements were reduced.

b) Reduction in levels of work-in-process inventory

Higher level of work-in-process inventory is another element of waste. In this research, efforts were made to reduce the level of WIP inventory. The simulation software Arena is capable of calculating WIP inventory levels when adequate input parameters are provided. This would in turn make it possible to quantify WIP level.

c) Introduction of an efficient material handling system

An efficient material handling system has been introduced in the process that would contribute towards reduction in lead time as well as costs. Moreover, it would help in streamlining the whole production process.

d) Streamline the layout by placing machines at optimum distances

The facility layout has been optimized by placing workstations closer to each other resulting in lesser traveling distances and time required. This has in turn reduced the lead time.

e) Reduce overall lead time by eliminating wastes

Reduction of lead time has been the most important aspect of this study. Each of the above objectives ultimately resulted in the reduction of lead time. The simulation software made it possible to quantify the lead time and reduce it.

1.6 Thesis Layout

This thesis report is organized into following chapters.

a) **Chapter 1:** The first chapter comprises of the overview of the company along with the product. Besides these, it also contains the problem statement, objectives of the study and its structure.

b) **Chapter 2:** The second chapter provides the literature review regarding the Facility Layout Problem and relevant case studies.

c) **Chapter 3:** The third chapter provides the methodology that was applied to carry out the research and achieve its objectives.

d) **Chapter 4:** The fourth chapter consists of the discussion and analysis regarding the current layout model.

e) **Chapter 5:** The fifth chapter consists of analysis of improved layouts and the results.

f) **Chapter 6:** The last chapter provides the avenues for future work along with the conclusion of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Facility Layout Problem

There are a number of aspects that are critical to a production facility's overall operational efficiency. One of them is the layout of the factory or shop floor. It can be defined as the way in which different machines / equipment are arranged within the shop floor. The aim of having an optimal layout is to ensure the smooth flow of material through the system. The way in which the various machines, facilities and amenities of the employees are located has a significant impact on the efficiency of production. Smooth and rapid flow of material, starting as raw material and ending as finished product, is only possible if the layout is optimally designed. Facility layout problem can be defined as the technique of placing different machines, workstations, processes within the shopfloor or factory in order to achieve the best mix of right output quantity and quality at minimal manufacturing costs. It also involves techniques to achieve the lowest amount of handling and movement that is required to convert raw material into finished product. It should help in achieving a number of objectives to ensure proper and efficient utilization of available floor space, availability of sufficient production capacity, efficient utilization of labour, reduction in accidents, volume and product flexibility, high utilization of equipment / machines, improvement in productivity, and employees' / workers' safety and health.

The design of a sound facility layout should be given due importance in the early stages of the designing of a production facility. According to Tompkins et al, material handling accounts for an estimated expense of 15-50% of the total costs incurred within the manufacturing system. Other factors that are influenced by the facility layout are system efficiency, lead time and work in process inventory. Newer forms of layouts like flexible and cellular manufacturing systems have been adapted in last two or three decades due to the fact that such layouts play a significant role in improving the efficiency and flexibility of a manufacturing system.

2.2 Discrete Event Simulation

Discrete Event Simulation (DES) is a type of simulation in which changes are marked at precise points in the simulated time. The parameters / variables of the modeled system that is being simulated are updated only at some precise points in time, called event. This is in contrast to continuous simulation in which these parameters / variables are tracked continuously in the simulated time. In DES, change of state in the system is updated once an event is occurred and therefore between two consecutive events, it is assumed that no change has taken place. This assumption allows the simulation to jump from one event to the next event directly in time. As a result, the DES is able to run comparatively faster than continuous simulation due to the fact that it does not need to track the variables continuously. This research is carried out using Arena simulation that is a Discrete Event Simulation software.

2.3 Arena Simulation

Arena is a simulation software produced by Rockwell Automation based on DES. It offers a number of graphical tools, called modules to create a model representing any physical system that needs to be simulated. These modules can be used to model processes, resources (such as workers, machines, equipment) distances, transportation systems and other elements. Arena uses the SIMAN language for simulating a model. The code based on SIMAN language runs in the background once the model is created using the GUI based modules. These modules provide a convenient way of developing a simulation model. Moreover, student versions of this software are also available because of which it was selected to conduct this research.

Figure 2 shows the Arena window with the Project Bar, Reports and Navigate tabs at the left. The central area is the one in which the modules are placed in order to create a simulation model. The Project Bar consists of different groups of modules, e.g. Basic Process and Advanced Transfer. At the top there is a toolbar containing various tools that are required for simulation model development.

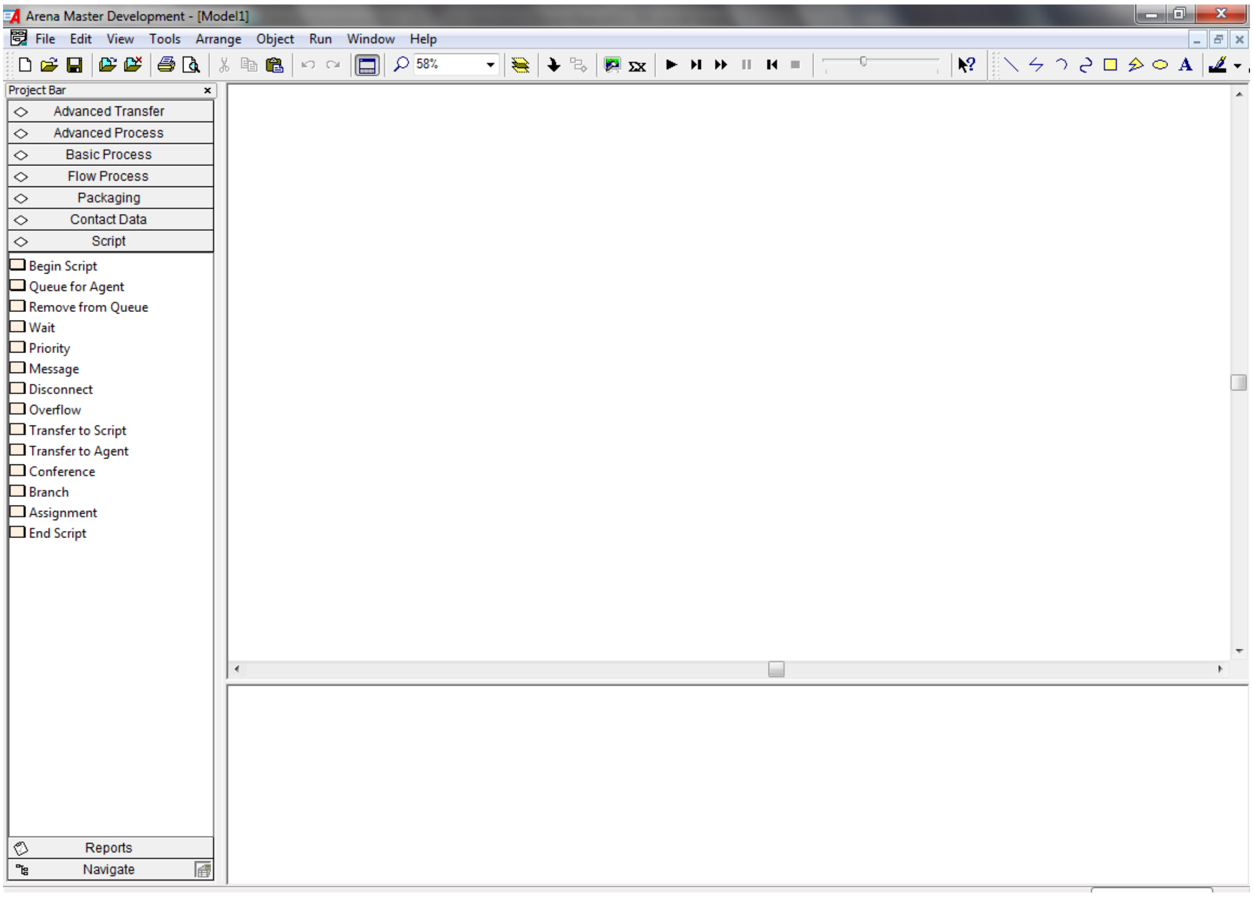


Figure 2. *The Arena window*

2.4 Applications of Facility Layout Problem

There have been various approaches taken to address the problem of facility layout optimization. Multi floor problems are much difficult to deal with as compared to single-floor layouts due to travelling time and distance and vertical transportation of material. Hosseini [1] employed the Systematic Layout Planning (SLP) method to optimize layout of a card and packet production facility having 20 departments and two floors by devising a plan based on material flow analysis and closeness rating. Distance charts on "from" and "to" basis for the material were developed, and number of movements between departments were recorded in order to obtain total distances travelled, which in turn provided closeness ratings. Multiple versions of the improved layouts were then devised on the basis of closeness ratings, with higher values given higher preference. Each was modelled in discrete time simulation software to analyze the results. The most optimized model yielded a decrease of 25.41 in the distance travelled and improvement of 36.84% in cross-traffic. Hosseini [1] concluded that the most significant layout problems of the company were cross traffic, higher travelling distances and costs. However, the authors did not address the bottlenecks that might have been present in the system which could have provided further improvements. Moreover, the approach was limited to a multi-floor layout only.

Kim [2] argued that the facility layout problems are usually described as the Quadratic Assignment Problem (QAP) that involves assignment of 'n' facilities to 'm' locations (m ≥ n). In these QAPs, all facilities are assumed to be identical and in terms of shape and size. However, the fact that the facilities usually have unequal sizes poses a limitation to the application of QAP. As a result, researchers have stressed on considering facilities with unequal sizes, for which a number of heuristic algorithms have been proposed. The QAP model was first put forward by Koopmans and Beckman and was NP-complete (Nondeterministic Polynomial Time). However, being NP, it is very much difficult even for a very powerful computer to handle a large instance of such problem. In QAP approaches, the most significant objective had been to minimize cost, time, distance travelled and flow.

Hari [3] used CRAFT (Computerized Relative Allocation of Facilities Technique) algorithm to determine an optimum layout for a typical manufacturing layout design. It is also known as computerized heuristic algorithm and it takes a matrix called load matrix as input that consists of flows between different departments along with transaction costs. The algorithm was used to compute departmental allocations and to estimate costs incurred. The main objective of the algorithm was to minimize total cost function. Number of departments were also required as input by the CRAFT algorithm. The algorithm was modelled in a computer program based on Java. An average of 57.95% improvement was observed for 5 planning periods.

Sa'udah [4] improved facility layout by using VSM (Value Stream Mapping) in conjunction with Discrete Event Simulation. The subject company was an SME involved in snack food production. The layout was developed by analyzing distance between machines, size of room, frequency of movement of material, information flow, communication between departments, safety and capacity. The initial operations of the company were modelled into VSM which is a tool that sketches the flow of value added and non value added activities required to transform raw materials into finished goods along with the visualization of the flow of information. The current state VSM was analyzed and optimized to form the future state VSM. Then, the optimized future state VSM was simulated on computer software to analyze the improvement outcomes. The authors concluded that the distance between machines/workstations and the time required to perform each step should be given prior importance. However, the author did not provide any figures regarding the improvements achieved.

Ojaghi [5] discussed layout optimization for small and medium scale food industry by combining Systematic Layout Planning (SLP) with Graph Based Theory (GBT). A company producing food products was targeted with the objective of coming up with an optimized facility layout that can reduce material handling costs and losses and distances travelled. Through this approach, multiple alternative layouts were generated and the best was selected on the basis of Efficiency Rate (ER) that was calculated for each layout. According to Chien [6], the Facility Layout Planning FLP can be divided into four parts namely data input, procedure's process, output results and evaluation process. The GBT is an algorithm based on adjacency of work cells and does not consider inter-departmental distances. The work included determination of the number of machines required under new capacity conditions, the area for each department, and the area that would be required around each machine. GBT algorithm was then employed to determine the most significant adjacency between the departments. Based on this, thirteen new layouts were generated and the one with the highest efficiency rate was selected. Matlab software was also used to enhance the best layout, as a result of which its efficiency rate increased from 90.43% to 94.78%. The researchers concluded that it is very important to conduct facility and layout planning prior to setting up a facility in order to ensure sustainable operation and loss reduction. The author, however, did not provide any specific details regarding the initial situation of the parameters. In fact, it stressed on generating newer layouts and then further improving the best one.

Tuzkaya [7] conducted a comparative analysis of meta-heuristic approaches taken towards the FLP optimization in context of an elevator manufacturer. The authors applied three different methods to solve the problem; Genetic Algorithm (GA), Simulated Annealing (SA) and a hybrid algorithm—Genetic Algorithm/Simulated

Annealing (HGASA). The two main objectives of the study were to minimize the total penalty values and material handling costs. It is necessary to place the departments closer that have high frequency of material flow between them. Genetic Algorithm is a search method that is stochastic and based on the natural selection and genetics. The algorithm requires an initial set of random solutions, known as population. The best solution is selected, based on an iterative process involving measurements of fitness (fitness tests). Simulated annealing (SA) is a probabilistic technique for approximating the global optimum of a given function. The researchers concluded that the best algorithm on the basis of fitness values and time related aspects is SA. However, they also noted, that as the problem size increases, the suitability of HGASA would also increase. The researchers came up with a novel solution by hybridizing two different techniques. However, provision of numeric values regarding comparison of initial and final states would have increased the impact of the research.

Anjos [8] proposed a two-stage optimization-based framework for unequal-areas facility layout by integrating two different mathematical models. The first step involved finding a nonlinear approximation for the solution of the problem, which provides a relative position of the various departments that form the facility. The second step involved exact convex optimization formulation of the problem that completes the solution by devising the final layout. The research focused on minimizing total costs associated with the flow between departments. The researchers found that the FLP is difficult for two reasons, firstly the various constraints that are present lack consistency and connection, and secondly the management of the aspect ratio of the departments. The work included calculations of squared Euclidean distance between departments in order to determine the overlapping limits. The researchers ended up with mixed results in comparison to previously deployed methods in terms of cost reductions and aspect ratio sensitivity analysis. The approach was found to be efficient and capable of generating optimized layouts. The algorithm is limited to solving problems of up to 100 departments which pose a limitation to its capabilities. On the other hand, the researchers focused on exploring a newer and lesser explored domain of FLP, i.e. departments with unequal areas.

Ulutas [9] addressed the Dynamic FLP in context of a footwear industry. Dynamic FLP (DFLP) is the FLP that is analyzed on the basis of multiple periods. The footwear industry was chosen as it exhibits seasonal demand changes and thus is a valid example for DFLP. The main aim of FLP as defined by authors is to increase the variety as well as the quality of the products. The research emphasized on flexible and reconfigurable manufacturing environments that exhibit demand patterns. The study utilized AIS (Artificial Immune System) algorithms to solve the DFLP. AIS have been found to be effective in dealing with routing and scheduling problems along with the numerical functions' optimization. The study involved analysis of N facility layouts for T periods. Other key attributes included flow between machines at a specific time and the distance between them. The researchers noted 5.4312% decrease in material handling costs when the original layout was improved by AIS. The research employed a heuristic technique in contrast with an exact technique. Heuristic techniques differ from exact and other techniques in that the method employed for problem solving may not be necessarily perfect or optimal. They are; however, capable of providing results is comparatively lesser time as compared to exact methods. Heuristic techniques can yield reasonable results in comparatively lesser time. Moreover, they can be used to obtain approximate solutions in cases where the classic approaches fail to provide an exact solution. Although results provided by heuristic methods may not be the optimum ones, they are adequate enough to meet immediate requirements.

Tarkesh [10] took a Virtual Multi-Agent System (VMAS) approach to solve the FLP. The research was a novel work based on multi-agent society in which 'agents' interactions result in the facility layout design. The main idea behind the research was that each facility was considered as an agent having inherent characteristics, emotions, amount of money that form its utility functions. Each unoccupied position is presented to all the 'applicant' agents and the one that offered highest price (in proportion to its utility function) was allocated the unoccupied position. Fuzzy logic was used to determine the utility function of each agent. The authors also stated that minimizing total material handling costs is the foremost objective of the FLP. The desirability of each location is defined for each agent's special utility function. The researchers used a modified SA method termed as "Parallel Adaptive Simulated Annealing" (PASA) involving both SA and GA concepts. The researchers concluded that VMAS outperformed improved CRAFT method in devising a layout having minimized costs. This novel approach was found to be better than the traditional heuristic and meta-heuristic techniques used for solving FLP.

Amaral [11] proposed an exact approach to the FLP related to one-dimension. The research involved arrangement of n departments of specific lengths on a line and at the same time minimizing the weighted sum of the distances between all the pairs of departments. The ODFLP (One Dimensional FLP) was described as the one that requires arrangement of facilities to reduce the total costs associated with the communication between all the pairs of departments. The problem is of much significance when it comes to arranging rooms in a corridor inside a building. The paper proposed a much effective mixed integer programming model capable of solving larger problems than those solvable by previous mixed integer models. A 0-1 (binary) quadratic program was used to solve the problem by determining the distance between centroids of the departments. The results demonstrated that the mixed integer programming model was able to solve problems of up to n=18 within reasonable time span.

Paul [12] put forward an algorithm known as Particle Swarm Optimization (PSO) to address the FLP involving passages and inner structure walls. The PSO algorithm was developed by Eberhart and Kennedy in 1995 as a simple evolutionary algorithm that is inspired by social behaviour. The algorithm is perhaps a swarm intelligence method that approximates the social behaviour of swarms. The researchers stated that PSO has features of both GA as well as Evolution Strategies (ES). The research used the number of facilities to be placed, available area, its boundary shape, and number of inner wall structures and flow of material between the facilities as some of the key parameters for the algorithm. The researchers defined the objective of the algorithm as minimization of the material flows between facilities while addressing other aspects like area constraints, aspect ratios etc. at the same time. The algorithm was tested for eight facilities and its performance was found to be superior to the GA as well as improved GA algorithms. The research was a notable effort regarding the new dimension of including inner structure walls and passages.

Cheng [13] defined FLP as identification of a location that is feasible for a group of interrelated objects while fulfilling all the design requirements and maximizing design quality along with cost minimization. To address FLP, they proposed another hybrid algorithm based on swarm intelligence for decision making. It involved integration of two swarm intelligence algorithms, the PSO (Particle Swarm Optimization) and BA (Bee Algorithm) and was named as PBA (Particle Bee Algorithm). It was based on the intelligent swarming behaviour of the honeybees and birds. The algorithm featured improved optimum search technique by utilizing neighbourhood windows technique and also included self-parameter updating technique. The researchers compared the results of PBA with PSO and BA and found it at par with both of them making it a sound option for solving FLPs with high dimensionality.

Djassemi [14] addressed the FLP under the special conditions involving mixed floor and overhead space utilization for materials. The study involved adjustment of flow of material under these specific conditions in context of a lawn mower engine assembly facility. Generally, the departments that have higher flow of material are placed closer during facility layout planning that demonstrates the strong relationship that exists between them. The researcher argued that most of the literature lacks the consideration of overhead space utilization and the trade-off that exists between it and interdepartmental distances. In fact, most of the literature deals with arrangement of departments closer to each other on the basis of material flow, not considering the fact that whether the transportation of material is accomplished by floor equipment or by overhead equipment. To address this, (Djassemi, 2006) used Modified Material Flow (MMF) as a measure defined as the product of overhead material flow volume in terms of unit loads between two departments and a weighting factor representing the ratio of the operational cost incurred in moving material between two departments by overhead equipment to that incurred for the same volume of material by floor equipment. The researcher improved the layout of the lawn mower assembly facility by combining the MMF approach and SLP. Two layouts were generated, one corresponding to actual material flow, and the other based on MMF factor. It was found that the one using MMF factor was much economical as it reduced Total Operating Cost (TOC) by 20.8%, whereas the one using actual material flow reduced TOC by 14.95%. The research was a noteworthy effort to address the unexplored domain of FLP and the approach can be applied to any plant layout having the mentioned specific conditions.

Aiello [15] addressed the FLP through a multi objective approach involving genetic search algorithm combined with Electre method. The researchers argued that the FLP involves several aspects to be considered that result in conflicting objectives. The Electre method is a decision making procedure that considers multiple criteria and is particularly useful in situations where a set of alternatives need to be ranked in accordance with a set of criteria based on the preferences of the decision maker. The research incorporated optimization of layout having rectangular shape with height H and width W. The research focused on the four aspects of the FLP namely handling cost, adjacency between departments, distance/separation between departments and aspect ratio of departments. The optimization process comprised of two stages. In the first stage, different solutions based on trade-off's were proposed with due consideration to the constraints. In the next stage, further information on the problem was used to evaluate and compare the different possible solutions using Electre method. The methodology was applied to a layout of 20 departments. The research was an innovative approach towards the FLP that considered multiple conflicting aspects at the same time.

Konak [16] presented a Linear Programming Based Genetic Algorithm for the unequal area facility layout problem. The research involved development of a new encoding scheme called the location/shape encoding scheme. The problem was formulated by means of Mixed Integer Programming (MIP), whereas Linear Programming (LP) and Genetic Algorithm (GA) were employed for the solution. The research considered number of departments, set of departments having positive flows, areas and the position of centroids of the departments as the key input parameters. The hybrid approach first searched the relative locations of the departments in the facility using GA. Then, the LP model was used to determine the shape and location of departments. The GA was thus able to generate new solutions by integrating different solutions found using LP. Several test problems were solved using this approach to test its validity, and the algorithm was found to be capable of improving an existing solution or finding the previous best-known solution for that problem. The researchers only provided graphical results as no numerical results were mentioned for comparison. The research was perhaps able to consider both size and orientation of the departments when solving the FLP which is a significant effort.

McKendall [17] presented the application of heuristics for the dynamic facility layout problem having unequal-area departments. One of the significant aspects of the paper was that the departments could have free orientations and unequal areas. The researchers focused on optimizing the DFLP such that the sum of the material handling costs as well as cost associated with re-arrangement of departments is minimized. The methodology applied for solving the DFLP comprised of three steps. The first step was to analyze flow data in order to determine the sequence for selection of departments to be placed on the facility floor. The next step was to use a placement procedure to place departments on the floor. This step generates a layout plan along with its cost. The last step as applied by the researchers was to utilize table search for improving the layout plan achieved by the previous step. The methodology was applied to two test problems, out of which the first problem comprised of 6 departments with 6 periods, whereas the second problem comprised of 12 departments with 4 periods. The results obtained validated the effectiveness of the algorithm. The researchers could have tested the algorithm with much larger problems to show its ability, however, this would have not been possible due to which development of an improved algorithm to deal with smaller and larger problems was recommended as future work by the researchers.

Datta [18] presented a permutation based genetic algorithm to solve the single row facility layout problem. The objective was to arrange n facilities along a line with the aim to minimize the costs associated with transportation between them. To achieve this, the researchers defined a function to be minimized as the sum of the products of the material flow between each of the ordered pair of facilities and the distance between their centres. The researched comprised of initialization of GA population by random permutations along with some rule-based permutations of the facilities. Then, the population was improved towards the optimum by means of specially formulated permutation based operators that produce new permutations of the facilities. The GA was coded in C language and was tested for 14 traditional instances of the single row FLP whose optimal solutions were already known. However, these 14 instances were of size $n \leq 30$. As a result, the researchers included additional 20 instances of sizes between 60 and 80 to demonstrate the algorithms effectiveness for larger sized instances. The optimum solution of the 20 instances was not known. The GA was found to be successful in devising the global optimum solution for each instance out of its 30 runs. Moreover, for the additional 20 instances, the GA was able to improve 9 of their previously known solutions. It was noted that the GA tends to become dependent on user-defined parameters as the size of instance increases. As a result, study should be targeted to reduce this dependency.

Sahin [19] proposed a simulated annealing algorithm for the purpose of solving the facility layout problem of bi-objective nature. The two objectives addressed were minimization of total material handling cost and the maximization of total closeness rating scores. The first one is a quantitative whereas the second is a qualitative factor. A properly designed layout can contribute towards reduced production cycles, work-in-process inventories and material handling times and increased output. SA algorithms usually begin with an initial solution that is randomly generated or a solution that is generated using heuristic methods. In this paper, the researcher initialized a randomly generated solution. The algorithm advanced by moving the search from current solution to a neighbouring solution by switching two departments that are selected randomly. In this way, an optimum solution is reached. The researcher tested the algorithm for two sets of test problems comprising of 6 instances containing 8, 12, 8, 12, 15 and 20 departments each. The results of test runs were compared with previously devised algorithms and tabulated. The SA algorithm produced results that were either similar to those of the previous ones or better. The algorithm achieved a best improvement of 9.66% for the problem set 2 of 8 departments. The algorithm, however, produced similar results most of the time and in most of the cases where there was an improvement, it was not very high. However, the noteworthy aspect of the research is that it addressed two important FLP objectives at the same time.

Goncalves [20] presented a biased random-key genetic algorithm (BRKGA) for solving unequal area facility layout problem. The paper involved placing a set of rectangular facilities of given area requirements on a floor space having rectangular shape. In this approach, overlapping of the facilities was not allowed and this was achieved by making use of the concept of empty maximal-spaces. The research included two different types of facility layout problems, unconstrained and constrained. In constrained case, problems with given dimensions for the final layout were considered whereas for unconstrained case, the dimensions of the floor space were determined by the optimization algorithm. The unconstrained approach was found to improve the best known solutions for14 out of 16 benchmark datasets while the constrained version improved the best known solutions for 5 of 12 studied benchmark datasets.

Azevedo [21] addressed the multi-facility layout problem with the objective of achieving flexibility and efficiency in operations. The study considered two aspects of facility layout; the location of departments within a group of facilities and the location of departments within each facility itself. The approach taken to solve the problem was based on Quadratic Programming Problem involving multiple objectives and unequal areas. As a result, the researchers were able to come up with the ability to reconfigure layout for each planning period. The researchers focused on reduction of material handling costs and improvement of adjacency between departments. The research was applied to company that produces plastic parts for the automotive industry. In total, 13 departments, 13 locations and 3 periods were considered in order to represent the dynamics of the model.

Pourhassan [22] considered the importance to analyze the layout and its re-designing due to the changes in demand. The researchers used a simulation model to minimize material handling and related costs. They came up with a non-dominated sorting genetic algorithm (NSGA-II) which was able to find the optimum solution for the problem. The study involved considering a manufacturing system having 'm' machines processing 'n' types of products. The products required processing by different subsets of the m machines. The number of periods in the planning horizon was also considered. Another objective of the model was to reduce the cost associated with machine re-arrangement. The study presented a novel approach that considered several significant aspects related to the facility layout problem.

Prajapat [23] used discrete event simulation model to analyze and optimize the factory layout of a repair facility. The study was focused on enabling the decision makers to analyze various potential layouts and configurations and select the best suited in order to optimize production. In total, 12 machines were modeled within the overhaul process that could be selected and moved in order to modify the layout. For material movement between machines, 4 cranes and 4 trolleys were also modeled to represent the material handling system. Cycle times of processes and data related to material movement was fed to the simulation model. The researchers improved various key performance indicators (KPIs) related to production such as the distance traveled by material and machine utilization.

Kulturel-Konak [24] put forward a zone-based block layout to solve the problem of dynamic facility layout. This zone based layout has the ability to adapt to different material handling systems due to the fact that it includes a variety of possible aisle structures. The research involved arrangement of unequal area departments in flexible zones having pre-determined locations. To achieve this, a matheuristic approach was employed which is derived from the combination of Tabu Search (TS) and mathematical programming. The Tabu Search algorithm was used to determine the relative positions of the departments. The dimensions of the departments were considered as decision variables. The researchers concluded that the algorithm provided significant results in solving the given facility layout problem.

Palomo-Romero [25] proposed an island model genetic algorithm to address the FLP of unequal area. The use of island model genetic algorithm was aimed at solving the problems, such as lack of diversity and higher computational costs, encountered with other algorithm based approaches such as mathematical models, heuristics and metaheuristics. The approach was able to provide better solution for 12 out of 20 problems when compared with the colony optimization algorithm. Moreover, it also outperformed the probabilistic tabu search algorithm for 12 problems. In short, the proposed algorithm was able to either match up or surpass the performance of previously proposed algorithms. The research was a significant attempt towards solving FLP that not only provided a new approach that solved many problems faced previously but also provided a comparison with other approaches as well.

Kang [26] came up with the idea of harmony search (HS) based heuristic algorithm to address the UAFLP. The study used Slicing Tree Structure (STS) which is described as an encoding scheme that arranges a layout in the form of a tree structure. The STS operates by dividing the floor space in either horizontal or vertical direction within a given floor space. The researchers considered various facility-related parameters such as the number of departments, dimensions of the floor space and the departments and the volume of material flow between different departments. The research was subjected to constraints that prevented departments from overlapping and make sure that they are positioned in the given floor space. The researchers coded the algorithm using JAVA. The algorithm was applied to data sets of problems that are well known having number of departments ranging from 7 to 62. The study concluded that the proposed algorithm proved to be reliable in solving the given problems as it was able to find the best solutions for most of the problem sets it had been applied to.

Yegul [27] addressed the FLP in context of the modern trend of multinational firms off-shoring their operations from workforce-intensive to capital-intensive production environments. This off-shoring usually requires the re-configuration of the manufacturing systems to match with the available machinery. The research was applied to a company planning to set up a manufacturing facility for electric car components. Simulation based approach was taken to solve the given problem using SIMUL8 software. Expected annual demand, costs and raw material and product costs and processing times of processes were provided as input to the software. A simulated annealing approach was formulated to benchmark the optimization. Various approaches for simulation-based optimization were taken and their results were compared with each other in terms of the quality of the solution provided by each of them and the speed with which they can compute the given problem.

Grobelny [28] proposed a novel version of the simulated annealing (SA) algorithm in order to solve the facility layout problem. The proposed algorithm was based on fuzzy theory approach and linguistic patterns (LP). The solution involved application of the algorithm on regular grids in which objects were modeled by a single cell or a group of cells. The researchers did not find any evidence of linguistic pattern being used in any of the previous studies. The research demonstrated the effectiveness of this simulated annealing algorithm in finding solutions with high mean truth involving complex facility layout problems. However, the researchers noted that the computational time for executing the algorithm was somewhat greater than those of other approaches. The study encompassed four different types of facility layout problems. The study concluded that the said algorithm was capable of finding logical, reasonable and satisfactory solutions to the facility layout problems.

Safarzadeh [29] put forward the use of genetic algorithm (GA) to solve an extended multi-row facility layout problem with fuzzy clearances. The multi-row FLP is defined as a type of FLP in which cells are arranged in a fixed number of rows in order to achieve minimum material handling costs. This is in contrast to single row FLP in which cells are arranged in a single row only. One of the unique aspects of this study was the evaluation of a special type of cost related to FLP, called lost opportunity cost. This cost is associated with spaces that are wasted. In this research, the distance between any two facilities was considered as a fuzzy number. This allows the existent inaccuracy in the distances to be reflected in the model. The research involved optimizing multi row FLP (MRFLP) in a two-dimensional environment with the objective of minimizing lost opportunity cost, material handling cost and the distance traveled by the material on the shop floor. A multi-product system was chosen to apply the algorithm. The study considered a production environment having two products and five machines.

Pourvaziri [30] addressed the dynamic facility layout problem based on open queuing network theory. The researchers argued that in most of the studies that have been conducted regarding the solution of the facility layout problem, the main objective is the minimization of the material handling cost. However, in this study another aspect that usually goes unaddressed, work-in-process inventory (WIP) was also considered. The authors took a two-step analytical approach to solve the FLP. The manufacturing system was modeled such that the behavior of each machine was analyzed as a generally distributed queuing system. In total 32 problems were formulated to test the approach. The researchers were able to demonstrate the accuracy of the proposed approach by means of a case study. The work can be regarded as a novel contribution as it considered WIP as well in the model.

Thus, it can be concluded from the above literature review that there are a number of dimensions for a facility layout that can be improved to enhance productivity. These include various costs like material handling cost and total operating costs, lead time, waste reduction, resource utilization, adjacency between workstations and work-in-process and other inventory levels. Different approaches have been taken by different researchers to address the Facility Layout Problem. Each approach comes with its own advantages as well as limitations. Moreover, in most of the cases, cost reduction has been the focus of the researchers, and as a result, lead time reduction has remained comparatively less explored.

CHAPTER 3

RESEARCH METHODOLOGY

The research was based on primary data that was acquired by means of direct observation. This collected data was then used to develop the simulation model for the current layout. This model representing the current production layout was then simulated to record the various parameters.

3.1 Data Collection

Data was gathered in terms of:

1. Number of operations
2. Resources required for each operation
3. Cycle time of each operation
4. Distance between workstations
5. Speed of movement of material between workstations
6. Lot sizes
7. Machine Footprints & Value-adding areas

Cycle times for each operation were measured by means of a digital stopwatch, whereas the distances between the workstations were measured by means of a measuring tape. Speed of movement of material between workstations was determined by measuring the time taken by the transporter to cover a pre-determined distance. Similarly, lot sizes were determined by direct observation. In order to gather data that is precise and accurate, multiple observations for cycles times were made at different times were made and their average was calculated. The readings for cycle times were evaluated against the normal values to determine their validity. This resulted in reduced errors that are associated with such measurements. Machine footprints and value-adding areas were also calculated by using measuring tape.

3.2 Key Inputs and Outputs of the Model

The following table lists the key inputs required by Arena Simulation software / research to execute a model, and the various outputs.

Table 1. *Table of various input and output parameters of the research*

Inputs (units)	Outputs (units)
Cycle time of each operation (minutes)	Total Time (minutes)
Distance between workstations (feet)	Value Added Time (minutes)
Speed of movement of material between workstations (feet/minute)	Wait time (minutes)
Batch size (number of units, dimensionless)	Transfer time (minutes)
Machine footprints and areas where value is added (square feet)	Work In Process Inventory (number of units, dimensionless)
	Resource utilization (expressed as percentage)
	Material handling cost (rupees/unit)
	Manufacturing Space Ratio (dimensionless)

a) Cycle Times

The current layout was modelled on the basis of data gathered by means of direct observation. The company operates an 8 hour shift per day, and to gather accurate and reliable data, two samples of readings were taken twice per shift for a period of 15 days. The average of these readings was used for further analysis. The exhaust muffler undergoes 10 different processes before being converted to a finished product. Following are the cycle times for each of the operation expressed in seconds.

Table 2. *Table of cycle times of workstation processes*

Process No.	Process Name	Cycle Time (seconds)
1	Shell forming	36
2	Shell Flanging	26
3	Shell Ovaling	32
4	Neck Spotting	30
5	Partition Insertion	26
6	Partition Spotting	33
7	Seaming	45
8	Welding	120
9	Leakage Testing	60
10	Cleaning and Final Inspection	75

b) Speed of Movement of the Material

Trolleys are used to move material from one work station to another and require a worker to operate. These trolleys travel at a speed of 4 feet / sec. In total, six trolleys are used on the production floor each driven by a worker.

c) Batch Size

The production facility operates at batch size of 5 units.

d) Machine Footprints & Value Adding Areas

The machine footprints and the areas where value is added to the product were measured by means of measuring tape.

e) Distances between Workstations

The following table represent the distances (in feet) between the workstations.

Table 3. *Matrix of distances b/w workstations (in feet) in current layout*

Station Name		Shell forming	Shell Flanging	Shell ovaling	Neck spotting	Partition insertion	Partition spotting	Seaming	Welding	Leakage testing	Cleaning & final inspection
	Station Number	1	2	3	4	5	6	7	8	9	10
Shell forming	1	0	30	10	78	30	50	93	116	120	110
Shell flanging	2	30	0	33	100	53	73	113	100	135	125
Shell ovaling	3	10	33	0	68	20	40	83	104	108	100
Neck spotting	4	78	100	68	0	48	28	15	38	40	32
Partition insertion	5	30	53	20	48	0	20	63	86	89	80
Partition spotting	6	50	73	40	28	20	0	43	66	68	60
Seaming	7	96	113	83	15	63	43	0	50	26	17
Welding	8	116	100	104	38	86	66	50	0	35	36
Leakage testing	9	120	135	108	40	89	68	26	35	0	9
Cleaning and final inspection	10	110	125	100	32	80	60	17	36	9	0

Figure 3 shows the distances between various workstations and the total available shopfloor area. In figure 4, the various movements of the material between workstations as it moves through the production process are shown.

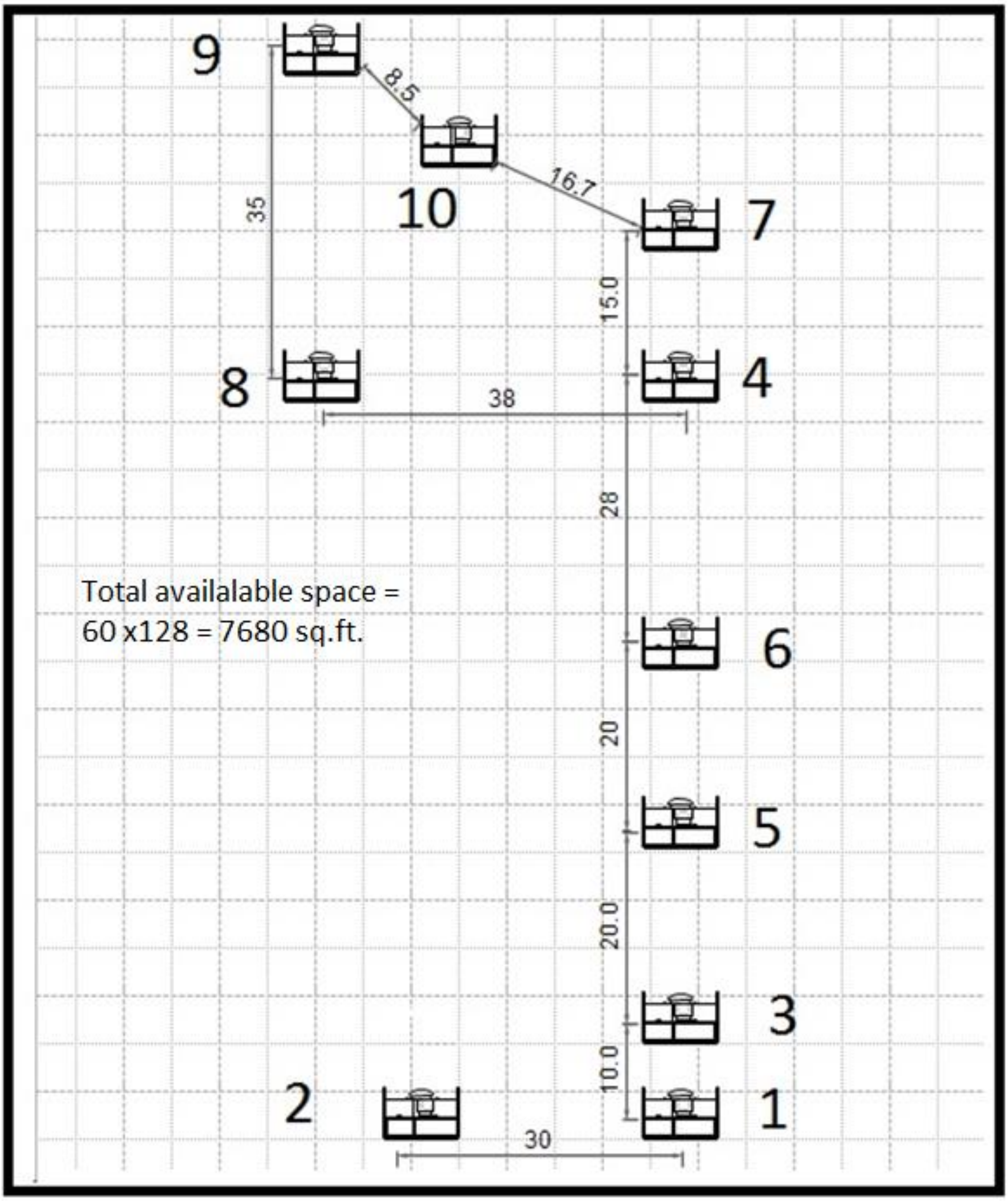


Figure 3. *Distances between workstations (in feet) for current facility layout*

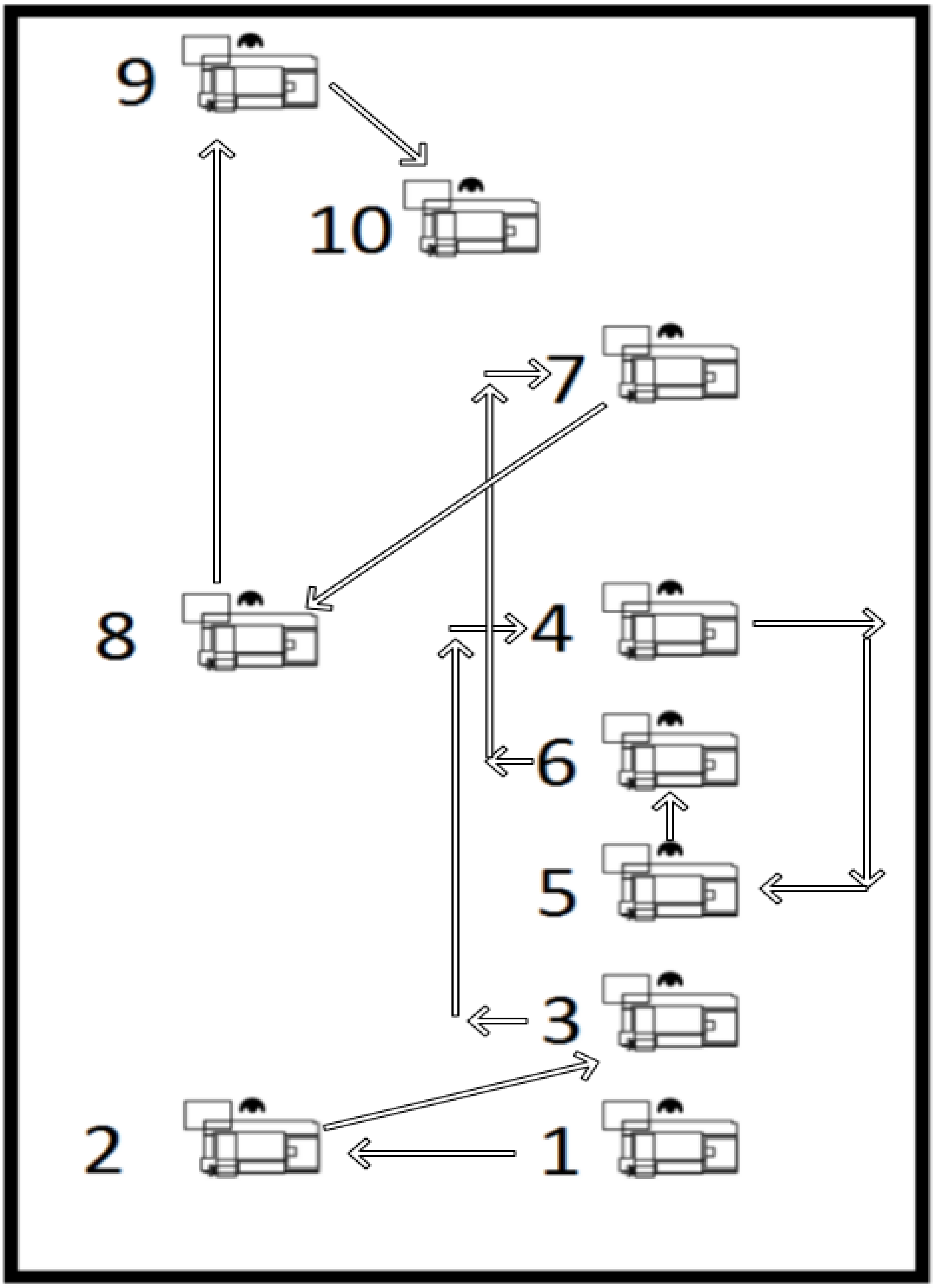


Figure 4. *Flow of material between workstations for current facility layout*

3.3 Simulation Model Development for the Current Layout

Based on the data collected, the current layout model was created on Arena Simulation and output results in terms of total time (lead time), value added and non-value added time, transfer and wait time and work in process inventory were recorded. These parameters provide significant information regarding the performance of a facility layout.

3.4 Simulation Model Validation

The simulation model that was developed for the current facility layout was then validated in order to determine the degree to which it is an exact representation of the real world production scenario from the perspective of its intended use. Three parameters were used to validate the simulation model.

3.5 Identification of Areas of Improvement

In the next step, avenues of improvement were identified in order to optimize the overall performance of the facility layout. The transfer of material from one workstation to another, means of material movement, distances between the workstations, lot sizes and related parameters were analyzed and improved so as to come up with optimized facility layouts whose performance metrics are better than those of the existing layout.

3.6 Simulation Model Development of Improved Layout

Once the improvements were made, they were translated to the Arena Simulation model to form the improved layout. This improved model was run and the outputs were recorded. These output parameters form the basis of improvement in the facility layout of the exhaust muffler manufacturing.

3.7 Develop and Interpret Results

The last step of the research was to come up with the results regarding the improvement in the facility layout. The output parameters of the current layout simulation model were compared to those of the improved layout simulation model in order to determine the extent to which they have been optimized.

This research has helped in devising improved layouts for the company's exhaust muffler manufacturing facility that can enable the company to achieve its shorter lead time goal. This has been done by placing workstations in a manner such that the flow of material is streamlined, by reducing the distances between them and optimizing the material transportation system.

Figure 5 provides a flowchart representation of the various steps involved in the research methodology.

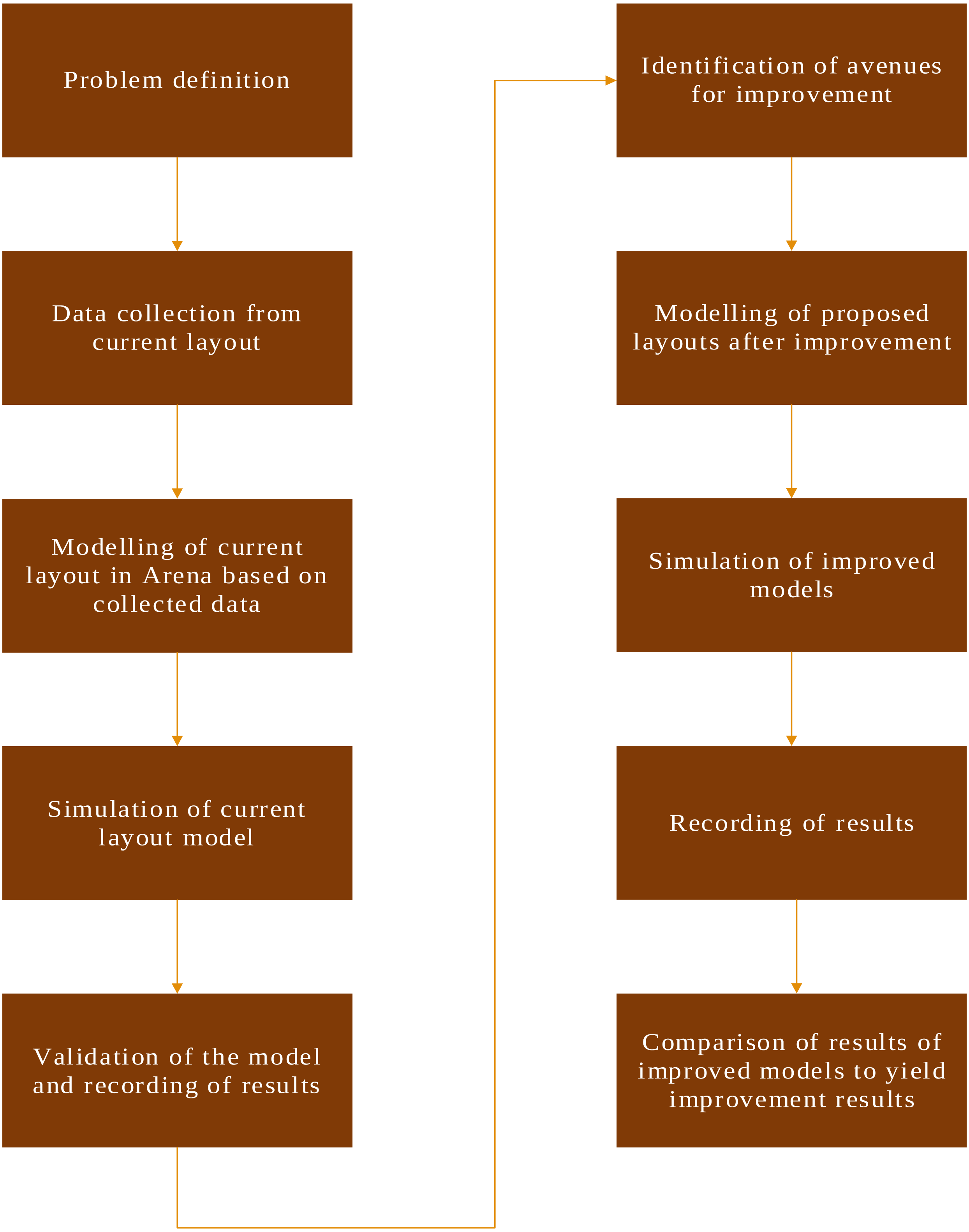


Figure 5. *Flow chart of various steps of research methodology*

CHAPTER 4

SIMULATION MODEL DEVELOPMENT, ANALYSIS AND RESULTS

4.1 Modelling of Current Layout

a) Modelling Processes

All the processes that take place are defined in the Arena model using the "Process" block. In the process block, the name of the process, the time taken, the resources utilized, the allocation of time (value added, non-value added etc) and the type of the process are defined. In our case, all the processes are of "Seize Delay Release" type, which means that the process first seizes the required resources, adds a time delay (which is the actual processing time) and then releases the resources. All the process times are defined as Value Added, whereas the time taken by each process and the resources required were defined accordingly.

Process - Basic Process

	Name	Type	Action	Priority	Resources	Delay Type	Units	Allocation	Value	Report Stati
1	Shell forming	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	36	☑
2	Shell Flanging	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	26	☑
3	Shell ovaling	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	32	☑
4	Neck spotting	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	30	☑
5	Partition insertion	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	26	☑
6	Partition spotting	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	33	☑
7	Seaming	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	45	☑
8	Welding	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	120	☑
9	Leakage testing	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	60	☑
10	Cleaning and final inspection	Standard	Seize Delay Release	High(1)	2 rows	Constant	Seconds	Value Added	75	☑

b) Modelling Resources

All the resources were modelled using the Resource tool. Workers and the machines / equipment required by each process are defined along with their capacity. It is assumed that all machines and workers are available whenever they are required by the process.

Resource - Basic Process

	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics
1	Workers	Fixed Capacity	21	0	0	0.0		0 rows	☑
2	Cleaning and inspection equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
3	Shell forming equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
4	Shell flanging equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
5	Shell ovaling equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
6	Neck spotting equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
7	Partition spotting equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
8	Seaming equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
9	Welding equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
10	Leakage testing equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑
11	Partition insertion equipment	Fixed Capacity	1	0.0	0.0	0.0		0 rows	☑

Double-click here to add a new row.

c) Modelling Transporters

Transporters that are required for moving the material from one station to another were modelled using the Transporter toolbox. Six trolleys (transporters) are used on the exhaust muffler production floor that each move with a speed of 3 feet per second.

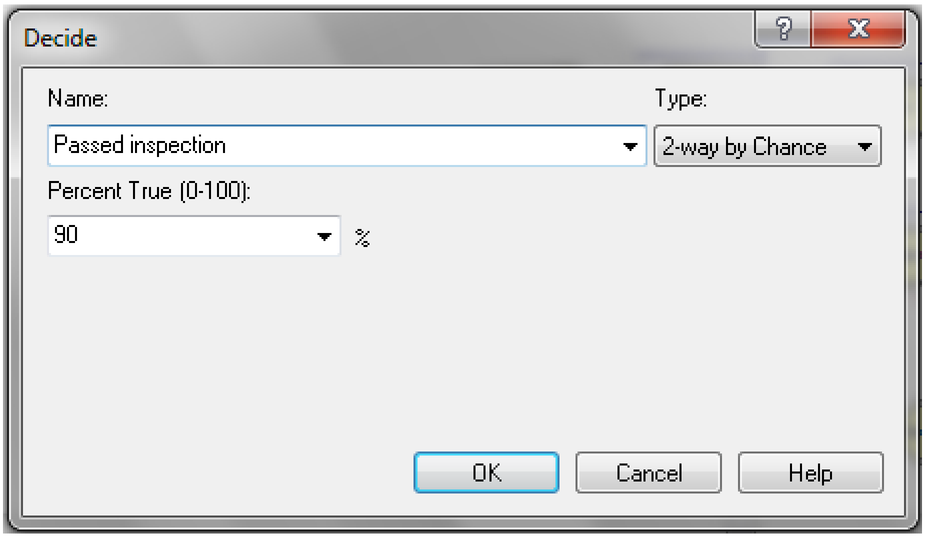
Transporter - Advanced Transfer

	Name	Number of Units	Type	Distance Set	Velocity	Units	Initial Position Status	Report Statistics
1	Transporter 1	1	Free Path	Transporter 1.Distance	3	Per Second	0 rows	☑
2	Transporter 2	1	Free Path	Transporter 2.Distance	3	Per Second	0 rows	☑
3	Transporter 3	1	Free Path	Transporter 3.Distance	3	Per Second	0 rows	☑
4	Transporter 4	1	Free Path	Transporter 4.Distance	3	Per Second	0 rows	☑
5	Transporter 5	1	Free Path	Transporter 5.Distance	3	Per Second	0 rows	☑
6	Transporter 6	1	Free Path	Transporter 6.Distance	3	Per Second	0 rows	☑

Double-click here to add a new row.

d) Modelling the Cleaning and Final Inspection process

The last of the ten processes that an exhaust muffler undergoes is the cleaning and the final inspection process. In this process, the exhaust mufflers are cleaned and inspected for any defect / damage. If the exhaust muffler is free of defects and damages, it is declared as QC passed, whereas if it fails the final inspection, it is declared as QC failed. Data showed that nearly 10% of the exhaust mufflers that undergo inspection are found to be defective, whereas 90% pass the inspection process. This functionality in the simulation model is accomplished by using the DECIDE module. In this module, the probability for the TRUE outcome (muffler passes the QC process) is defined as 90% and thus the probability of FALSE (muffler fails the QC process) becomes 10%. In this way, the model follows the real production scenario.



The complete Arena simulation model for the current layout is provided in Annexure C.

4.2 Manufacturing Space Ratio

The Manufacturing Space Ratio is a measure that reflects the degree to which the manufacturing shop floor area is efficiently utilized. It is calculated by summing up the footprint areas of the machines and the areas of the workstations where value is added to the product and then dividing by the total area that is available for manufacturing. Higher value of this ratio is desirable.

$$\text{Manufacturing Space Ratio} = \frac{\text{Total footprint of machines} + \text{total area where value is added}}{\text{Total area of the facility}} \quad \ldots\ldots\ldots\ldots(4.1)$$

In this research, the total area of the shop floor is found to be,

Total Shopfloor area = 60 ft. x 128 ft. = 7680Sq.feet.

The machine footprint area plus the area where value is added is given in the following table.

Table 4. *Machine footprints and areas where value is added*

Name of Station	Total Value Addition Area (square feet)
Shell forming	166.16
Shell Flanging	23.875
Shell Ovaling	82.27
Neck Spotting	23.66
Partition Insertion	23.08
Partition Spotting	23.66
Seaming	45
Welding	26.4
Leakage Testing	71.6
Cleaning And Final Inspection	66.78
Total	**552.485**

So, Manufacturing Space Ratio $= \frac{552.485}{7680} = 7.19\%$

4.3 Material Handling Cost

In the current layout, material handling is achieved by means of trolleys that are moved by workers. Six trolleys, each with a worker transport material from one station to another. Thus the material handling cost depends upon the labour cost being incurred by employing the six workers. The company evaluates its material handling cost by determining the full-time labour cost incurred and then dividing it by number of units produced.

Calculation of the total material handling cost for the current layout is as follows:

Total number of workers = 6

Labour cost of each worker = Rs. 120 per hour,

So total cost for one worker working for 8 hour shift = 120 x 8 = Rs. 960.

Total cost for six workers per shift = 960 x 6 = Rs. 5760.

Currently 79.8 units are produced per 8 hour shift, so

$$\text{Material Handling Cost (per unit)} = \frac{\text{Total material handling cost}}{\text{Total units produced}} \quad \text{................ (4.2)}$$

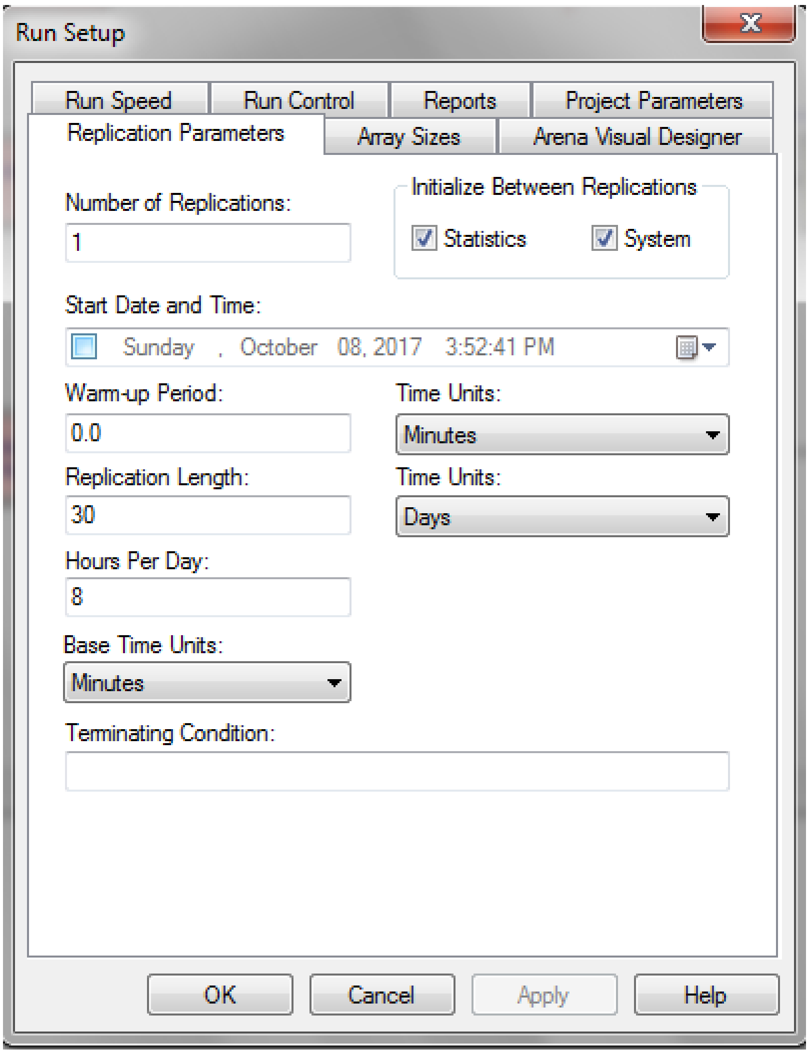
$$= \frac{5760}{79.8} = \quad 72.18/\text{- per unit}$$

4.5 Running the Initial Simulation Model

The initial simulation model was run for 30 days and the output results were recorded.

Few assumptions were made in this regard which are as follows:

a. There are 8 hours available per day for production
b. All machines are available
c. Machines operate normally throughout the shift
d. All workers are present.



4.6 Research Parameters

The research was based on the improvement of the following parameters

1. **Total units produced:** Number of units produced in given time. [33]
2. **Total time:** Total time a product spends in the manufacturing process, also known as manufacturing lead time. [33]
3. **Cycle time:** Measure of the production rate of the manufacturing system obtained by dividing the total production time by total units produced.
4. **Wait time:** Time spent by an entity in queues, waiting for its turn to be processed further. [33]
5. **Transfer time:** Total time an entity spends during transportation between workstations. [33]
6. **Work in process inventory:** Number of units that are present within the manufacturing system and being processed i.e. partially finished goods.

$$WIP = \frac{\text{Total time}}{\text{Cycle time}} \text{.............. (Little's law) [31]...................(4.3)}$$

7. **Total distance travelled:** Total linear distance that a product moves through between workstations from start to completion. [32]
8. **Material handling cost:** Cost incurred in movement, storage and handling of material. In this study, the costs associated with the movement of the material were considered.
9. **Manufacturing space ratio (MSR):** The degree to which the manufacturing shop floor area is efficiently utilized. It is obtained by dividing the sum of machine footprints and other value addition areas by the total shopfloor area. [32]

$$MSR = \frac{\text{Total footprint of machines+total area where value is added}}{\text{Total area of the facility}} \text{................(4.1)}$$

10. **Resource utilization:** Ratio of time spent by a resource in processing (busy time) divided by its total available time. [33]

4.7 Results of the Initial Simulation Model

Following were the results observed per exhaust muffler for an 8 hour shift.

Table 5. *Simulation results of current layout*

Parameter	Value
Total Units produced	79.8
Total Time	46.63 minutes
Cycle Time	6.01 minutes
Value Added Time	8.05 minutes
Wait Time	33.23 minutes
Transfer Time	5.35 minutes
Work in process inventory	8.06 units
Total Distance Travelled	312 feet
Material handling cost	75.12/-
Manufacturing Space Ratio	7.21%
Resource Utilization (average)	13.39%

$$\text{*Cycle time} = \frac{\text{Total Production time}}{\text{Total number of units produced}} \quad \text{......................}(4.4)$$

$$= \frac{\text{480 minutes}}{\text{79.8 units}}$$

$$= \text{6.01 minutes.}$$

The results of the Arena simulation model for the current layout are provided in Annexure D.

Table 6.*Resource utilization for current layout*

Resource	Utilization
Workers	13.36%
Cleaning & inspection equipment	20.79%
Leakage testing equipment	16.63%
Neck spotting equipment	8%
Partition insertion equipment	7.22%
Partition spotting equipment	9%
Seaming equipment	13%
Shell flanging equipment	7.22%
Shell forming equipment	10%
Shell ovaling equipment	8.88%
Welding equipment	33%

Table 6 provides the utilization of all the resources used in the production process. The equipment required for the partition insertion and shell flanging processes are the least utilized i.e. 7.22% while the welding equipment is the most highly utilized resource. The average resource utilization was found to be 13.16%. Improvement in the overall resource utilization is one of the improvement parameter of this research.

4.8 Validation of the Initial Simulation Model

Validation of a simulation model is the process that establishes the degree of the model to which it accurately represents the real world scenario from the perspective of the model's intended use [34]. In our case, we have selected three parameters to validate the model, i.e. the number of units produced, cycle time and the work in process inventory.

a) Total Number of Units Produced

By drawing a comparison between the number of units produced in actual and the number of units produced in the simulation model, the degree to which the simulation model follows the real world scenario can be established. From the data collected through direct observation, the average number of units produced per shift was found to be 83 units, whereas the simulation results show total produced units as 79.8 units. So,

Total units produced (observed) = 83,

Total units produced (simulation) = 79.8

We have,

$$\% \text{ error} = \frac{\text{ABS}\{\text{Units produced (observed)} - \text{Units produced (simulation)}\}}{\text{Units produced (observed)}} \times 100$$

$$= \frac{\text{ABS}(83 - 79.8)}{83}$$

$$= 3.85\%$$

b) Cycle Time

We first compare the actual cycle time by the cycle time obtained from the simulation and then calculate the percentage error. The actual cycle time for the exhaust muffler manufacturing can be calculated by dividing the total production time by the number of units produced. In our case, production time is 8 hours (480 minutes) and the average number of units produced was observed to be around 83. So,

Cycle time (actual) = 480 / 83 = 5.78 minutes

Now we consider the cycle time obtained from the simulation model. According to the simulation results obtained, 79.8 units are being produced in the 480 minutes production time. So,

Cycle time (simulation) = 480 / 79.8 = 6.01 minutes

Now we find the % error as

$$\% \text{ error} = \frac{\text{ABS}\ \{\text{Cycle time (observed)} - \text{Cycle time (simulation)}\}}{\text{Cycle time (observed)}} \times 100$$

$$= \frac{\text{ABS}(5.78 - 6.01)}{5.78} \times 100$$

= 3.97 %

c) Work in process inventory

The company uses Little's law to calculate the average work in process inventory which is given as

WIP Inventory = Throughput x Lead time................(4.5)

Where throughput is the reciprocal of cycle time, and lead time is the total time, so the equation becomes

$$\text{WIP Inventory} = \frac{\text{Total TIme}}{\text{Cycle Time}} \text{.....................(4.3)}$$

From the simulation results, we have Total time = 46.6 minutes, and Cycle time = 6.01 minutes / unit. So,

$$\text{WIP Inventory} = \frac{46.6}{6.01}$$

WIP Inventory = 7.75 units

Now we consider the WIP inventory obtained by the simulation model which is found to be 8.06 units. So now we have

WIP (calculated) = 7.75 units

WIP (simulation) = 8.06 units

So,

$$\text{\% error} = \frac{\text{ABS\{WIP (calculated)} - \text{WIP (simulation)\}}}{\text{WIP (calculated)}} \times 100$$

$$= \frac{\text{ABS}(7.75 - 8.06)}{7.75} \times 100$$

= 4 %

Figure 6 provides the comparison of the various parameters used for validation in a graphical manner.

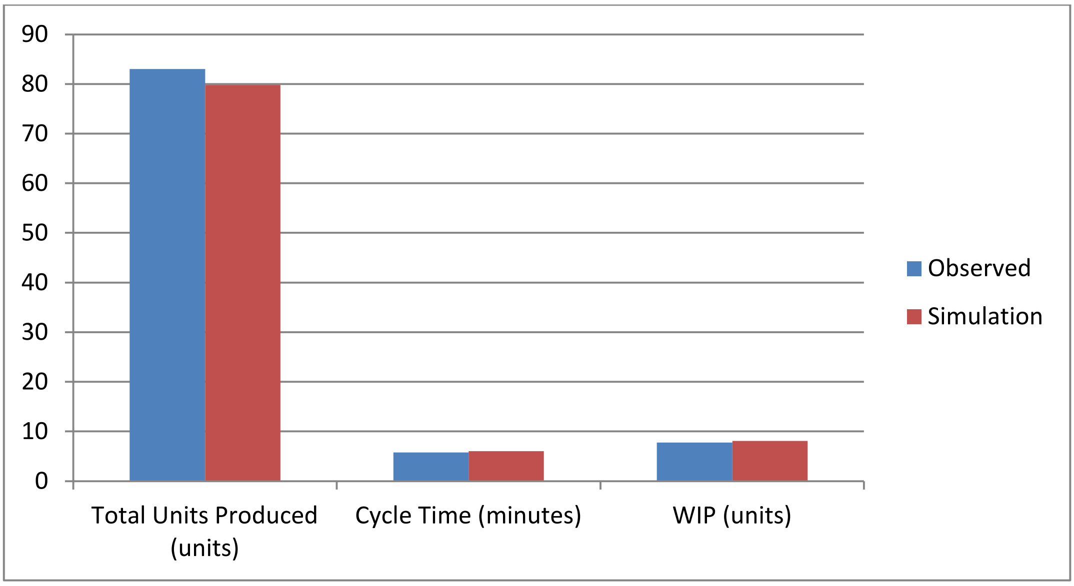


Figure 6. *Graphical representation of comparison of actual and simulated parameters*

The errors associated with all the validation parameters are less than 5%, which is very insignificant and can easily be attributed to the limitations of the simulation software. Such errors are present in almost all types of simulation models and are generally attributed towards the software limitations and the variations present in the real world scenarios that the simulation software usually do not take into account. Thus the closeness of these parameters to the real data provides the required validation for this simulation model.

CHAPTER 5

THE IMPROVED LAYOUTS

5.1 Overview

Once the existing layout was simulated and analyzed, the next step was to identify potential areas of improvement. In the current layout, there is a lot of zigzag and back tracked movement of the material as it moves form one station to another. Moreover, the batch size of 5 units adds to the wait time for the exhaust muffler, resulting in increased total time. Also, the machines are placed at long distances from one another, resulting in higher and unnecessary movement of material. All these factors were considered while designing the new improved layout. All these delays ultimately result in higher levels of work-in-process inventory.

As far as optimization is concerned, two different layouts have been devised. The first one was devised by swapping the workstations with each other as to eliminate the zigzag and back tracked movements of the material. The layout was designed while considering the constraints of the shop floor, e.g. the area of the shopfloor. Stations whose positions cannot be changed were not re-arranged in this layout.

The second layout that was devised was perhaps the one that would be close to the ideal for facilities having product layout. In this layout, all the workstations were placed sequentially with smallest distances between them as possible. This layout will also require complete re-designing of the shop floor. Once implemented, this layout would be regarded as close to the ideal layout for this type of facilities, i.e. product layout, in which material moves from one machine to another as it is converted from raw material to finished good.

In this new layout, machines were placed closer to one another in order to decrease the transfer time for the material. Moreover, the material handling system is changed to conveyor systems. By using conveyors, material movement can be accomplished on single unit basis, i.e. each exhaust muffler is moved to the next workstation as soon as its processing at the current workstation is completed. This reduces the time that is accumulated due to waiting for a batch of 5 units before they are transported to the next station.

5.2 Constraints of the Layout

There are few constraints that are related to the facility layout and need to be considered while devising the improved layouts. First is the total area of the facility. The arrangement of workstations cannot exceed the boundary of the facility layout. The new area can be less than or equal to the current facility area, but it cannot be greater than it. Secondly, the leakage testing station needs to be placed adjacent to a wall (as in the current layout) as it is filled with water and has water and pressurized air pipe connections and placing it not adjacent to the wall would require these pipes to be extended. This will hinder the movement of the material. This is also done to avoid water spills. While designing the improved layouts, both these constraints were considered.

5.3 Proposed Layout # 1

In this layout, locations of the workstations were swapped in order to eliminate the back-track movements of the material, wherever possible. This also allowed for streamlining the flow of the material through the production facility. Systematic Planning Layout calls for placement of workstations that are related closer to each other. In this layout, following changes were made:

1. Workstation 1 and 2 were swapped.
2. Workstations 4, 5 and 6 were re-arranged sequentially.
3. Workstations 7 and 8 were swapped.
4. The position of workstation 9 (air leakage testing) could not be changed due to constraints.
5. Batch size reduced to 3 units.

Once these changes were made, they were translated to the arena simulation model. The new model was simulated and the results were recorded. Figure 7 provides the distances between the workstations for the proposed layout-1, while figure 8 shows the movement of material between workstations.

The Arena simulation for the proposed layout-1 is given at Annexure E.

a) Distances between workstations for the Proposed Layout-1

The following table represent the distances between workstations for proposed layout-1.

Table 7.*Matrix of distances b/w workstations (in feet) in proposed layout-1*

Station Name		Shell forming	Shell Flanging	Shell ovaling	Neck spotting	Partition insertion	Partition spotting	Seaming	Welding	Leakage testing	Cleaning & final inspection
	Station Number	1	2	3	4	5	6	7	8	9	10
Shell forming	1	0	30	33	53	73	100	100	113	135	125
Shell flanging	2	30	0	10	30	50	78	116	93	120	110
Shell ovaling	3	33	10	0	20	40	68	104	83	108	100
Neck spotting	4	53	30	20	0	20	48	86	63	89	80
Partition insertion	5	73	50	40	20	0	28	66	43	68	60
Partition spotting	6	100	78	68	48	28	0	38	15	40	32
Seaming	7	100	116	104	86	66	38	0	50	35	36
Welding	8	113	93	83	63	43	15	50	0	26	17
Leakage testing	9	135	120	108	89	68	40	35	26	0	9
Cleaning and final inspection	10	125	110	100	80	60	32	36	17	9	0

b) Manufacturing Space Ratio

Manufacturing Space Ratio for this layout is the same as the one for the current layout since the area of the facility and the sum of all machine footprints and value-adding areas is unchanged.

$$\text{Manufacturing Space Ratio} = \frac{\text{Total footprint of machines+total area where value is added}}{\text{Total area of the facility}}$$

..............................(5.1)

$$\text{Manufacturing Space Ratio} = \frac{552.485}{7680} = 7.19\%$$

c) Material Handling Costs

In the proposed layout 1, material handling system is the same as that of the initial layout, i.e. six trolleys that are moved each by a worker.

Calculation of the total material handling cost for the current layout is as follows:

Total number of workers = 6

Labour cost of each worker = Rs. 120 per hour,

So total cost for one worker working for 8 hour shift = 120 x 8 = Rs. 960.

Total cost for six workers per shift = 960 x 6 = Rs. 5760.

In improved layout-1, 95.8 units are produced per 8 hour shift, so

$$\text{Material Handling Cost (per unit)} = \frac{\text{Total material handling cost}}{\text{Total units produced}} \quad \text{......................(5.2)}$$

$$= \frac{5760}{95.8} = 60.12\text{/- per unit}$$

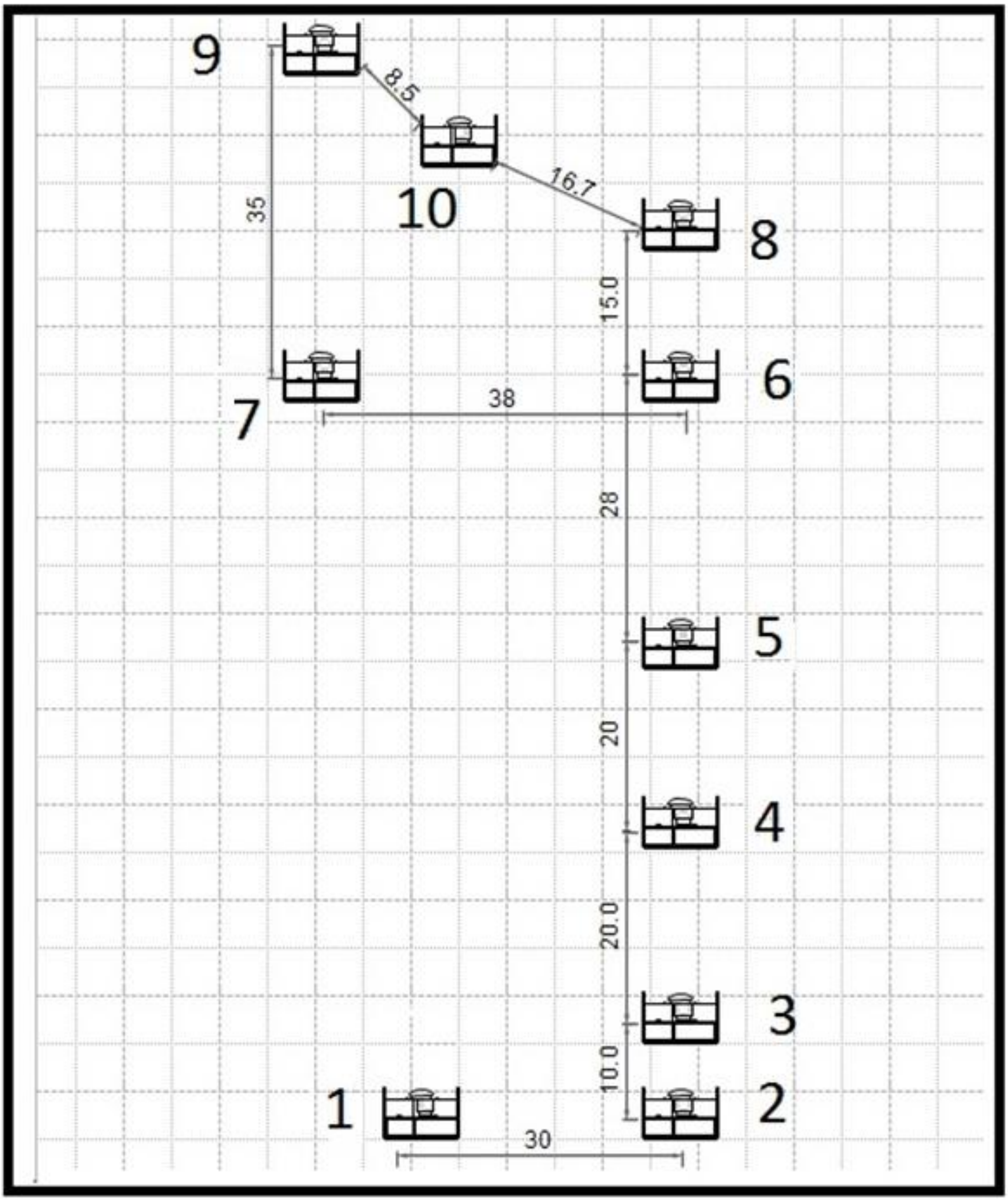


Figure 7. *Distances between workstations (in feet) for proposed layout-1*

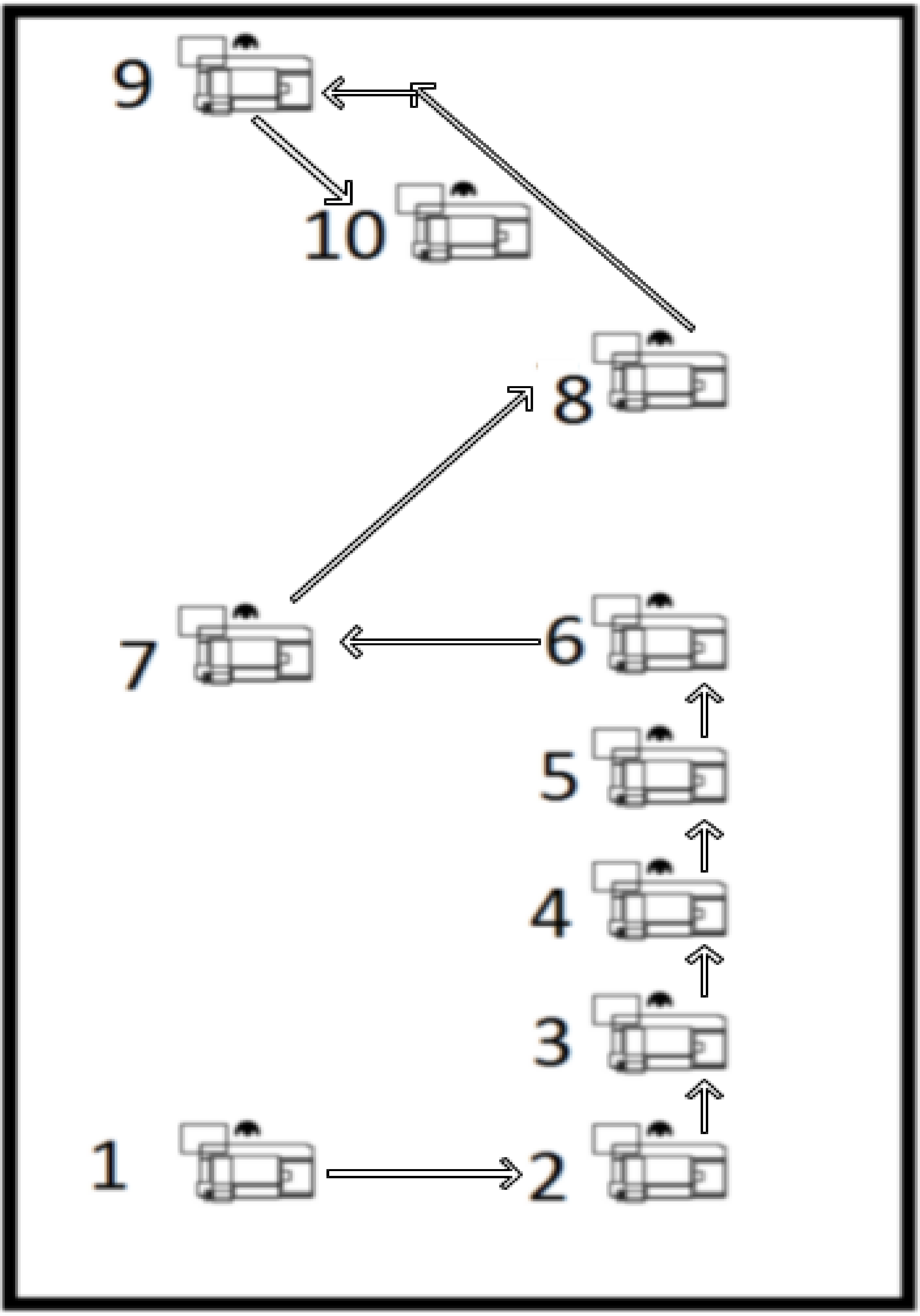


Figure 8. *Flow of material between workstations for proposed layout-1*

e) Results of the Proposed Layout-1

The first proposed model was run with the same parameters and assumptions as of the initial model. Results of the simulation were recorded as follows:

Table 8. *Simulation results of proposed layout-1*

Parameter	Value
Total Units produced	95.8
Total Time	34.4 minutes
Cycle Time	5.01 minutes
Value Added Time	8.05 minutes
Wait Time	21.4 minutes
Transfer Time	4.99 minutes
Work in process inventory	7.44
Total Distance Travelled	193 feet
Material handling cost	60.12/-
Manufacturing Space Ratio	7.21%
Resource Utilization (average)	16.08%

The results of the Arena simulation model for the proposed layout-1 are given at Annexure F.

Table 9.*Resource utilization for proposed layout-1*

Resource	Utilization
Workers	16.04%
Cleaning & inspection equipment	24.96%
Leakage testing equipment	19.98%
Neck spotting equipment	10%
Partition insertion equipment	8.66%
Partition spotting equipment	11%
Seaming equipment	15%
Shell flanging equipment	8.66%
Shell forming equipment	12%
Shell ovaling equipment	10.67%
Welding equipment	40%

Table 9 represents the utilization of resources in the proposed layout-1. The partition insertion and shell flanging equipment are the least utilized at 8.66%. However, their utilization is slightly greater than it was in the current layout. Moreover, the welding equipment utilization has also increased to 40%. The average utilization has increased to 16%.

5.4 Proposed Layout # 2

The second proposed layout was designed by placing the workstations in a sequential manner and close to each other while keeping in mind the total area of the shopfloor and inputs from the management of the facility. This layout was so designed so as to enable the use of conveyors for material handling. Using conveyors could significantly improve the production process as it makes it feasible to have a batch size of 1 unit. As the processing of a unit completes on one workstation, it can be immediately forwarded to the next workstation. This results in reduced waiting time. The constraints were also considered in designing this layout.

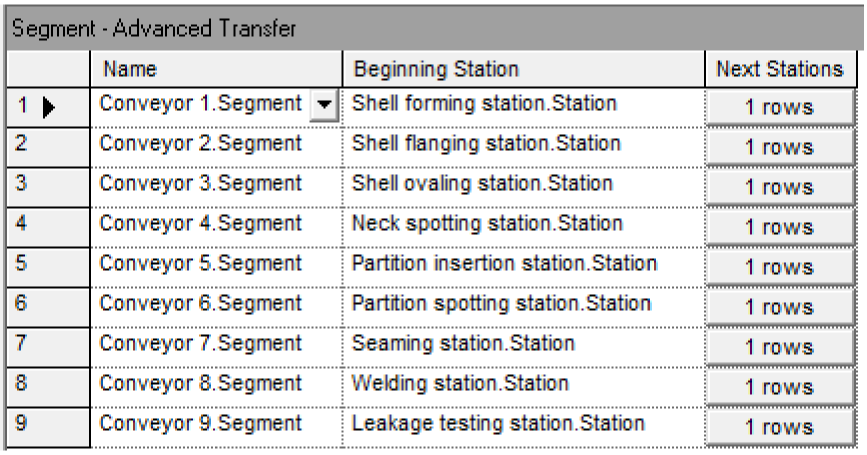
In this layout, the total facility area used for production is also reduced, thereby saving space that can be used for other uses, such as inventory storage, or offices / rooms for personnel. As a result the manufacturing space ratio is also significantly improved. Figures 9 and 10 provide the distances between the workstations and the movement of material between workstations for the proposed layout-2. For the Arena simulation model of the proposed layout-2, refer to Annexure G.

a) Modelling the Conveyors

Conveyors can be modelled in Arena simulation using the conveyor module. A conveyor must have a defined name and speed with which it moves. Moreover, each conveyor needs to be assigned a segment that defines the name of the beginning station and the ending station. It also contains the distance between the two stations. In our case, 9 conveyors are defined each moving with the speed of 3 units per second.

Conveyor - Advanced Transfer

	Name	Segment Name	Type	Velocity	Units	Cell Size	Max Cells Occupied	Initial Status	Report Statistics
1	Conveyor 1	Conveyor 1.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
2	Conveyor 2	Conveyor 2.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
3	Conveyor 3	Conveyor 3.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
4	Conveyor 4	Conveyor 4.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
5	Conveyor 5	Conveyor 5.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
6	Conveyor 6	Conveyor 6.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
7	Conveyor 7	Conveyor 7.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
8	Conveyor 8	Conveyor 8.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑
9	Conveyor 9	Conveyor 9.Segment	Non-Accumulating	3	Per Second	1	1	Active	☑



Segment - Advanced Transfer

	Name	Beginning Station	Next Stations
1	Conveyor 1.Segment	Shell forming station.Station	1 rows
2	Conveyor 2.Segment	Shell flanging station.Station	1 rows
3	Conveyor 3.Segment	Shell ovaling station.Station	1 rows
4	Conveyor 4.Segment	Neck spotting station.Station	1 rows
5	Conveyor 5.Segment	Partition insertion station.Station	1 rows
6	Conveyor 6.Segment	Partition spotting station.Station	1 rows
7	Conveyor 7.Segment	Seaming station.Station	1 rows
8	Conveyor 8.Segment	Welding station.Station	1 rows
9	Conveyor 9.Segment	Leakage testing station.Station	1 rows

Table 10. *Distances between workstations in proposed layout-2*

Start Station	**End Station**	**Distance (feet)**
Shell forming	Shell flanging	10
Shell flanging	Shell ovaling	10
Shell ovaling	Neck spotting	10
Neck spotting	Partition insertion	10
Partition insertion	Partition spotting	20
Partition spotting	Seaming	10
Seaming	Welding	10
Welding	Leakage testing	10
Leakage testing	Cleaning and final inspection	10

b) Manufacturing Space Ratio

In this layout, the required area for the shopfloor is decreased to 70 x 55 = 3850 sq. Ft.

Since the sum of all machine footprints and value-adding areas is same, i.e. 550.25 sq. ft,

So we have,

$$\text{Manufacturing Space Ratio} = \frac{\text{Total footprint of machines+total area where value is added}}{\text{Total area of the facility}} \quad \text{.........................(5.3)}$$

$$= \frac{550.25}{3850}$$

$$= 14.29\%$$

c) Material Handling Costs

In this proposed layout, material handling system is changed from worker-driven trolleys to conveyor belts. In total, 9 conveyor segments have been defined in the simulation model, each between a pair of consecutive workstations. Each segment is driven by an electric motor, whose power rating has been calculated using available online calculators (see annexure). It was found that a 2KW motor is sufficient to drive each of the conveyor segments. The material handling cost now is the cost of electrical energy consumed to drive these conveyor segments.

The calculation for material handling cost is as follows.

Power consumption of each motor = 2000 watts.
Energy consumption for one motor for one hour = 2KWh
Energy consumption for one motor for 8 hour shift = 2 x 8 = 16KWh
In total, there are 9 motors, so
Energy consumed by 9 motors running for 8 hours = 16 x 9 = 144 KWh
Historical data shows that the current cost of electrical energy incurred by the company is Rs. 20 per KWh,
So the total cost for running 9 motors for 8 hours = 144 x 20 = Rs. 2880
Since in this improved layout-2, 120 muffler units are produced per shift, we have

$$\text{Material Handling Cost (per unit)} = \frac{\text{Total material handling cost}}{\text{Total units produced}} \quad \text{......................(5.4)}$$

$$= \frac{2880}{120} = \text{24/- per unit}$$

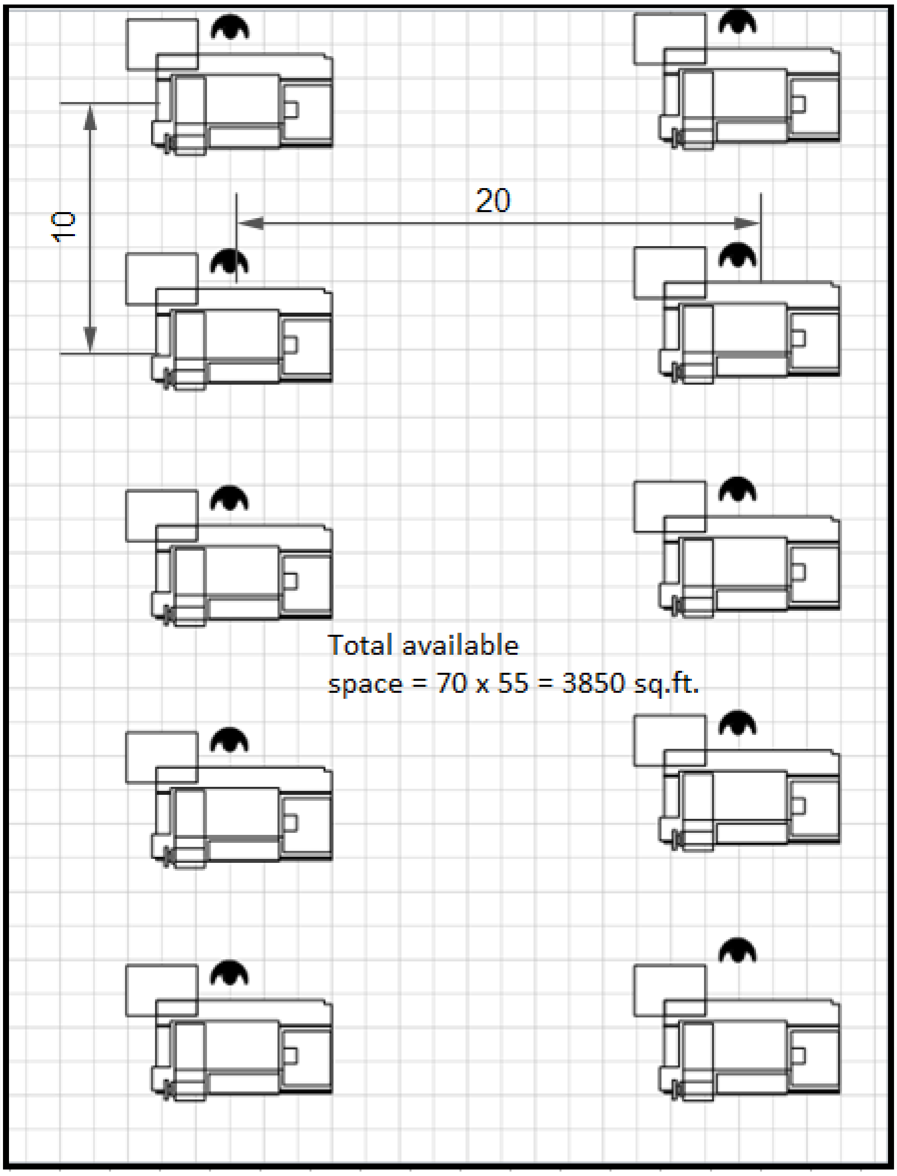


Figure 9. *Distances between workstations (in feet) for proposed layout-2*

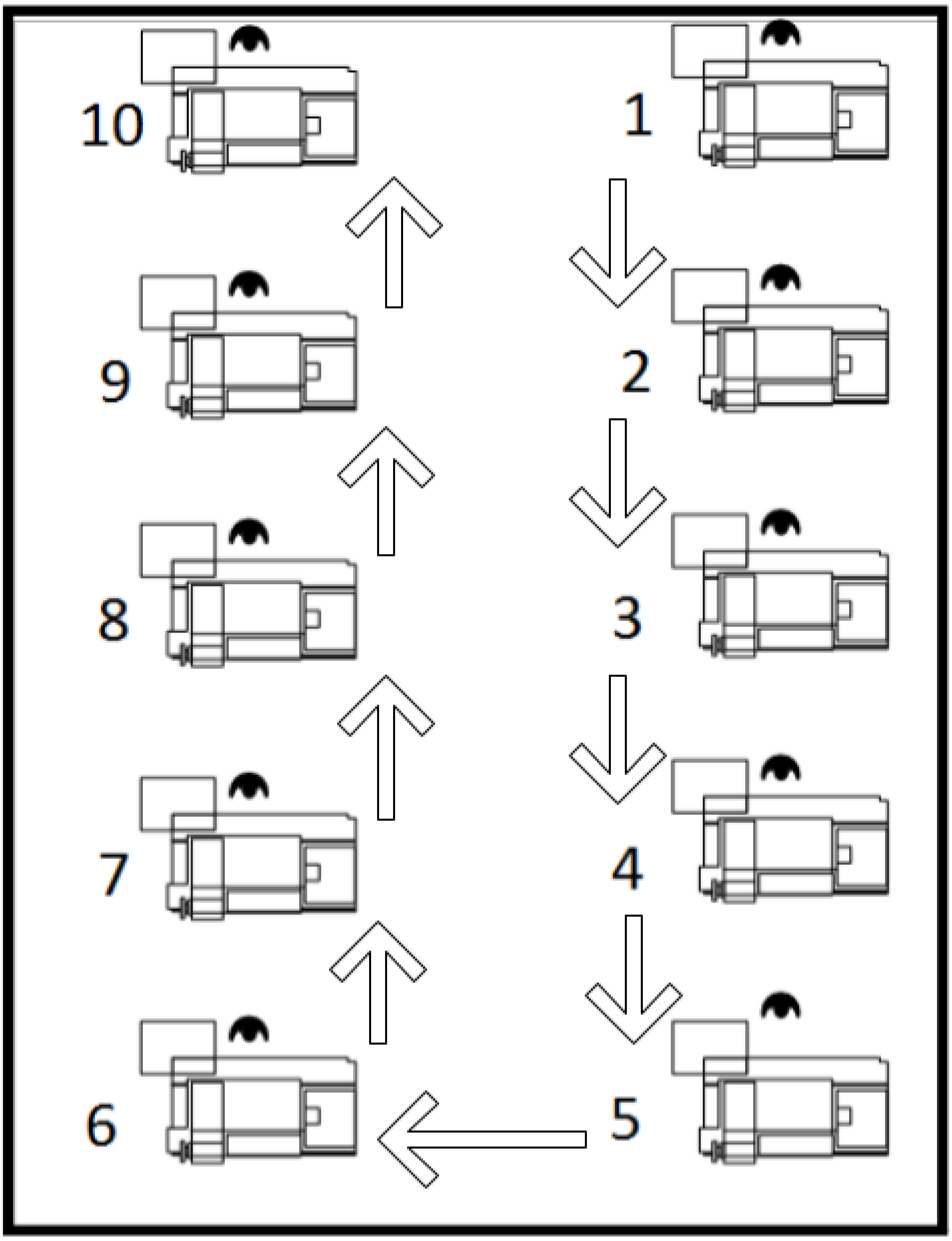


Figure 10. *Flow of material between workstations for proposed layout-2*

e) Results of the Proposed Layout-2

The second improved model was run with the batch size of 1 and conveyors as the material handling system. The distances between workstations were updated as provided above. The results of this improved model are as follows.

Table 11.*Simulation results of improved layout-2*

Parameter	Value
Total Units Produced	120
Total Time	12.43 minutes
Cycle Time	4 minutes
Value Added Time	8.05 minutes
Wait Time	1.99
Transfer Time	2.38
Work In Process Inventory	3.10
Total Distance Travelled	100 feet
Material Handling Cost	24/-
Manufacturing Space Ratio	15.72%
Resource Utilization (average)	20.08%

Refer to Annexure H for the results of Arena simulation model for the proposed layout-2.

Table 12.*Resource utilization for proposed layout-2*

Resource	Utilization
Workers	20.06%
Cleaning & inspection equipment	31.24%
Leakage testing equipment	24.99%
Neck spotting equipment	13%
Partition insertion equipment	10.83%
Partition spotting equipment	14%
Seaming equipment	19%
Shell flanging equipment	10.83%
Shell forming equipment	15%
Shell ovaling equipment	13.33%
Welding equipment	50%

Table 12 provides the resource utilization for the proposed layout-2. The resource utilization is further improved in this proposed layout. The utilizations of partition insertion and shell flanging equipment increased to 10.83% and that of the welding equipment to 50%. The average resource utilization also increased to 20.08% in contrast to 13.16% of the current layout.

5.5 Results and Discussion

The following table and graphs (figures 11 – 14) provide the comparative analysis for all the three layouts, i.e. the current layout and the two proposed layouts in terms of the parameters being studied including total number of units produced, total time, cycle time, WIP inventory levels and material handling cost. It is apparent from the below provided table and graphical analysis that there have been significant improvements in the performance metrics of the two proposed layouts as compared to those of the current layout. The total number of units produced that has a direct impact on the total time and consequently the cycle time has been improved in addition to the total linear distance travelled due to the fact that the proposed layouts are more streamlined as compared to the initial one. Both the flows of material as well as the distances between the workstations have been optimized which resulted in this improvement. The use of conveyors for material transportation in proposed layout-2 has been reflected by the drastic reduction in its transfer time of 55%.

The wait time has also been reduced considerably in both the proposed layouts. The optimized placement of workstations resulted in reduction in the time a muffler needs to wait in queue. This improvement is quite higher in proposed layout-2 due to the fact that the batch size had been reduced to single unit by using conveyors. This has helped in reducing the wait time by a steep margin. This reduction in the wait time has had a positive impact on the work-in-process inventory levels, with around 8% and 61% improvement for the two proposed layouts. The material handling cost has been reduced due to an increase in the number of units being produced as implied by economies of scale. Moreover, a further reduction in it is observed when conveyors are used. The placement of workstations at optimized distances allowed for saving in shopfloor space as a result of which the manufacturing space ratio is also improved. In addition, these improvements in the performance related parameters resulted in increased resource utilization, specifically due to reduced cycle time and wait time. This would add to the facility’s efficiency.

Table 13. *Comparative analysis of the current and proposed layouts*

Parameter	Units	Current Layout	Proposed Layout 1	Percentage Improvement	Proposed Layout 2	Percentage Improvement
Total Units produced	units	79.8	95.8	**20.05**	120	**50.38**
Total Time	minutes	46.63	34.4	**26.23**	12.43	**73.34**
Cycle Time	minutes	6.01	5.01	**16.64**	4	**33.44**
Wait Time	minutes	33.23	21.4	**35.60**	1.99	**94.01**
Transfer Time	minutes	5.35	4.99	**6.73**	2.38	**55.51**
WIP inventory	units	8.06	7.44	**7.69**	3.1	**61.54**
Distance Travelled	feet	312	193	**38.14**	100	**67.95**
Material handling cost	Rs.	75.12	60.12	**19.97**	24	**68.05**
Manufacturing Space Ratio	%	7.21	7.21	**Same**	15.72	**118.03**
Resource Utilization (avg)	%	13.39	16.08	**20.09**	20.08	**49.96**

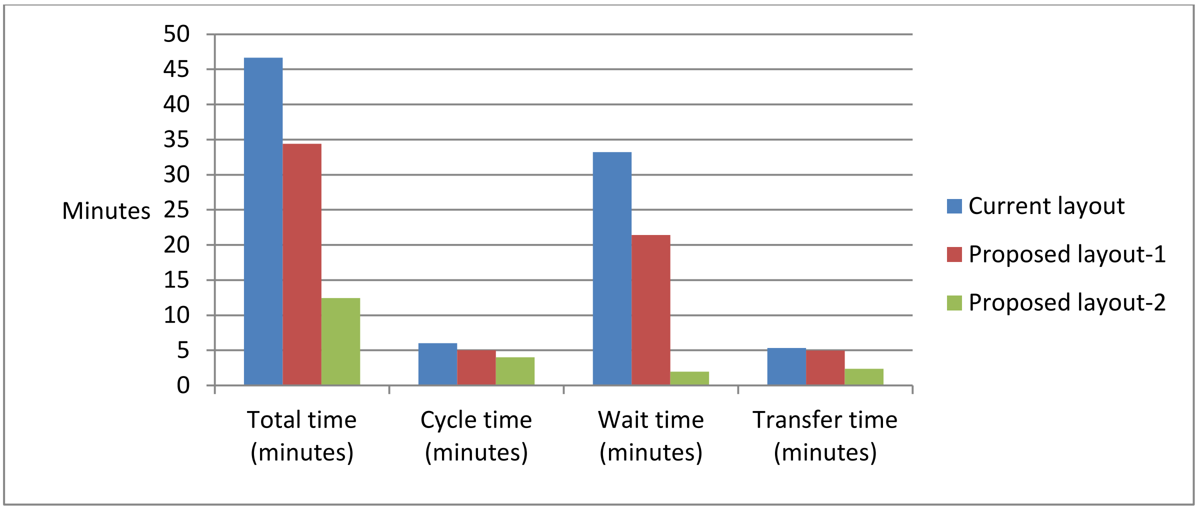
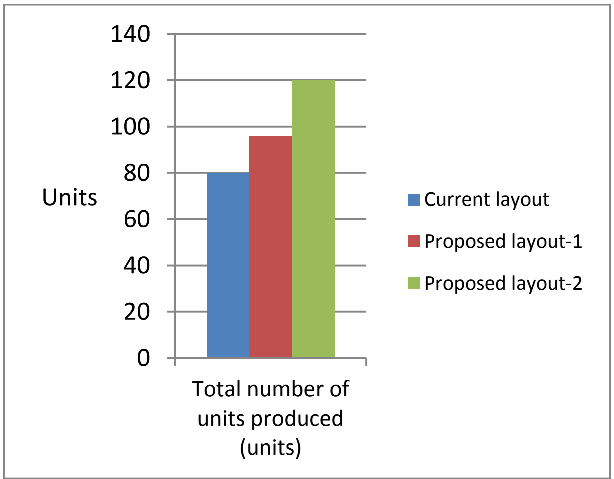


Figure 11. *Comparison of time-related parameters for the current and proposed layouts.*



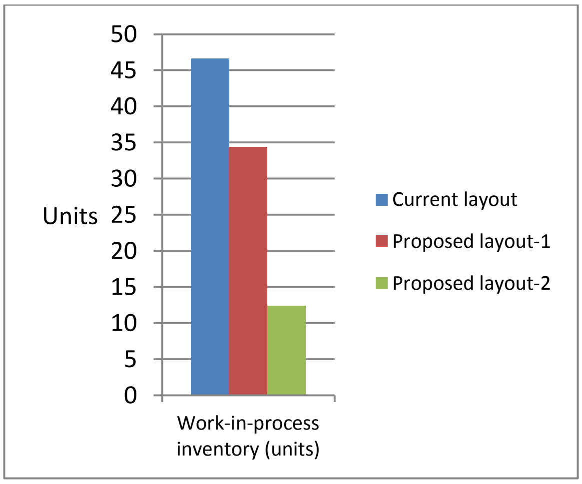


Figure 12. *Comparison of total units produced & WIP inventory for the current and proposed layouts.*

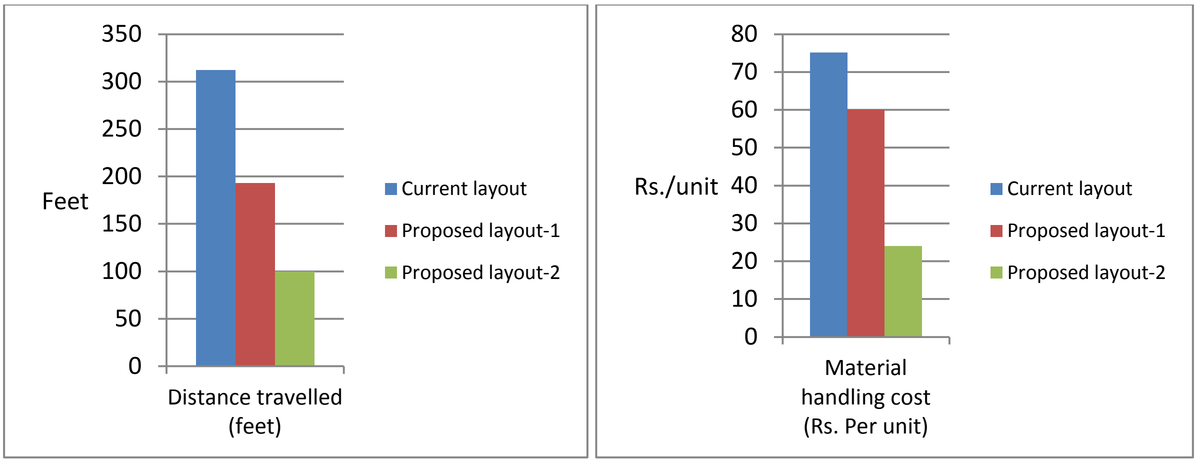


Figure 13. *Comparison of total distance travelled & material handling cost for the current and proposed layouts.*

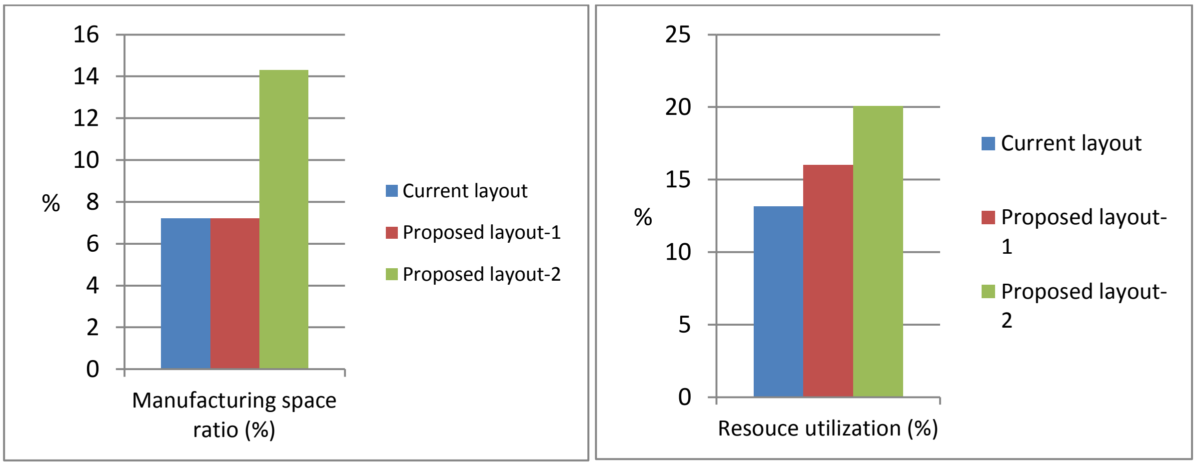


Figure 14. *Comparison of MSR & resource utilization for the current and proposed layouts.*

CHAPTER 06

CONCLUSIONS AND FUTURE RECOMMENDATIONS

6.1 Conclusions

The objective of this study was to achieve optimization regarding various parameters related to the facility layout of exhaust muffler manufacturing. Using discrete event simulation software and applying SLP and other waste elimination methods, considerable improvement in the performance metrics of the layout was observed. Two improved layouts were proposed. The first layout showed around 20% whereas the second layout showed 50% improvement in the number of units that are produced, corresponding to 17% and 33% reduction in cycle time respectively. Also, work-in-process inventory levels dropped by 8% for the first layout and by a significant 61% for the second. The linear distance travelled by the product is reduced by 38% and 68% for proposed layout one and two respectively. For the first proposed layout, material handling cost had been reduced by 20% whereas for the second layout, this improvement was found to be 68%. The second proposed layout also showed an improvement of 98% for the manufacturing space ratio, thereby providing the company with additional space that can be utilized for other purposes. Another key performance metric, resource utilization is improved by 23% and 52% in proposed layouts one and two respectively. To conclude, both the proposed layouts show significant improvement, with the second layout performing way better than the first one. The first proposed layout can serve the company's short-term goals, whereas the second one is best-suited for achieving long-term objectives.

6.2 Recommendations for Future Work

This study can provide a framework for future improvement plans related to facility layout optimization. This research can be extended to other production lines operated by the company such as the radiator shop. It can also be applied to improve the individual cycle times of the machines as well as processes. Moreover, this framework may be applied in conjunction with Value Stream Mapping (VSM) to determine the possible improvement by this combined approach, or VSM can be applied separately and the improvement results can be compared with those of this study to determine the overall effectiveness of both the approaches.

The study utilized discrete event simulation, which is equally useful for service based organizations too for better queue management. Similarly, this approach can be applied to other manufacturing industries having product layout to optimize their facility layouts.

6.3 Limitations of the Study

As for any other research, this work too had a few limitations. The research was simulation based and therefore cannot take into account the variations present in the real world scenarios and other random factors that can influence the performance of the layout. Moreover, the improved layouts were proposed on the basis of simulation results, and the implementation of these proposed layouts will add to the credibility of the model. Also, the application of the study is limited to facilities having product layout, due to the fact that the simulation software requires an entity to "flow" through the production line, thereby resembling a product layout.

Moreover, the installation and investment costs related to the introduction of conveyors as the material handling system were not calculated in this study. Once it is decided to install the conveyors to enhance the material transportation system, the company may first need to evaluate these costs.

REFERENCES

[1] Hosseini, S. S., Mirzapour, S. A., & Wong, K. Y. (2013). Improving Multi-Floor Facility Layout Problems Using Systematic Layout Planning and Simulation. In Advances in Information Technology (pp. 58-69). Springer International Publishing.

[2] Kim, J. G., & Kim, Y. D. (2000). Layout planning for facilities with fixed shapes and input and output points. International Journal of Production Research, 38(18), 4635-4653.

[3] Prasad, N. H., Rajyalakshmi, G., & Reddy, A. S. (2014). A Typical Manufacturing Plant Layout Design Using CRAFT Algorithm. Procedia Engineering, 97, 1808-1814.

[4] Sa'udah, N., Amit, N., & Ali, M. N. (2015). Facility Layout for SME Food Industry via Value Stream Mapping and Simulation. Procedia Economics and Finance, 31, 797-802.

[5] Ojaghi, Y., Khademi, A., Yusof, N. M., Renani, N. G., & Bin Syed Hassan, S. A. H. (2015). Production Layout Optimization for Small and Medium Scale Food Industry. Procedia CIRP, 26, 247-251.

[6] Chien, T. K. (2004). An Empirical Study of Facility Layout Using a Modified SLP Procedure. Journal of Manufacturing Technology Management, 15(6), 455-465.

[7] Tuzkaya, G., Gülsün, B., Tuzkaya, U. R., Onut, S., &Bildik, E. (2013). A Comparative Analysis of Meta-Heuristic Approaches for Facility Layout Design Problem: A Case Study for an Elevator Manufacturer. Journal of Intelligent Manufacturing, 24(2), 357-372.

[8] Anjos, M. F., & Vieira, M. V. (2016). An Improved Two-Stage Optimization-Based Framework for Unequal-Areas Facility Layout. Optimization Letters, 1-14.

[9] Ulutas, B., &Islier, A. A. (2015). Dynamic Facility Layout Problem in Footwear Industry. Journal of Manufacturing Systems, 36, 55-61.

[10] Tarkesh, H., Atighehchian, A., &Nookabadi, A. S. (2009). Facility Layout Design Using Virtual Multi-Agent System. Journal of Intelligent Manufacturing, 20(4), 347-357.

[11] Amaral, A. R. (2008). An Exact Approach to the One-Dimensional Facility Layout Problem. Operations Research, 56(4), 1026-1033.

[12] Paul, R. C., Asokan, P., &Prabhakar, V. I. (2006). A Solution to the Facility Layout Problem Having Passages and Inner Structure Walls Using Particle Swarm Optimization. The International Journal of Advanced Manufacturing Technology, 29(7-8), 766-771.

[13] Cheng, M. Y., & Lien, L. C. (2012). A Hybrid AI-Based Particle Bee Algorithm for Facility Layout Optimization. Engineering with Computers, 28(1), 57-69.

[14] Djassemi, M. (2007). Improving Factory Layout under a Mixed Floor and Overhead Material Handling Condition. Journal of Manufacturing Technology Management, 18(3), 281-291.

[15] Aiello, G. I. U. S. E. P. P. E., M. Enea, and G. Galante. "A Multi-Objective Approach To Facility Layout Problem by Genetic Search Algorithm and Electre Method." Robotics and Computer-Integrated Manufacturing 22.5 (2006): 447-455.

[16] Kulturel-Konak, S., &Konak, A. (2013). Linear Programming Based Genetic Algorithm for the Unequal Area Facility Layout Problem. International Journal of Production Research, 51(14), 4302-4324.

[17] McKendall, A. R., &Hakobyan, A. (2010). Heuristics for the Dynamic Facility Layout Problem with Unequal-Area Departments. European Journal of Operational Research, 201(1), 171-182.

[18] Datta, D., Amaral, A. R., &Figueira, J. R. (2011). Single Row Facility Layout Problem Using a Permutation-Based Genetic Algorithm. European Journal of Operational Research, 213(2), 388-394.

[19] Sahin, R. (2011). A Simulated Annealing Algorithm for Solving the Bi-Objective Facility Layout Problem. Expert Systems with Applications, 38(4), 4460-4465.

[20] Gonçalves, J. F., &Resende, M. G. (2015). A biased random-key genetic algorithm for the unequal area facility layout problem. European Journal of Operational Research, 246(1), 86-107.

[21] Azevedo, M. M., Crispim, J. A., & de Sousa, J. P. (2017). A dynamic multi-objective approach for the reconfigurable multi-facility layout problem. Journal of Manufacturing Systems, 42, 140-152.

[22] Pourhassan, M. R., &Raissi, S. (2017). An Integrated Simulation-based Optimization Technique for Multi-Objective Dynamic Facility Layout Problem. Journal of Industrial Information Integration.

[23] Prajapat, N., Waller, T., Young, J., & Tiwari, A. (2016). Layout optimization of a repair facility using discrete event simulation. Procedia CIRP, 56, 574-579.

[24] Kulturel-Konak, S. (2017). A Matheuristic Approach for Solving the Dynamic Facility Layout Problem. Procedia Computer Science, 108, 1374-1383.

[25] Palomo-Romero, J. M., Salas-Morera, L., &García-Hernández, L. (2017). An island model genetic algorithm for unequal area facility layout problems. Expert Systems with Applications, 68, 151-162.

[26] Kang, S., &Chae, J. (2017). Harmony search for the layout design of an unequal area facility. Expert Systems with Applications, 79, 269-281.

[27] Yegul, M. F., Erenay, F. S., Striepe, S., &Yavuz, M. (2017). Improving configuration of complex production lines via simulation-based optimization. Computers & Industrial Engineering, 109, 295-312.

[28] Grobelny, J., & Michalski, R. (2017). A novel version of simulated annealing based on linguistic patterns for solving facility layout problems. Knowledge-Based Systems, 124, 55-69.

[29] Safarzadeh, S., &Koosha, H. (2017). Solving an extended multi-row facility layout problem with fuzzy clearances using GA. Applied Soft Computing, 61, 819-831.

[30] Pourvaziri, H., &Pierreval, H. (2017). Dynamic facility layout problem based on open queuing network theory. European Journal of Operational Research, 259(2), 538-553.

[31] Little, J. D., & Graves, S. C. (2008). Little's law. In Building intuition (pp. 81-100). Springer US.

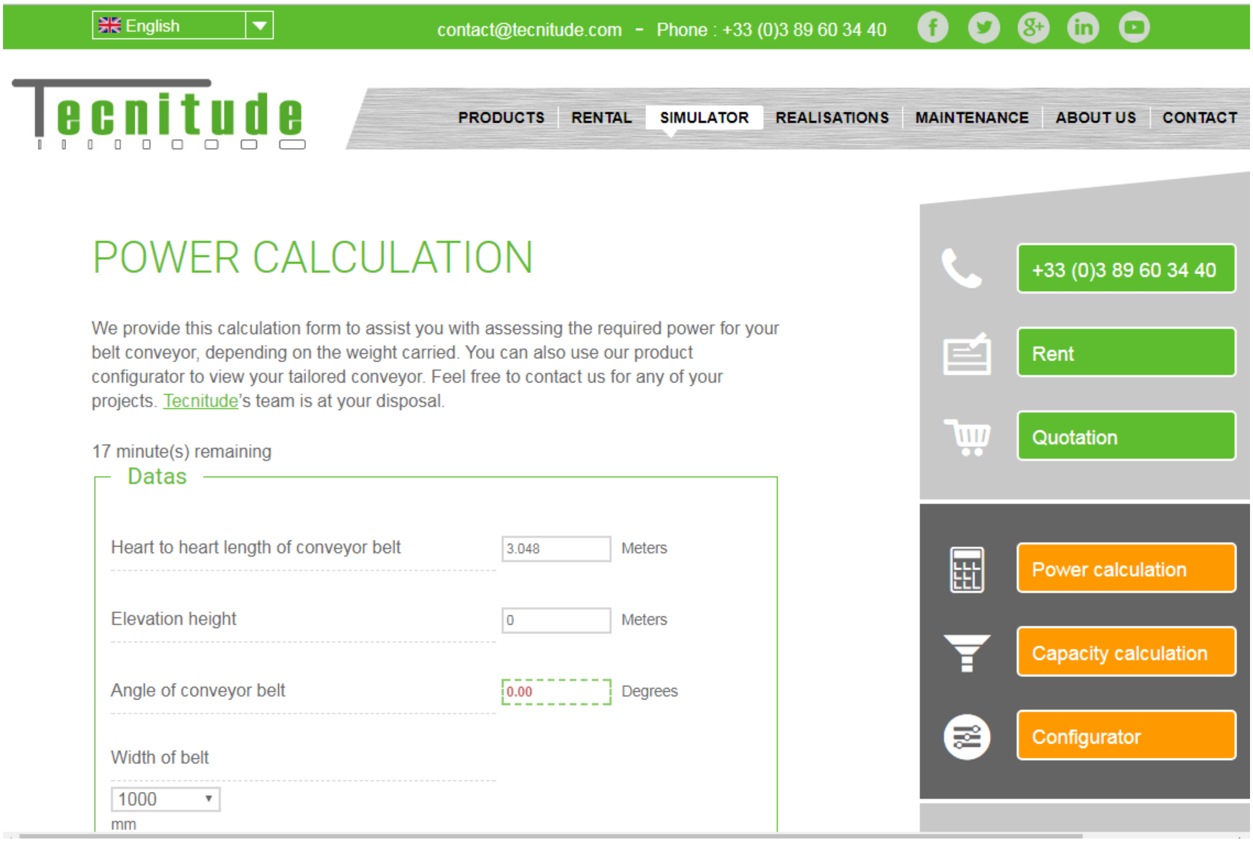
[32] Nisar, S. (2015). Introduction to CIM & Manufacturing Enterprise

[33] Rockwell Automation (2012). Variables Guide. Arena. Publication Arenav-RM001K-EN-P–January 2012

[34] Sargent, R. G. (2013). Verification and validation of simulation models. Journal of simulation, 7(1), 12-24.

ANNEXURE A

Online calculator used to determine the power rating for conveyor driving motors



Required capacity	2	t/h
Velocity	0.914	m/s
Diameter of head pulley	100	mm
Length of reception trough		Meters
Scraper	○ Yes ◉ No	

Calculated Power

Power absorbed

0.69	Kw
0.94	H.P.

Minimum power to be installed

1.18 Kw

1.60 H.P.

Technical information

Rotation speed of the head pulley	174.56	rev/min
Reducer drive couple	64	Nm

ANNEXURE B
Observation Sheet

Station Name	Cycle time (seconds)			
	Sample 1		Sample 2	
	Reading 1	Reading 2	Reading 1	Reading 2
Shell forming				
Shell Flanging				
Shell Ovaling				
Neck Spotting				
Partition Insertion				
Partition Spotting				
Seaming				
Welding				
Leakage Testing				
Cleaning and Final Inspection				

Distances between workstations (feet):

Station Name		Shell forming	Shell Flanging	Shell ovaling	Neck spotting	Partition insertion	Partition spotting	Seaming	Welding	Leakage testing	Cleaning & final inspection
	Station Number	1	2	3	4	5	6	7	8	9	10
Shell forming	1										
Shell flanging	2										
Shell ovaling	3										
Neck spotting	4										
Partition insertion	5										
Partition spotting	6										
Seaming	7										
Welding	8										
Leakage testing	9										
Cleaning and final inspection	10										

Batch Size (no. of units): ________________________________

Speed of trolley movement (feet per sec): ___________________

Value addition areas (square feet):

Name of Station	**Value Addition Area (square feet)**
Shell forming	
Shell Flanging	
Shell Ovaling	
Neck Spotting	
Partition Insertion	
Partition Spotting	
Seaming	
Welding	
Leakage Testing	
Cleaning And Final Inspection	
Total	

Total shopfloor area (square feet):

ANNEXURE C
Completed Arena Model for Current Layout

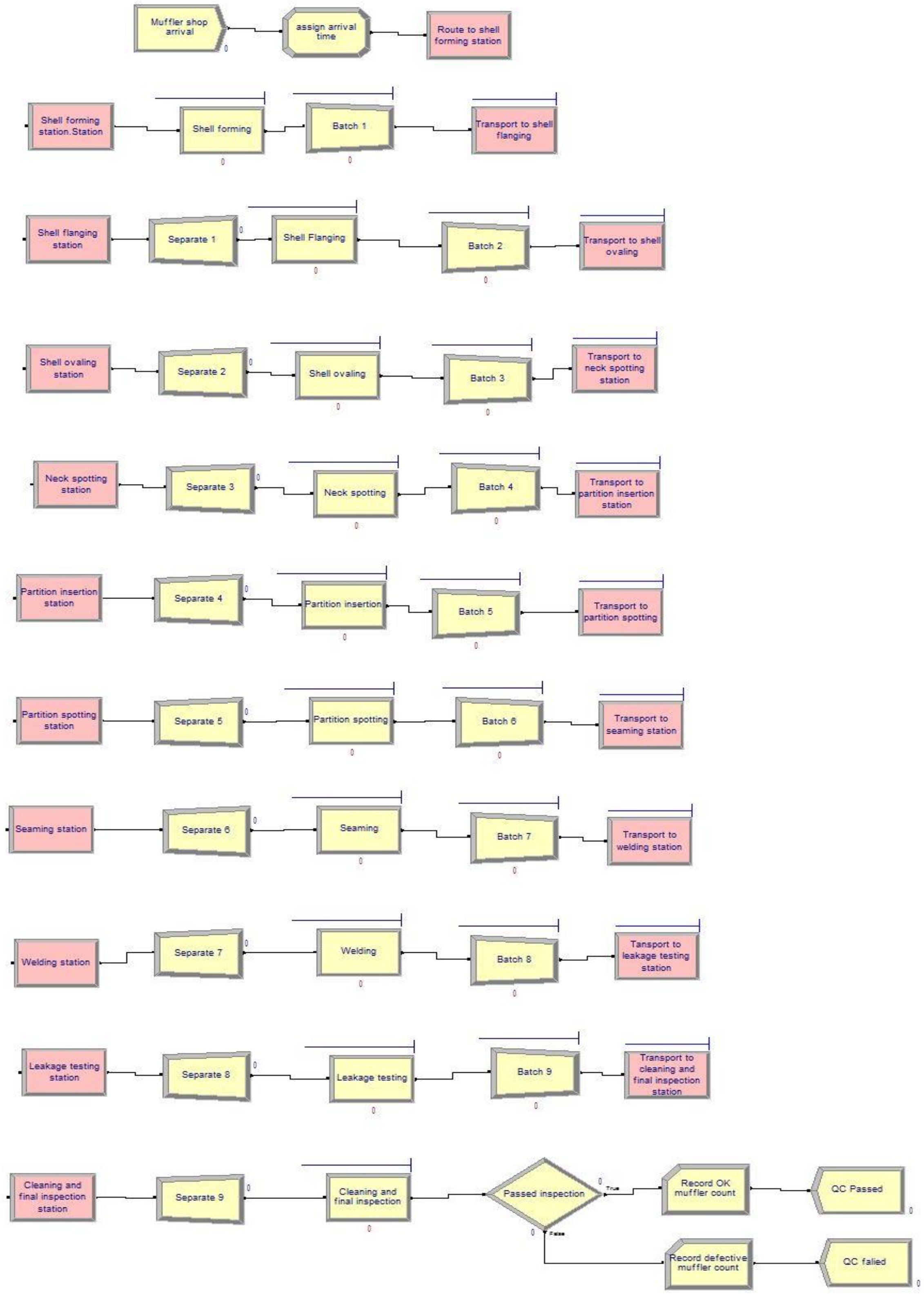


Figure 15. *Completed simulation model for the current facility layout*

ANNEXURE D
Results of the Initial Simulation Model

7:01:46PM **Category Overview** December 18, 2017

Current Faciliy Layout

Replications: 1 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	2,395

Current Faciliy Layout

Replications: 1 Time Units: Minutes

Entity

Time

VA Time

	Average
muffler	8.0500

NVA Time

	Average
muffler	0.00

Wait Time

	Average
muffler	33.2325

Transfer Time

	Average
muffler	5.3556

Other Time

	Average
muffler	0.00

Total Time

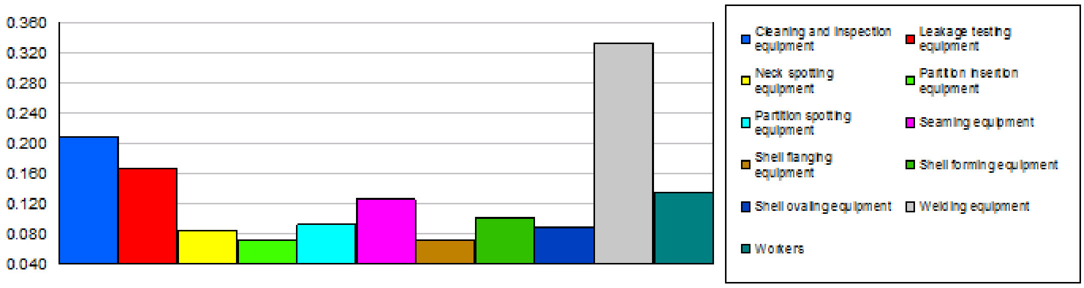
	Average
muffler	46.6381

WIP

	Average
muffler	8.0627

Scheduled Utilization

	Value
Cleaning and inspection equipment	0.2079
Leakage testing equipment	0.1663
Neck spotting equipment	0.08333333
Partition insertion equipment	0.07222222
Partition spotting equipment	0.0917
Seaming equipment	0.1250
Shell flanging equipment	0.07222222
Shell forming equipment	0.1000
Shell ovaling equipment	0.08888889
Welding equipment	0.3330
Workers	0.1336



ANNEXURE E

The Completed Arena Model for Proposed Layout-1

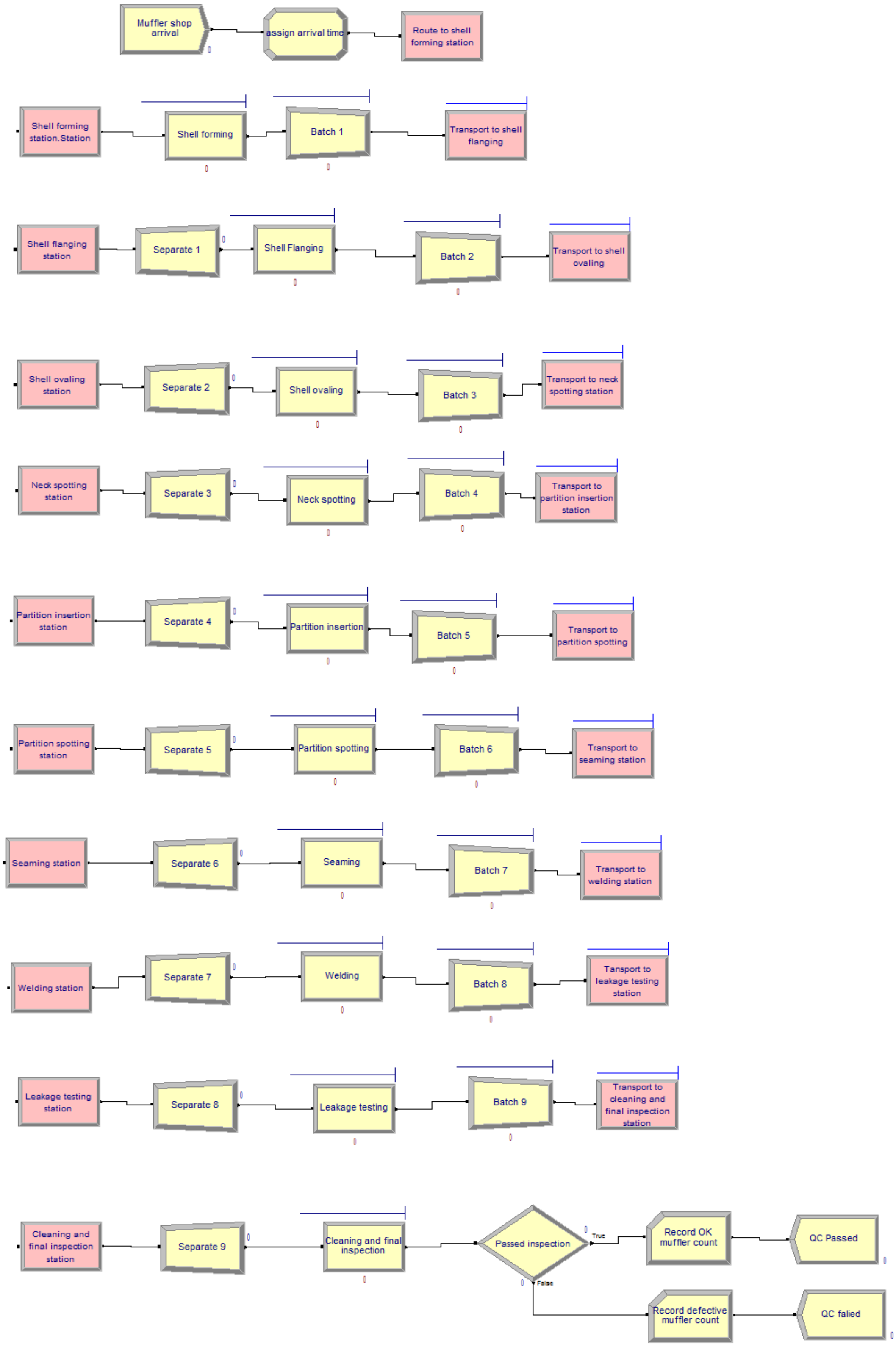


Figure 16. Completed simulation model for proposed layout-1

ANNEXURE F

Results of the ProposedLayout-1

Key Performance Indicators

System

	Average
Number Out	2,874

Entity

Time

VA Time

	Average
muffler	8.0500

NVA Time

	Average
muffler	0.00

Wait Time

	Average
muffler	21.4104

Transfer Time

	Average
muffler	4.9917

Other Time

	Average
muffler	0.00

Total Time

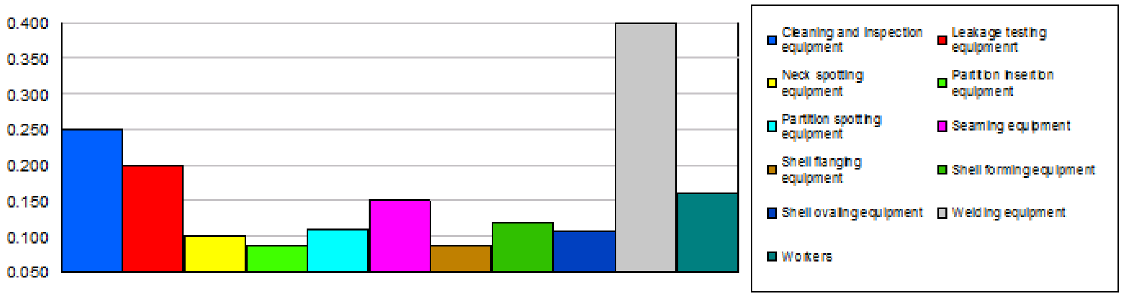
	Average
muffler	34.4521

WIP

	Average
muffler	7.4446

Scheduled Utilization

	Value
Cleaning and inspection equipment	0.2496
Leakage testing equipmenrt	0.1998
Neck spotting equipment	0.1000
Partition insertion equipment	0.08666667
Partition spotting equipment	0.1100
Seaming equipment	0.1500
Shell flanging equipment	0.08666667
Shell forming equipment	0.1200
Shell ovaling equipment	0.1067
Welding equipment	0.4000
Workers	0.1604



ANNEXURE G

Completed Arena Model for Proposed Layout-2

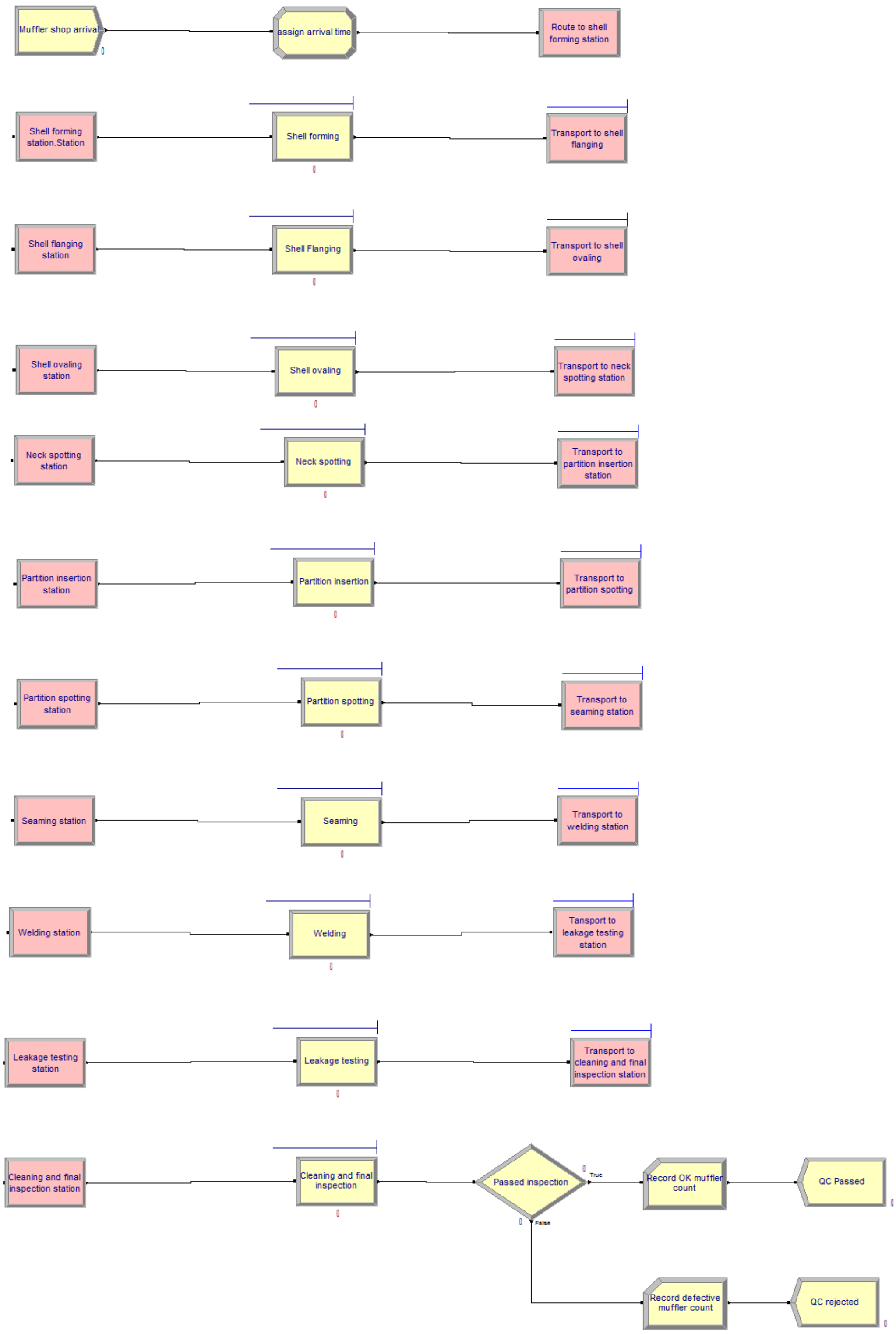


Figure 17. *Completed simulation model for proposed layout-2*

ANNEXURE H

Results of the ProposedLayout-2

Key Performance Indicators

System	Average
Number Out	3,598

Time

VA Time	Average
muffler	8.0500

NVA Time	Average
muffler	0.00

Wait Time	Average
muffler	1.9994

Transfer Time	Average
muffler	2.3833

Other Time	Average
muffler	0.00

Total Time	Average
muffler	12.4328

WIP	Average
muffler	3.1081

Scheduled Utilization

	Value
Cleaning and inspection equipment	0.3124
Leakage equipment equipment	0.2499
Neck spotting equipment	0.1250
Partitiion spotting equipment	0.1083
Partition Spotting equipment	0.1375
Seaming equipment	0.1875
Shell flanging equipment	0.1083
Shell forming equipment	0.1500
Shell ovaling equipment	0.1333
Welding equipment	0.5000
Workers	0.2006