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MASTER THESIS

Liberec 2021 Nandhakumaar Paranthaman

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Design of manufacturing cell in the company BOS Klášterec nad Ohří

Master Thesis

Study programme:	N2301 Mechanical Engineering
Study branch:	Manufacturing Systems and Processes
Author:	**Nandhakumaar Paranthaman**
Thesis Supervisors:	Ing. František Koblasa, Ph.D. Department of Manufacturing Systems and Automation

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Master Thesis Assignment Form

Design of manufacturing cell in the company BOS Klášterec nad Ohří

Name and surname:	**Nandhakumaar Paranthaman**
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Rules for Elaboration:

Specification of the master thesis is the design of manufacturing cell in the company BOS Automotive Products CZ s.r.o. and optimization of its processes. Manufacturing cells design has to take into account production volume, human factors engineering while maintaining the high quality of the product. The design has to be verified by the analytical tool as simulation including evaluation of KPI. The master thesis will include naturally detailed analysis of the suggestions and their realizations. It is recommended that the thesis will follow the classical project-based methodology:

1. Introduction into design and optimization of manufacturing systems (e.g., Lean Six Sigma methods, Ergonomics, rules of designing material and information flow, Process analysis, 5S).
2. Analysis of current state and requirements (job data analysis, available layout analysis, process analysis).
3. Design of manufacturing cell and assembly process options.
4. Evaluating and selecting the best solution according to the simulation results.
5. Conclusion and final evaluation.

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[1] DORF, Richard C. a Andrew KUSIAK. Handbook of design, manufacturing, and automation. New York: Wiley, c1994. ISBN 978-0-471-55218-5.
[2] IRANI, Shahrukh A. Handbook of cellular manufacturing systems. New York, Wiley, 1999. ISBN 978-0471121398.
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Liberec March 5, 2020

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TÉMA: **Návrh výrobní buňky ve firmě BOS Klášterec nad Ohří**

ANNOTATION: Představená diplomová práce se zabývá návrhem výrobní buňky ve společnosti BOS Automotive Products CZ s.r.o. v Klášterci a Ohři. Cílem je navrhnout novou univerzální výrobní buňku ve společnosti při uspokojení ročního požadavku zákazníků. Prováděné výrobní procesy byly popsány a analyzovány pomocí nástrojů, jako je popis procesu, technologická matice produktu, analýza výrobní buňky. Na základě analýzy byly definovány procesy na dílně a byla navržena výrobní buňka. K vizualizaci toku procesu u navrhovaných buněk byly použity špagetové diagramy. Nejlepší řešení bylo vybráno pomocí multikriteriální analýzy. K simulaci modelu navrhované buňky byl použit simulační software Witness 14 za účelem ověření zda návrh uspokojuje roční poptávku zákazníků z hlediska kapacity.

Klíčová slova

Návrh Výrobní buňky, procesní tok, analýza, simulace

THEME: **Design of manufacturing cell in the company BOS Klášterec nad Ohří**

ANNOTATION: The work exhibited in this thesis is the design of a manufacturing cell in the company BOS Automotive Products CZ s.r.o. in Klasterec and Ohri. The aim of this is to design a new universal manufacturing cell for the company and also meet the yearly customer demand. The production processes carried out was described and analysed using tools such as process description, product technology matrix, manufacturing cell analysis. Based on the analysis, the workshop phase was defined and the manufacturing cell was designed. Spaghetti diagrams were used to visualize the process flow for the suggested cells. The best solution was selected using multi-criteria analysis. The Witness 14 simulation software was used to simulate the model of the suggested cell and obtained the result satisfying the yearly customer demand from capacity point of view.

Keywords

Design of Manufacturing cell, process flow, analysis, simulation

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LIST OF SYMBOLS

T_{ac}	-	Processing Time
T_{bc}	-	Setup Time

LIST OF ABBREVIATIONS

GT	-	Grouping Technology
CMS	-	Cellular Manufacturing Systems
PFA	-	Production Flow Analysis
C&C	-	Classification and Coding
ZODIAC	-	Zero–One Data–Ideal seed Algorithm for Clustering
JIT	-	Just In Time
FIFO	-	First In First Out
VSM	-	Value Stream Mapping
PLT	-	Production Lead Time
VA Index	-	Value Added Index
VAT	-	Value Added Time
NVAT	-	Non-Value-Added Time
BLT	-	Business Lead Time
C/O	-	Change Over time
C/T	-	Cycle Time
WIP	-	Work in Process
SMED	-	Single Minute Exchange Dies
DMAIC	-	Define Measure Analyze Improve Control
DMADV	-	Define Measure Analyze Design Validate
DFSS	-	Design for Six Sigma
KPI	-	Key Performance Indicator
CTD	-	Cumulative Trauma Disorders
MSD	-	Musculoskeletal Disorders
TT	-	Takt Time
TCT	-	Total Cycle Time

1. INTRODUCTION

The basic purpose of the design of a manufacturing cell is to carry out the production in an orderly manner and meet the demand of the customer within the appropriate time period. The manufacturing cell should be designed in such a way that it ensures safety in the workplace, ergonomic to work, utilize the human potential effectively, implement lean manufacturing by eliminating wastes and so the production output can be increased. The layout design can be optimized in such a way that it reduces the production space area and it optimally uses production floor.

In this thesis, the manufacturing cell in the BOS Automotive Products CZ s.r.o. must be designed and simulated using the Witness 14 simulation software. A universal cell must be proposed that is able to produce the product luggage cover of two variants SK 382 and SK 326 which are currently produced in the manufacturing lines GEAF II and Schwalbach respectively. The purpose of the formation of the universal cell is that to reduce the production space, reduce machine idling time and deliver the yearly customer demand without any shortage.

At first, the theoretical parts that supports the design of a manufacturing cell, lean manufacturing, and tools, six sigma and the workplace ergonomics must be explained in detail. Then the analysis of the current state of the cells must be carried out in order to design a cell from the technological point of view. The optimal one from suggested variants can be chosen using the multi- criteria analysis.

The main objectives of the thesis are to reduce the production space area, improve the utilization rate and reduce the cost of machines. This should be achieved on by designing a new universal layout. From the capacity point of view, the designed cell should be able to meet the required yearly customer demand. To ensure this, the capacity equations must be formed and the machine utilization rates are to be checked. This model can be visually represented using the Witness 14 simulation software and the machine utilization rates are to be cross verified, so that the suggested cell design can produce required quantities can be ensured.

2. LEAN MANUFACTURING

This methodology is collectively used to remove all kinds of waste from the system and improve the performance of the manufacturing process. Lean generally focuses on the removal of waste form the process and the six sigma aim to optimize and reduce the deviation in a production process.

In modern days the two entities are clubbed together and have become a powerful tool in the manufacturing sector. Lean six sigma is a perfect tool for companies that aim for improving their product by eliminating their defects and wastes while on production and enhances their customer satisfaction.

2.1 JUST-IN-TIME

Just-In-Time is a material requirement planning technique that is ensures the provision of raw materials at the right time for production. By implementing the JIT, the on-hand inventory also called as the buffer stock can be reduced and so the inventory waste can be reduced. In simple, it is making availability of right inventories at the right place at the right time. The elements that support to achieve the JIT are, highly coordinated supply and demand systems, streamlined machine setup times.

Kaizen technique is used to monitor, identify, implement the improvements continuously in a graded manner. It ensures the removal of waste and an immediate step is taken out whenever there is a small degradation in efficiency is recorded.

2.2 DEFINITION OF WASTES

In lean, the waste refers to every activity that unless and until meets the customer requirements or that activity could be presented in a more economical manner. TOYOTA defines waste as: "anything other than the minimum amount of equipment, materials, parts, and working time absolutely essential to production". MUDA is the Japanese word for wastes. There are eight types of wastes in lean manufacturing. [2]

- Transport
- Inventory
- Motion
- Waiting time
- Over production
- Over processing
- Non- utilized talent
- Defects

2.2.1 TRANSPORT

The unnecessary movement of materials, products from one place to other in a manufacturing process is a transportation waste. The sequence of process should be placed closer to each other and the unnecessary transportation of raw materials and goods should be reduced so that the transportation waste can be avoided.

Causes of transportation wastes could include poor layouts- large distance between operations, large batch sizes, multiple storage locations, huge and complex material handling systems.

2.2.2 INVENTORY

The storage of raw materials and goods in excess quantities than the required amount for production leads to inventory waste. This leads to the increase of storage costs. Thus, the concept of Just in Time (JIT) is introduced. JIT provides the raw materials at the right time before the need for production, thus reducing the inventory waste.

Lack in balance of work flow, FIFO (First in First Out) is not followed, long change over time could be some of the reasons for the inventory waste.

2.2.3 MOTION

Motion of human, any other equipment in a manufacturing process that does not contribute to add value to the product or service is denoted as a motion waste. Generally, the motion waste occurs due to the unergonomic work place spaces, poor work place layouts- bending, excessive walking.

2.2.4 WAITING TIME

The idle time of worker, machine is considered as a waiting time. This symbolizes that the man power and the machine is not utilized well to their efficiencies. This occurs when there is no synchronization between the machine and the worker, the job is done more than the stipulated time period and that could be due to slow working, reworking, batch completion.

2.2.5 OVER PRODUCTION

Manufacturing of products exceeding the market or customer demand leads to over production. This waste leads all other wastes and it increases the cost of production. It can be caused due to the unstable schedules, inaccurate forecasting or not analyzing the actual market demands. This can be avoided by balancing supply and demand.

2.2.6 OVER PROCESSING

All the processes carried out in a product that are not valued or appreciated by the customers are concluded as the over processing wastes. Also, the processes that are done beyond its standardized level also leads to this waste. This increases the manufacturing time, the human potential is wasted, cost of production is also increased.

2.2.7 NON-UTILIZED TALENT

The proper identification and employing the skilled persons in the appropriate work places is important to obtain the optimal utilization of a process in a workplace. It is generally the placing the right skill at the right place. The improper use or wrong employment of the human abilities or skills in a workplace leads to this waste and this in turn decreases the efficiency of the work

2.2.8 DEFECTS

The errors that occur in a finished product that requires a rework to change it to a desirable product or the products that may go as a scrap due to the damages on producing are the defects. This is caused due to the lack of knowledge of process and handling of machines and equipment, unskilled workers, unstandardized operating procedures.

2.3 LEAN TOOLS

Lean tools are the methods that are implemented to eliminate the wastes and achieve lean manufacturing in an organization. This helps in maintaining of a well-organized and sustainable work environment.

2.3.1 VALUE STREAM MAPPING (VSM)

The value stream mapping is a lean manufacturing tool that graphically represents the flow of information and material in a system. A value stream comprises of both value adding and non-value adding activities required to bring a product / service through the main flows essential to every product.[12] This is a process flow chart that contains the information about the current material flow, processing steps and the output and thus it helps to understand flow of products in a system. This tool contains the value added and non-value-added information with their respective timeline. This graphical tool also used for the identification of eight types of waste and sources of the problematic areas.

The Value Stream Mapping (VSM) gives the material and the information flow in the system. Here the VSM is done for the main edge processes for easy understanding. The timeline is made according to the data obtained from the real systems. There are 4 main steps in construction of a value stream map. They are as follows,

1. *Creating an outline of the process* – This primary step is the backbone of the process where operations that are carried out are identified and written onto boxes along with the supplier and customer on the top left and right corners respectively.

2. *Draw the information flow and material flow* – In this step we visualize how the material and information travels on each stage of a production process. Each flow is marked from supplier to the customer using unique flow arrows.

3. *Add process data* – This includes the calculation and reflection of the data such as cycle time (C/T), change over time (C/O), production lead time (PLT), value added time (VAT), non-value-added time (NVAT), business value added time (BVAT) and much more.

4. *Add timeline and calculations* – This final step is meant for the calculation of takt time and in our case the takt time are provided for the company.

The calculation for the making the timeline of processes is given below as,

PLT = $VAT + NVAT + BVAT$ (1)

VA Index = VA/PLT (2)

Where, C/T	–	Cycle Time
VAT	–	Value Added Time
NVAT	–	Non- Value-Added Time
BVAT (C/O)	–	Business Value Added Time (Change Over Time)
PLT	–	Production Lead Time
VA Index	–	Value Added Index

There are unique symbols that denotes different processes in a manufacturing line which are used in the construction of the value stream mapping. These are standardized symbols, used for easy understanding and readability of the document. The Table 1 below shows some commonly used symbols in the value stream mapping and their purposes and Figure 1 shows the VSM.

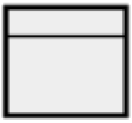
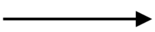
Symbol	Purpose
	Operation and data box
	Customer or supplier
	Movement of materials
	Manual information flow
	Electronic information flow
	Inventory, Work in process (WIP)
	Workers deployed at the work station
	Transportation from or to external sources

Table 1: Commonly used symbols in VSM [own]

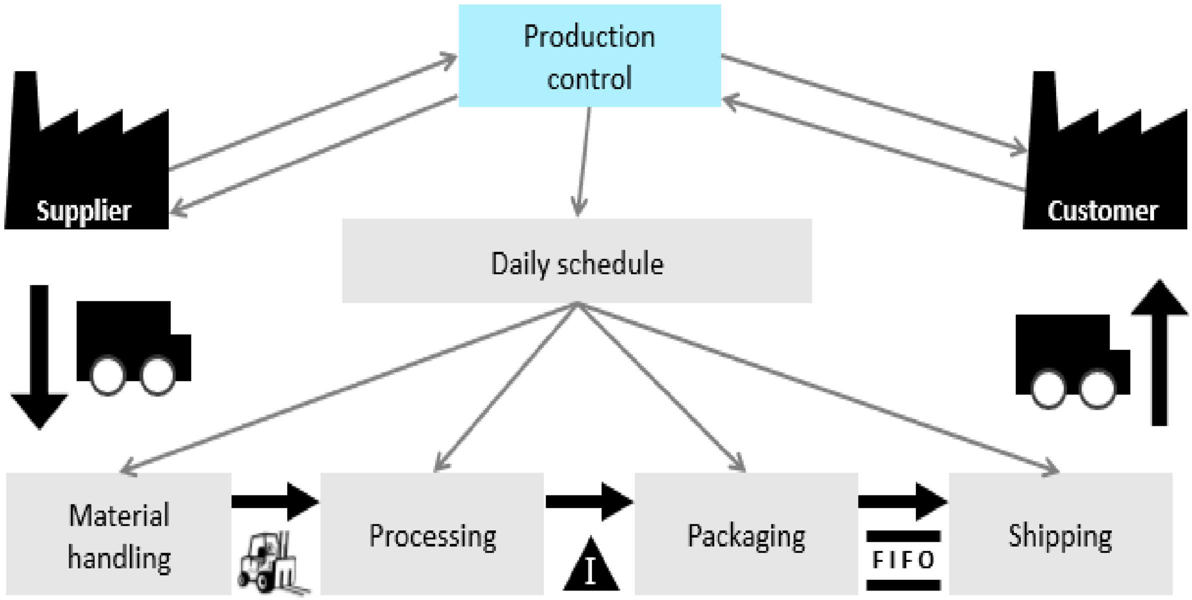


Figure 1: Value stream mapping [20]

USES OF VALUE STREAM MAPPING

- The flow of process can be visualized in a production with help of VSM.
- The sources of wastes can be identified using the mapping.
- It is considered as a standard documentation to understand about the manufacturing processes.
- It combines the lean concepts and methodologies together.
- It has a unique property that it forms bridge between the material flow and the information flow.
- It forms the basement of a production process designing and improvement for the lean implementation.

2.3.2 SMED

Single Minute Exchange of Die (SMED) a lean tool was developed by the Japanese engineer Shigeo Shingo. This tool is used for analyzing and reducing the setup time. When there is frequent change to be made in machine to follow up with different model of a product, there is a possibility of increase in setup time. By introducing this technique, the change over time was reduced to minutes from several hours. The setup time is a waste according to the lean terminology and reducing the setup time could lead to increase in productivity. The phases of SMED methodology are represented in a graphical manner below in Figure 2,

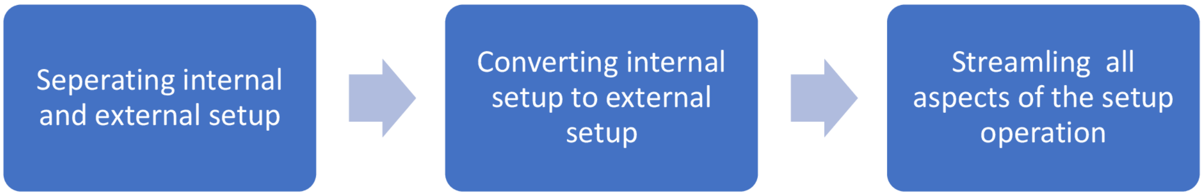


Figure 2: Phases of SMED methodology [own]

2.3.3 5S

5S is a Japanese methodology that was developed for organizing and maintain the work places in a standardized manner, so that the work can be performed efficiently and effectively. This is a fundamental tool in the implementation of lean manufacturing.

5S system could make the workplace safe, reliable, and improvises the quality of working process in a production floor. On successful implementation of 5S in an organization, it can easily regulate and control the processes carried out by requiring less time, capital, increase human potential and quality of the products that are produced. The below Figure 3 shows 5S implementation and the Table 2 gives the 5S and its brief explanation.

Figure 3: 5S Implementation [9]

SEIRI	SORT OR ORGANIZE	The unnecessary things that are present in the production area are eliminated on making a red tag.
SEITON	SET IN ORDER OR SYSTEMIZE	Useful for the production process is orderly arranged and organized
SEISO	SHINE OR CLEAN	Clean the workplace, tools, equipment, and machinery
SEIKETSU	STANDARDIZING	Visual management is achieved so that everyone knows where a problem occurs.
SHITSUKE	SUSTAINING AND SELF DISCIPLINE TO MAINTAIN IT	Making an audit regularly for the purpose of sustainment of 5S in the workplace

Table 2: 5S in Lean [own]

5S USES

- Disciplined approach for an organized workplace
- Ergonomic work environment
- Cleanliness and Safety
- Employee Involvement and increased efficiency
- Space management
- Timely delivery of products
- Quicker training of new employees

2.4 ONE PIECE FLOW

One piece flow method is also called as a continuous flow method which is used in lean manufacturing to achieve Just-In-Time in production. This method is entirely different from conventional manufacturing where one process is done for a batch of products and then moved to the next process. But here in this method, one product completes all the processes to be done and then the next product is piled up from the primary process. So, the cell is designed in such a way that the machines are in an orderly manner as per the processes done. The amount of work performed should be equally distributed on each work station to maintain a smooth working process, which is called as the 'Line Balancing'. The main advantages of adapting the one-piece flow are,

- Avoiding over production
- Reduced lead time
- Number of Work in Progress (WIP)
- Reduces the chances of mass defect in production
- Storage space can be reduced as inventory are cut down

3. SIX SIGMA

Primarily six sigma (6σ) was created and implemented by the Japanese company "Motorola" in 1986 as a quality management process. The sigma denotes the standard deviation of the values obtained from the mean value. When the process has six deviations or sigma above and below the mean value, it is acknowledged as the extremely low in the defect i.e., 3.4 defects per million. [2]

Six sigma uses DMAIC and DMADV primarily. This is a performance improvement model that abbreviates as Define- Measure- Analyze- Improve- Control. The DMAIC is used in the process of manufacturing of a product or in the service sector. This thesis structure follows the DMAIC to define, analyze and improve the existing state. DMADV- Define- Measure- Analyze- Design- Validate comes under the DFSS (Design for Six Sigma) that is deployed when the customer requirements are not met and are implemented by the higher-level persons of six sigma. The Table 3 shows the DMAIC phases and the corresponding tools used.

- Define the problems or the goals of the improvement activity.
- Quantify the existing system.
- Analyze the system, identify the problems' root cause, and find the ways to remove the problems.
- Improve the process by implementing the solutions.
- Control the new process.

DMAIC phase steps	Tools used
Define • Define the customer requirements • Develop project plan • Define resources • Mention goals and benefits	Project charter, Process flow chart, Voice of customer
Measure • Define Defect, Opportunity, Unit and Metrics • Processing map • Data collection and validation	Measurement System analysis, Benchmarking
Analyze • Identification of value added and non- value-added steps. • Performance Objectives are defined • Determine root causes	Histogram, Pareto chart, Ishikawa diagram, 5 Whys, Process map analysis
Improve • Perform design of experiments • Potential solutions are developed • Validate and re-correct the developed solutions.	Poka-yoke (fool proofing), Failure Mode Effect Analysis (FMEA), House of Quality, Simulation software
Control • Develop standards and Procedures • Statistical Process control • Verify calculated benefits	Control plan, control charts, Process sigma calculation

Table 3: DMAIC phases and corresponding tools [own]

4. CELLULAR MANUFACTURING

Cellular manufacturing is an application of Grouping Technology (GT). Grouping technology is a manufacturing concept that is used to identify the similarities such as shape, design, technological processes in a collection of parts and then group the parts with similarities to take advantage of the similarities. Generally, it focuses on the proximity of parts and the processes involved in the manufacture of the parts and groups them into categories.

GT is defined as “a method of manufacturing piece parts by the classification of these parts into groups and subsequently applying to each group similar technological operations”[6]. A modern definition of GT is “the realization that many problems are similar, and that by grouping them, a single solution can be found to a set of problems, thus saving time and effort” [7].

A Cellular Manufacturing System (CMS) gives the operational benefits to the flow of production. A collection of process is grouped, and those machineries are arranged in such a way for hassle free production in the cellular manufacturing. A single part family is usually allocated to a cell and a part of that can be manufactured within a cell, also there should be minimum communication between the cells in a Cellular Manufacturing System (CMS). So, the CMS is a system where a group of cells are incorporated to manufacture a part or group of products from the part family in each cell respectively.

A manufacturing cell can be defined as “an independent group of functionally dissimilar machines, located together on the floor, dedicated to the manufacture of a family of similar parts.” Furthermore, a part family can be defined as “a collection of parts which are similar either because of geometric shape and size or because similar processing steps are required to manufacture them.” [8].

4.1 METHODS FOR CELL DESIGN

The main and time-consuming work in a cellular layout is the grouping of elements accordingly. This grouping and layout forming is done by the trained professionals since it involves analysis of the processes. The methods for design are,

- Eyeballing
- Production Flow Analysis (PFA)
- Parts Classification and Coding(C&C)

4.1.1 EYEBALLING

Eyeballing is inspection and analyzing the parts visually. The visual inspection can be done by looking onto the shape, size of parts and by its design to make groups. This is the simplest and cheapest of the three methods. The constraint of this method happens when there are huge number of parts for grouping and the accuracy level is minimum.

4.1.2 PRODUCTION FLOW ANALYSIS (PFA)

In this method, part families are formed and grouping of machines is made by analyzing the process data collected, listed on the parts manufactured in the route sheets**.** The parts with similar operational sequences are grouped together. It requires process route sheets that are reliable and well documented. The constrain of this method is that it depends on the route sheets and it usually assumes that they are accurate and not check its up-to-date documentation of the processes. There are four stages in this method, where a part of factory is addressed by each stage.

4.1.3 PARTS CLASSIFICATION AND CODING (C&C)

This method is highly complicated and thus it is a time consuming one, aims to group parts with similar or identical attributes of geometric design and manufacturing processes into families. The attributes such as shape, dimension, holes of a part are denoted by a numerical code. This numerical code contains the attributes of parts which then used to put into families by sorting and grouping. Each part family is identified to a cell according to the machine capabilities and available capacities.

4.2 DESIGN OF A MANUFACTURING CELL

Basically, the key principles of production flow must be kept in mind before designing a manufacturing cell. Those includes the path of flow must be short or fastest one, path should be well defined and continuous, it should be one directional and wide enough without any crossings. In design of a manufacturing cell, there are primarily four important steps to be followed. The Figure 4 shows the steps in cell formation.

- Group Products
- Review the Work Sequence
- Define the infrastructure
- Design the Cell Layout

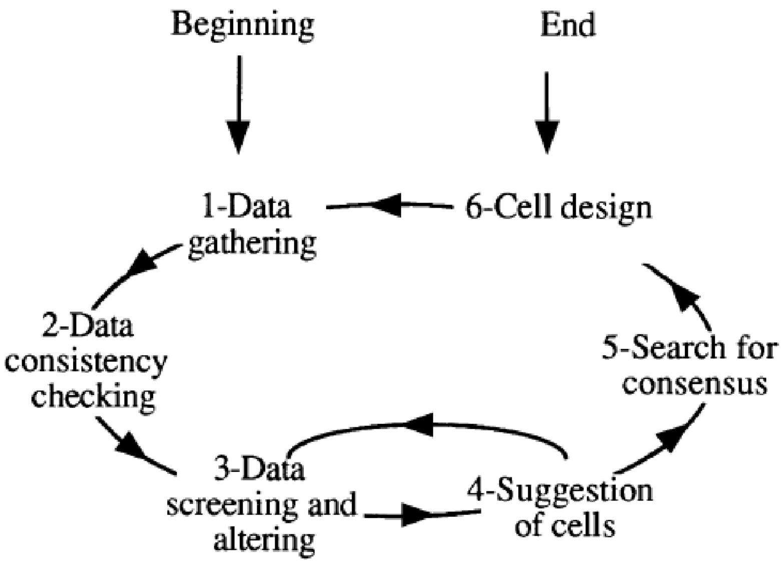


Figure 4: Steps in cell formation [3]

Group Products

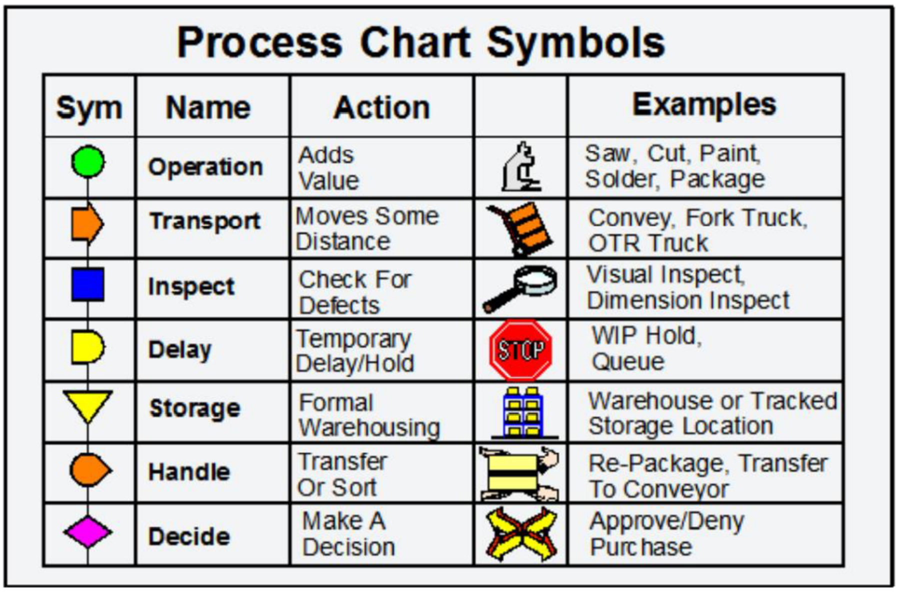
The main aim of the product grouping is to seek the compatible product families that a group of machines can process the similar kind of operations with less or no changeovers. The attributes of the products such as similar processes, similar operational sequences, resource requirements, machining capacities are grouped together. The changeover time or setup time, process time variations are also taken into consideration for this grouping. The tools that are used for this step include the product or process matrix, process mapping.

This is a tool associated to the grouping technology (GT). In product or process matrix the interrelationship between the product and its corresponding process requirements is marked accordingly. This helps to group products and form product families. The daily demand and production requirements can also be addressed here to carry out processes as per the requirements. The above Table 4 shows the algorithms that are used for the cell formation process.

Grouping Algorithms	Steps involved
Production Flow Analysis (PFA)	This method is used for transforming traditional functional layout into product-oriented layout.
Rank order clustering Algorithm	In this algorithm the machines are arranged in a decreasing order of their weights.
Similarity-Based clustering Algorithm	The similarity coefficients are computed and groups are formed with high similarity.
ZODIAC Algorithm	It is a non- hierarchical for clustering where the Jaccard similarity coefficient matrix is computed and seed points for natural seed clustering is chosen.
Genetic Algorithm	This is based on the theory of natural evolution of chromosomes. The new combination of data is formed by crossing, mutation, and inversion. The fitness function is used for the evaluation purpose.

Table 4: Algorithms for cell formation [own]

Process mapping is a tool to visualize the streamline of the work process. This flow chart tool could include additional information that are essential for the process analysis include the cycle time, inventory time and the equipment information. The below Figure 5 shows the important process chart symbols.



Process Chart Symbols

Sym	Name	Action		Examples
	Operation	Adds Value		Saw, Cut, Paint, Solder, Package
	Transport	Moves Some Distance		Convey, Fork Truck, OTR Truck
	Inspect	Check For Defects		Visual Inspect, Dimension Inspect
	Delay	Temporary Delay/Hold	STOP	WIP Hold, Queue
	Storage	Formal Warehousing		Warehouse or Tracked Storage Location
	Handle	Transfer Or Sort		Re-Package, Transfer To Conveyor
	Decide	Make A Decision		Approve/Deny Purchase

Figure 5: Process Chart Symbols [8]

Review the work sequence

The study and well understanding of the work sequences or the processes is done in this step. The cycle time, machine capacity, change over times are studied and the value added and the non- value-added segments are observed.

Define the infrastructure

The elements that could support the production processes are pointed out as the infrastructure. These do not have direct contact to the products but with the help of these elements the production process can carried out and run in an orderly manner. These infrastructures are intangible and must be considered for the cell design. The elements may include the schedule, material handling containers, the balance methods such as line balancing that distributes the workload evenly to the work stations, quality assuring tools.

Design the cell layout

By carrying the preceding steps this physical layout can be made successfully. The processes involved, optimal physical arrangements, space for the layout, handling of external constraints are taken into consideration of the design of the cell layout. On comparing to the conventional layouts such as line or product layout and function layout the cell layout is easier to manage.

4.3 U- SHAPED CELL

U shaped cell is a special kind of cell used in Just in time and part of the lean manufacturing that aims to eliminate wastes and meet customer demand and quality. The most important change resulting on the JIT implementation is the conversion of straight lines to the U-shaped cells. In a U-shaped cell, the machines are arranged in u shape line to perform the operations. The operators work inside the U-shaped line. the workers could move to the adjacent work station to carry out further processing of the production process as the machines are placed closely and in an orderly manner. Unlike straight-line cells the walking distance from the starting point of a process to the finishing point is reduced and so walking distance by the worker is minimized. In a U-shaped cell, the number of workers is influenced by the customer demand.

5. PROCESS ANALYSIS

The study of the processes that are carried out in manufacturing of a product is generally referred as the process analysis. This is carried out for the better understanding of the processes and so the modifications if needed can be done appropriately in a process.

5.1 KEY PERFORMANCE INDICATORS

In order to be successful competitor in the market, the manufacturers must continuously monitor the actions performed in a system. This is where the need of the Key Performance Indicators (KPIs) comes in which could monitor, investigate the key elements in a system such as efficiency, competence, effectiveness, and reliability of the manufacturing operations. There are various KPI elements such as type, description, unit of measurement, mode of measurement, formula that helps the manufacturers to define, analyze and measure the KPIs that are relevant to their production floor operations. This enables the manufacturers to continuously increase and maintain the quality, productivity, and throughput of the product.

The performances of the whole manufacturing unit are basically measured in two ways as result indicators and the performance indicators. The result indicators measure the after effects of processes done, while the performance indicators are used to create an action plan to implement for the results obtained. Some of the categories of KPIs are cost, time, quality, control, sustainability, maintenance, inventory management, resource usage, planning which are subjected to the purpose of the application.

The problems that could occur on a manufacturing cell are, unnecessary motion or walking steps, waiting time, inventories, production space. So, the KPIs that we are defining must be based on these problems to reduce and eliminate it. In this thesis, the performance indicators that we would use are the objectives that have to be met, which are as given below in Table 5,

Key Performance Indicators	Units
Production space	Sq. m
Movement of Persons	Total number of steps
Intersections	Number of intersections
Process distance	meters

Table 5: Key Performance Indicators used

5.2 FLOW CHART

Flow chart is also called as the process flow diagram is one of the seven basic tools in quality management. This represents the flow of sequential processes by unique shapes for each element present in a process. A flowchart is used as standardized representation of process flow in a system that everyone can understand. It shall also be taken as a study document to analyze and improve a process. The mainly used flow chart symbols are specified in the below Table 6,

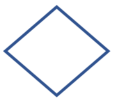
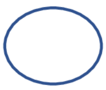
	Input or output data
	Process steps
	Decision making
	Flow arrows from one step to the other
	Termination of process
	Connector for flowcharts

Table 6: Flowchart symbols [own]

5.3 SWIM LANE DIAGRAM

Swim lane diagram is another form of flow chart, where the different departments in an organization is made into lanes as shown in Figure 6. As these lanes makes the flow chart look like a swimming lane it is generally called as the swim lane diagram. This swim lane process maps are used for the representation of the information flows, each lane in the diagram is separate entity in a company. The lanes can be of either horizontal or vertical according to the suitability of process flow. The information flow can be non- linear, circular form as the information could pass from one department and to other and again return to the same department for further processing.

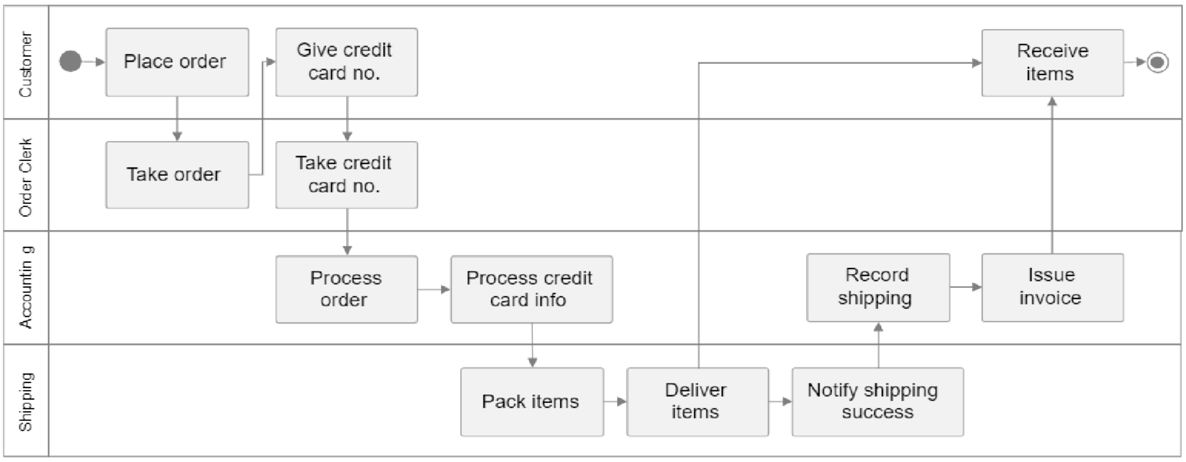


Figure 6: Swim Lane diagram [21]

5.4 SPAGHETTI DIAGRAM

Spaghetti diagram is a visual representation of the product flow path from one stage to the other stage in a manufacturing system. A spaghetti diagram is a one in which the flow arrow lines are drawn from one element or stage to the other in a layout map that consists of the machines and other equipment as in the real system. The steps in making spaghetti diagram are,

- Designing of the workspace layout
- Drawing of arrows from starting of an element in a process to the proceeding element or stage. This process drawing arrows is continued in such a way it represents the real flow in a system till the end of the process.
- The analysis of the diagram is done to achieve the improve in workflow.

The main objective of the spaghetti diagram on improving the workflow can be achieved by evaluating the value added and non-value-added flow, implementing the production flow principles such as ensuring the shortest steps between sequential processes, well defined, making the flow as one directional and continuous, eliminating crossings between the paths. These production flow principles should be realized by making changes in the cell layout design and the optimal solution that depicts the improvised workflow must be proposed. The below Figure 7 shows an example of the spaghetti diagram,

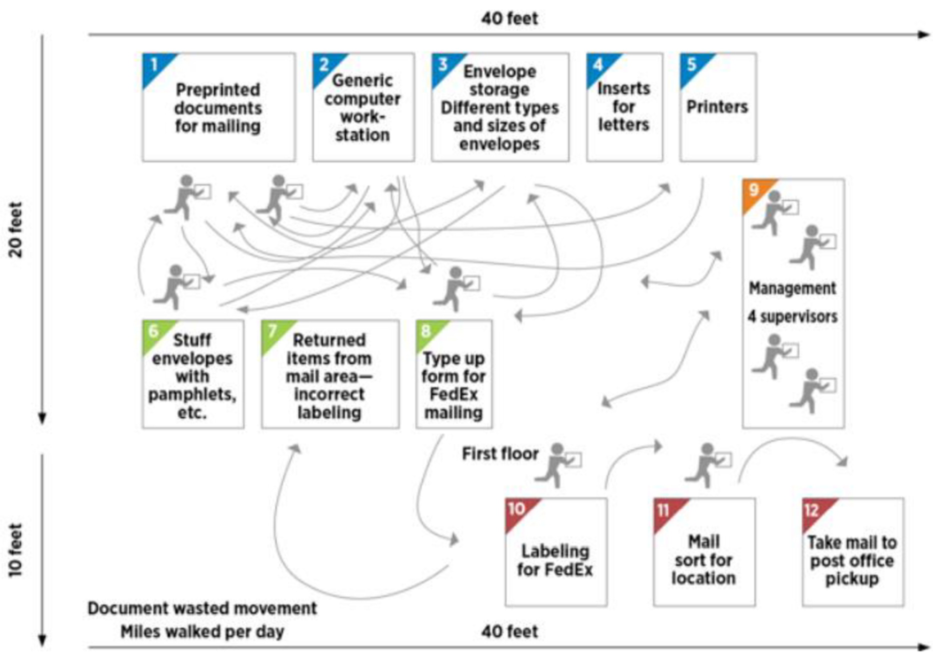


Figure 7: Spaghetti diagram [17]

5.5 PRODUCT TECHNOLOGICAL MATRIX

A technology matrix is a new quality management tool, in which the relationship between the technological data can be established and analysed. A matrix can display the relationship between two, three or four sets of technological data. There are different types of technological matrices where the type depends upon the number of data sets is considered for the comparison. The below Table 7 shows the types of technological matrices in practice and their corresponding relationship between the data sets,

L-shaped	2 groups	A ↔ B (or A ↔ A)
T-shaped	3 groups	B ↔ A ↔ C but not B ↔ C
Y-shaped	3 groups	A ↔ B ↔ C ↔ A
C-shaped	3 groups	All three simultaneously (3D)
X-shaped	4 groups	A ↔ B ↔ C ↔ D ↔ A but not A ↔ C ↔ or B ↔ D
Roof-shaped	1 group	A ↔ A when also A ↔ B in L or T

Table 7: Differently shaped matrices based on uses [18]

6. ERGONOMICS

The ease and correct fitting to do a job in an effortless manner is referred as ergonomics. In other words, the motion of a human to carry out a specified work with the machine or its elements should be in a simplified way, so that the motion of work does not create any stress, pain to the body. This is a methodology of setting up the work place to make the working motion simpler and aims to reduce or nullify the awkwardness, discomfort, pain, and fatigue that could occur to our body on continuous working or repeating the same work several times and so the safety, productivity, comfort, job satisfaction can be increased and the human potential waste is decreased.

Generally, an ergonomic design in a work station helps to reduce the risk factors such as illness, injuries, work stress, stains, and Cumulative Trauma Disorders (CTDs) and adapt to the abilities of the worker. The awkward work positions and motions leads to continuous stress, stain in the ligaments, muscles, and tissues of the body that in turn causes the injuries commonly known as the Musculoskeletal Disorders (MSDs).

6.1 MUSCULOSKELETAL DISORDERS (MSDS)

The physical motions and positions that mismatch between a person and the working elements cause an unergonomic work standards which in turn causes wear and tear in the ligaments, tendons, blood vessels, nerves called as the Musculoskeletal Disorders (MSDs). MSDs represents a massive range of disorders that could be from a symptomatic level to a severe chronic condition. Some of the disorders are carpal tunnel syndrome, rotator cuff injuries, epicondylitis, tendinitis.

Factors that contribute to MSDs include awkward and static postures, repetitive motions, pressure points and contact stress, vibration, and forceful exertions. These could affect the health of the workers and affects productivity which incur more costs and loss to the organization. Informing or detection at the early stages of the disorder such as pain, weakness, swelling, burning sensation, tingling, stiffness could help to improvise the health and reduce the risk factors of the workers.

6.2 WAYS TO REDUCE ERGONOMIC RISKS

- Analyzing, rearranging, and redesigning of the workplace to fit in for the work person to carry out the work in a comfortable manner.
- Periodic altering of works or providing various jobs on a rotational manner instead of a repeating job.
- Providing work spaces with tables, equipment with compatible height and distance according to the worker.
- Providing anti-fatigue floor mats, footrests, sit-stand stools could make the workers more relaxed.
- Knowledge of the way of stressless motions of work must be provided.
- Working tools and equipment must be placed in such a way that there are no physical difficulties in taking, using, and keeping it back on to its position.
- The tools which must be given excess pressure to handle, should be avoided and alternate ways like pneumatic tooling systems should be implemented.

Advantages of ergonomics

- Improved health and safety of employees.
- Increase in human potential and productivity.
- Reduced risk factors and discomfort in work place.
- Increase in morale
- Reduction in medical costs and claims.

7. BOS AUTOMOTIVE PRODUCTS CZ S.R.O.

BOS Automotive is an international company founded in 1910 by Wilhelm Baumeister, with locations across Europe, North America, and Asia with headquarters in Germany. The company develops, manufactures, and distributes automobile systems and components that are innovative.[20]

In Czechia, the plant is located at Klášterec nad Ohri with area of 3600 sq. m and employs around 800 persons. The products that are manufactured by BOS automotive include sun protection systems, panoramic roof systems, luggage cover systems, carrier systems, safety restraining nets, electric body nets, plastics in the engine components. [20]

7.1 PRODUCT DESCRIPTION

The product luggage cover is been manufactured in two different models namely SK382 and SK326 at two manufacturing cells for different automotive. Luggage cover is an optional equipment which is fitted to the back side of the head rest of the seat. A luggage cover helps to cover the items stored in the trunk, prevents the backpacks or other luggage stuffs from exposure to heat and light.

The below picture shows the luggage cover model SK326 for the Skoda Karoq car. Figure 8 is the view without the expansion of the luggage cover.

Figure 8: Luggage cover model SK326 [own]

The below Figure 9 shows the luggage cover model SK382 for Skoda Octavia.

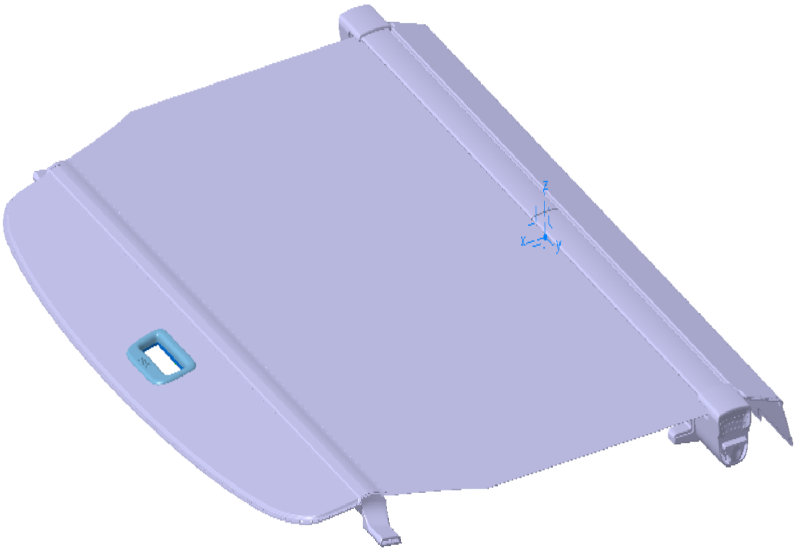


Figure 9: Luggage cover model SK382 [own]

Figure 10: Luggage cover SK382 inside the car [own]

The practical view of the fully expanded luggage cover taken inside the Skoda Octavia is shown below in Figure 11.

Figure 11: Expanded Luggage cover SK382 [own]

7.2 PROCESS DESCRIPTION

The step-by-step process is explained briefly for the better understanding of the processes that are carried out in manufacturing a product in the production floor. This understanding can help to identify the procedures that are carried out in each step of a process and so the similarities, problematic areas in a process can be figured out easily. The process description is preceded by the process flow diagram or the flow chart.

- The technological process for SK382 is as follows in the sequential order,
    1. Oven
    2. HF-Welding
    3. Crimping
    4. Sand Cutting
    5. Machine Pre-assembly
    6. Tube Pre-assembly
    7. Roll up table
    8. Spacer wedge
    9. Winding
    10. Final assembly

11. Endcap Pre-assembly
12. Design check
13. Final check

- The technological process for SK326 is as follows in the sequential order,
  1. Roll-welding
  2. Oven
  3. HF-Welding
  4. Sand Cutting
  5. Hook Assembly
  6. Machine Pre-assembly
  7. Tube Pre-assembly
  8. Roll-up
  9. Spacer Wedge
  10. Final Assembly
  11. Endcap Pre-assembly
  12. Final Check

The swim lane diagram for the above stages of operation is given as shown in the Figure 12,

1. Oven	2. HF-Welding	3. Crimping
4. Sand Cutting	5. Machine Pre-assembly	6. Tube Pre-assembly
7. Roll up table	8. Spacer wedge	9. Winding
10. Final assembly	11. Endcap Pre-assembly	12. Design check
13. Final check	14. Roll welding	15. Hook assembly

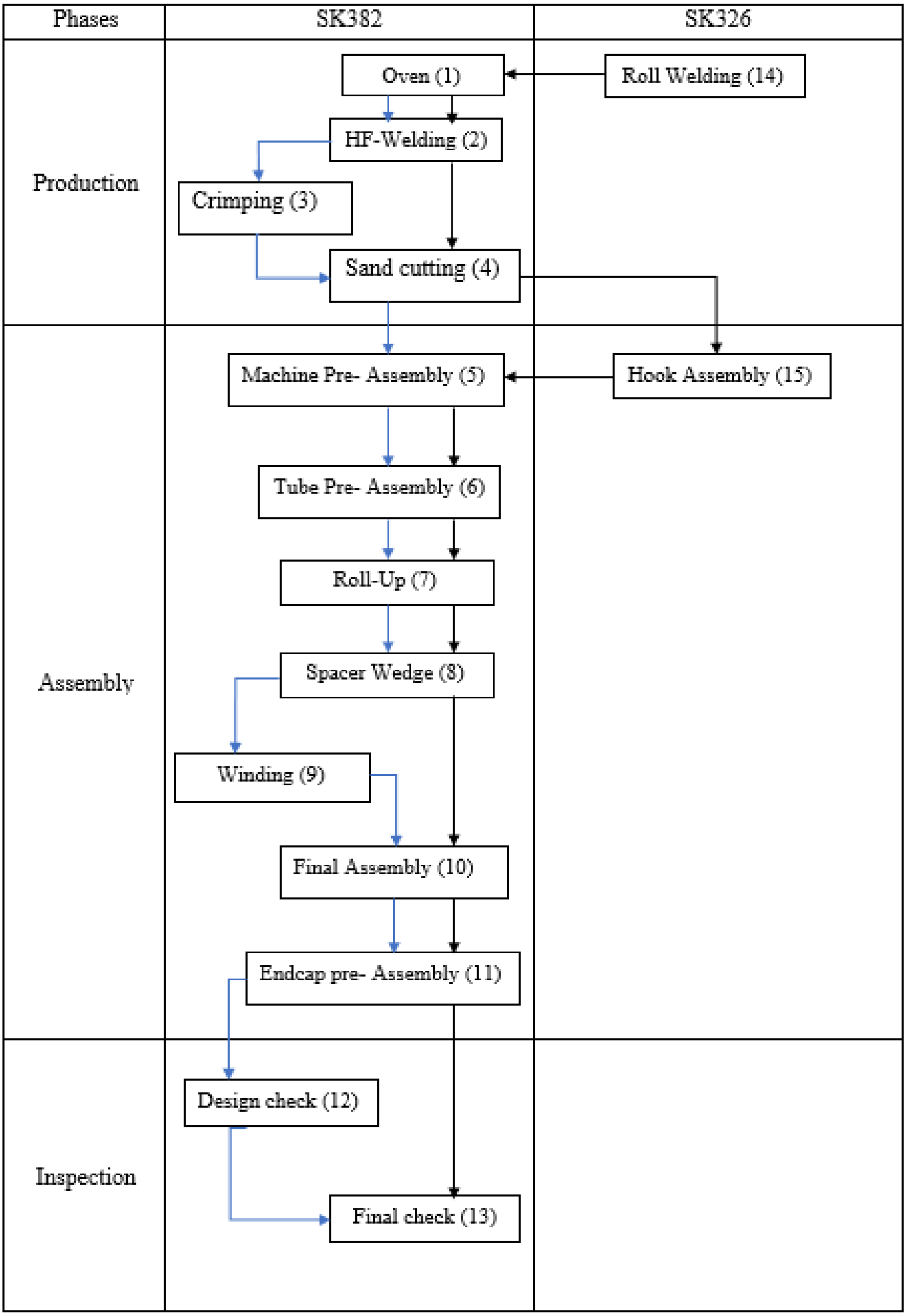
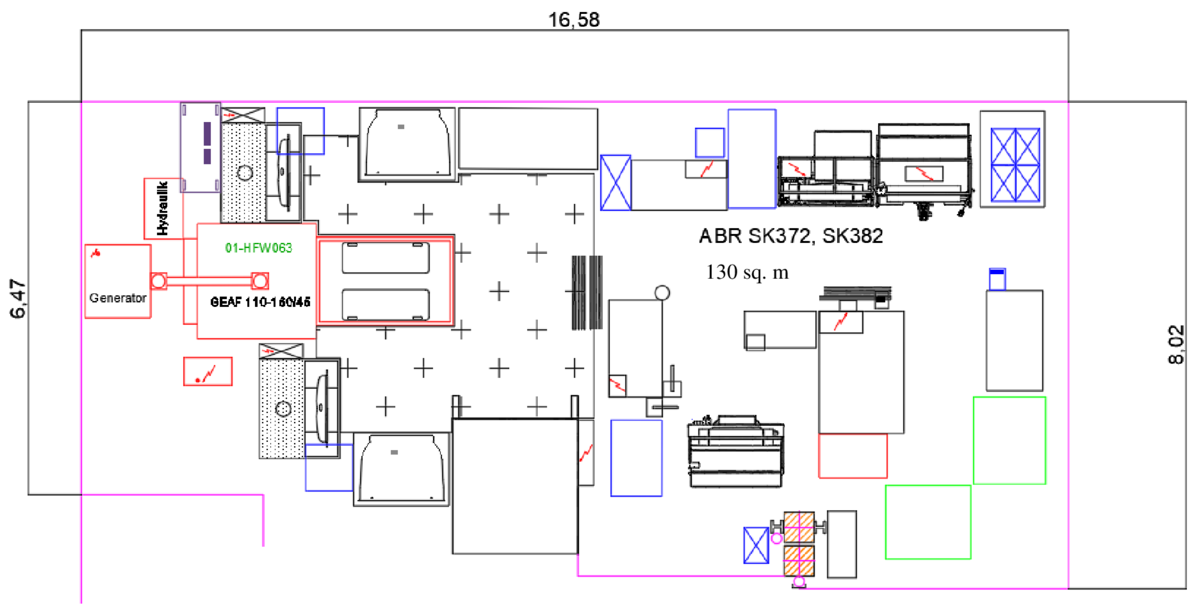


Figure 12: Swimlane diagram [own]

7.5 PRODUCTION LAYOUT

Production layout is the pictorial representation of the elements present in a real manufacturing cell. The clear idea of what is present in the cell and location of the elements should be precise and accurate. In order to make the production process a continuous one and an efficient one, the arrangement of machines and other equipment in a production cell is very much important. This is where the need for the production layout comes in, to visualize, analyze the real production environment and make the changes by rearranging the positions of elements within the planned space without disturbing the real production floor. Many suggestions for the layouts can be proposed and the optimal one is selected and reflect it to the real production space.

The production layout has included the following elements such as production area and dimension, process numberings, machines with boundaries, machine names, machine terminology, inventory space, operator positions, distance between work areas, equipment position and space. The production space of GEAF II is 130 sq. m and the Schwalbach is 148 sq. m. For legend of machine numbers, refer Table 8. The below layouts are presented as they are placed in the major lay out.



All dimensions are in m

Figure 13: Layout SK382 [own]

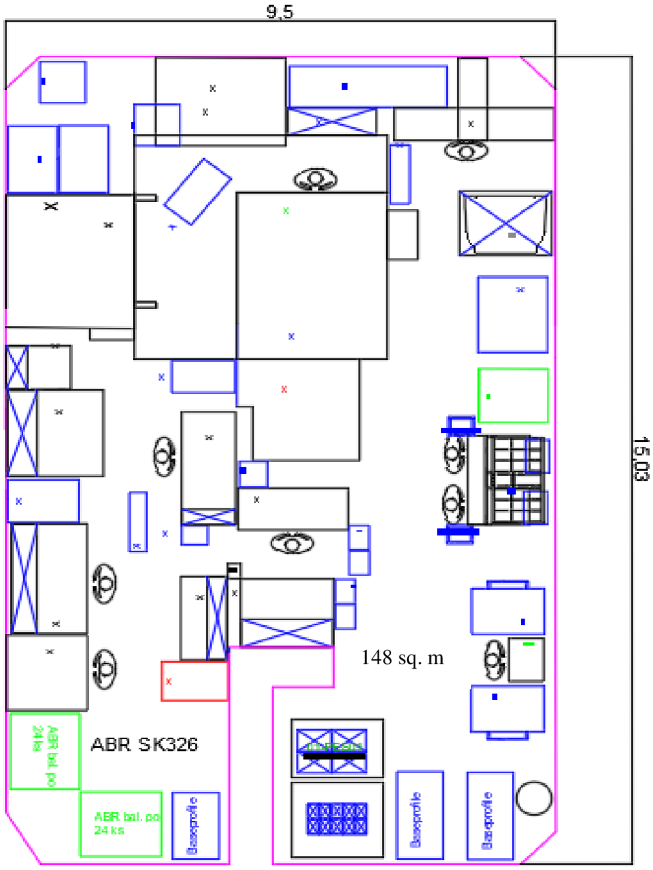


Figure 14: Layout SK326 [own]

7.6 PRODUCT TECHNOLOGY MATRIX

Product technology matrix shows the similarities in the production processes carried out for the products. From a technology matrix, the product families can be sorted out and it gives the interrelationships between the technological parameters. It can be used to plot the differences in the process carried out for the process which will be useful to make the respective changes on to the production cell for making more efficient use of the workspace.

From the technological matrix given below, we can infer the similar operations that are carried out and the operations that differ for each model is highlighted. So, when the two layouts are merged to form a single cell, these constrains must be considered and included in the layout accordingly. The Table 8 below shows the operations that are carried out for producing models SK 382 and SK 326.

Code	Product Technology matrix	Octavia SK 382	SK326 Karoq
1	Oven	x	x
2	HF-Welding	x	x
3	Crimping	x	no
4	Sand Cutting	x	x
5	Machine Pre-assembly	x	x
6	Tube Pre-assembly	x	x
7	Roll up	x	x
8	Spacer Wedge	x	x
9	Winding	x	no
10	Final Assembly	x	x
11	Endcap Pre-assembly	x	x
12	Design Check	x	no
13	Final Check	x	x
14	Roll welding	no	x
15	Hook assembly	no	x

Table 8: Product Technology Matrix [own]

7.6.1 EXTRA WORKING OPERATIONS

To setup a universal production cell that can produce the two products, the cell must be constructed with machines with similar and dissimilar processes. So, production capacity point of view it is suitable to add up the machines of Schwalbach line which operates 1 shift in a day with the GEAF II which operates 2 shifts in a day, to utilize the new universal U-shaped cell for 3 shifts per day. From the technological matrix, the processes such as roll welding and the hook assembly are the extra working operations in Karaq.

7.7 MANUFACTURING CELL ANALYSIS

In our case, for the production line named GEAF II that produces luggage covers of model SK382 operates for 2 shifts as 7.5 hours for each shift. For the third shift the machine is left idle due to customer demand constrains. On the other hand, in Schwalbach production cell, it operates only 1 shift with less than 5 hours of operation. Since both lines produce luggage covers of different models on each, it has many similar operations and the lines can be combined for obtaining a 3-shift operation.

The graph below shows the working per day where the x-axis denotes the months and the y-axis denotes the hours of working. The month of August has low utilization due to less customer demand. From the Figure 15, we can infer that the machines are run for only 2 shift operation and they are idle for one whole shift which must be eliminated.

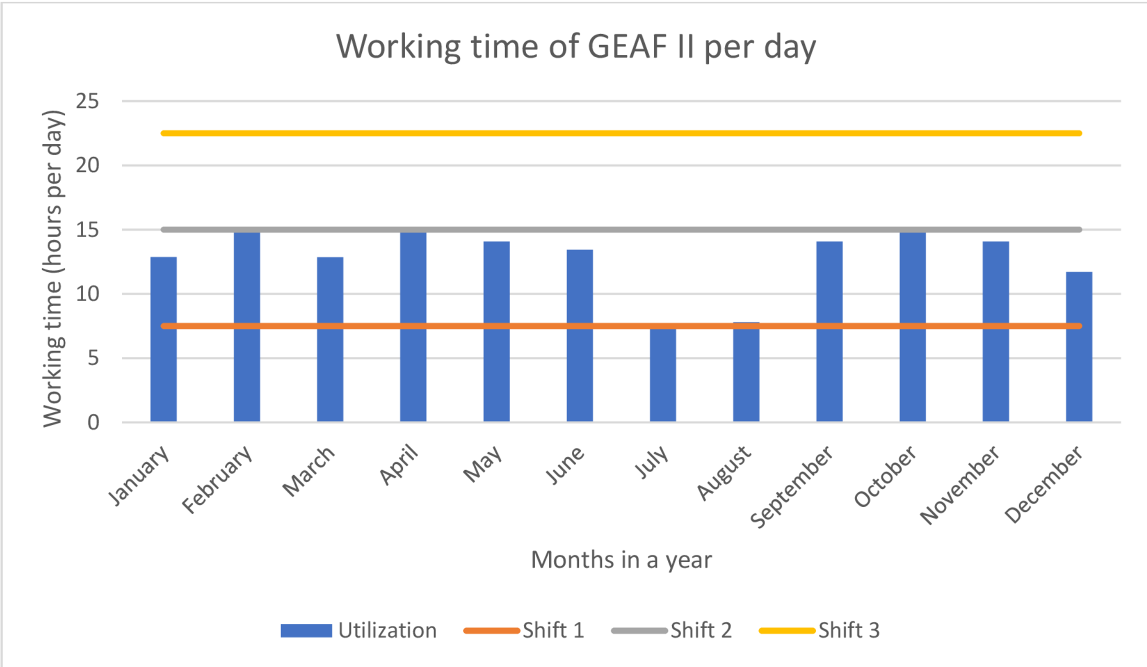


Figure 15: Working time of GEAF II [own]

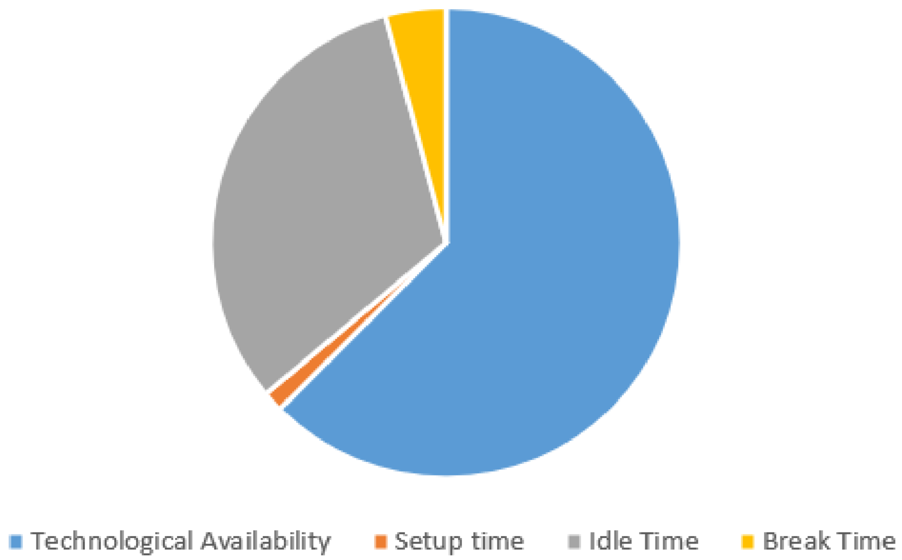


Figure 16: Time periods of GEAF II [own]

The above pie chart shows the technological availability, the setup time and the non-value-added times. The idle time give in the pie chart refers to the idling of machines for a whole shift without any production. From the Figure 15, we can conclude that the ideal time of the cell is higher and can be decreased to increase the efficiency.

The below Figure 17, shows the working time of Schwalbach cell, where it operates less than 5 hours a day. The idle time of this cell is very much higher and occupies a high production space. So, the possible way to reduce this waste and produce the required amount of customer demand is to eliminate this cell by combining its operations.

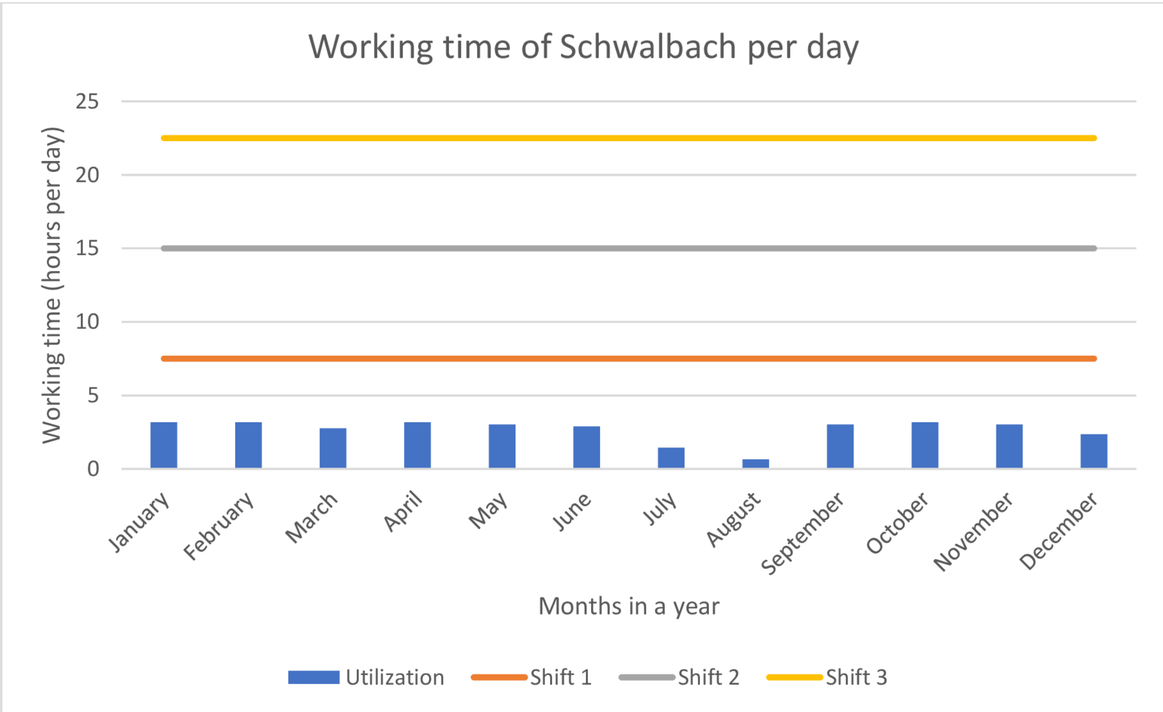


Figure 17: Working time of Schwalbach [own]

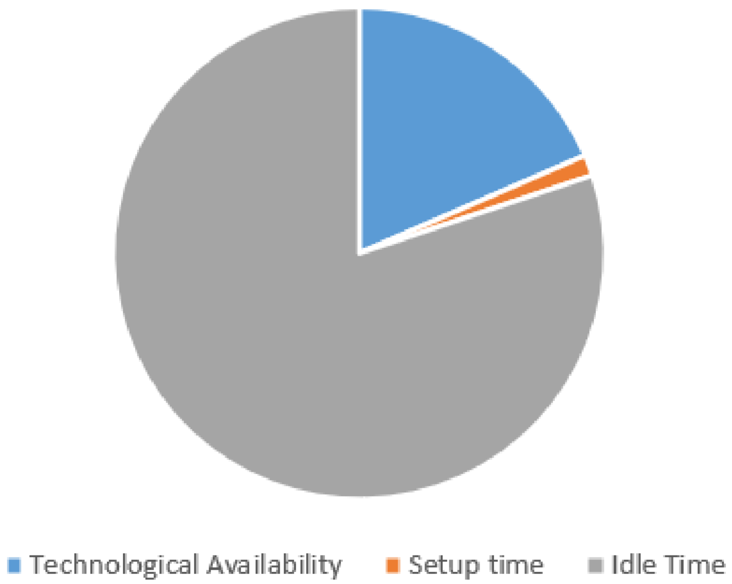


Figure 18: Time period of Schwalbach [own]

The idle time that is represented in Figure 18 above is the time where the machine is not used for any production activity. From the aboove pie chart it is clear to say that the machines are utilized at very low rate per day and the with considering the yearly customer demand, it is not profitable to increase the machine utilization rate, instead the methods to merge it with other line will be a optimal process.

8.DESIGN OF MANUFACTURING CELL

On considering the analyzed data above, new suggestions of the cell are proposed from which the best one is selected using multi-criteria evaluation.

8.1 WORKSHOP PHASE

Workshop is the space where the actual manufacturing processes are carried out in an orderly manner according to the standard operating procedures. When designing a new layout, the total takt time and the bottleneck process which is considered as the problematic step in a process plays a vital role. The takt time for GEAF II is 1.5 minutes and for the Schwalbach is 1.59 minutes. The bottleneck of the process is the HF welding process, where the process time is higher and so it affects the takt time. Since, the standard production process and the process times are same as before, the takt time will not change. So, we are going to suggest new U-shaped cells and make sure that the process is continuous, decide where it can be put on the general layout and calculate its advantages and the return of investments.

In the two work cells, the number of working persons is 10 people in each cell. The breakdown of number of working persons in each phase of production are as follows, 2 people in HF Welding, 2 people in cutting, 6 persons in assembly section. As the Schwalbach runs only one shift for less than 5 hours in a day, the ideal time of workers and machines is high and the cost to company also increases as the salary to be given for the workers. In compliance to reduce these unsustainable activities in a production floor, the cell Schwalbach can be merged with the GEAF II, as suggested with the above data analysis.

The cell Schwalbach can be merged in such a way with GEAF II as finding out the odd steps that are carried out, as suggested in the analysis. And then the machines that process the odd steps can be fit to the appropriate positions, so that the first two shifts of production in GEAF II is not affected. The position and the way of process flow in GEAF II to be changed, so that it is continuous and better than the previous state of formation. Therefore, the formation of a universal cell should be able to produce both the models such as SK382, SK326.

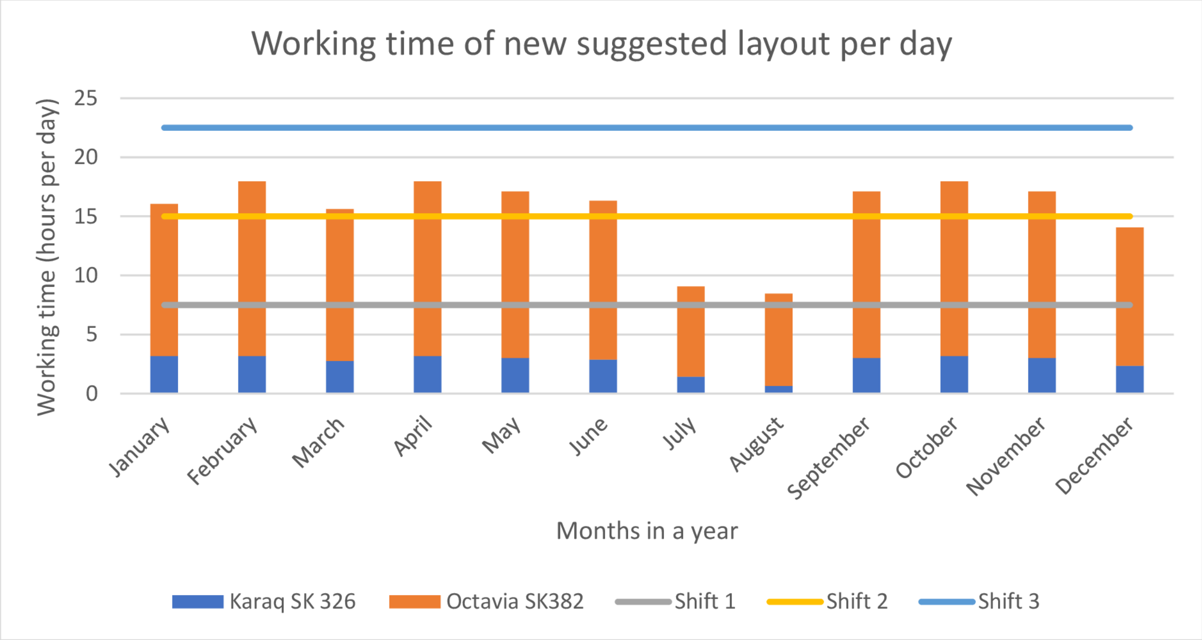


Figure 19: Expected Working time of suggested cell[own]

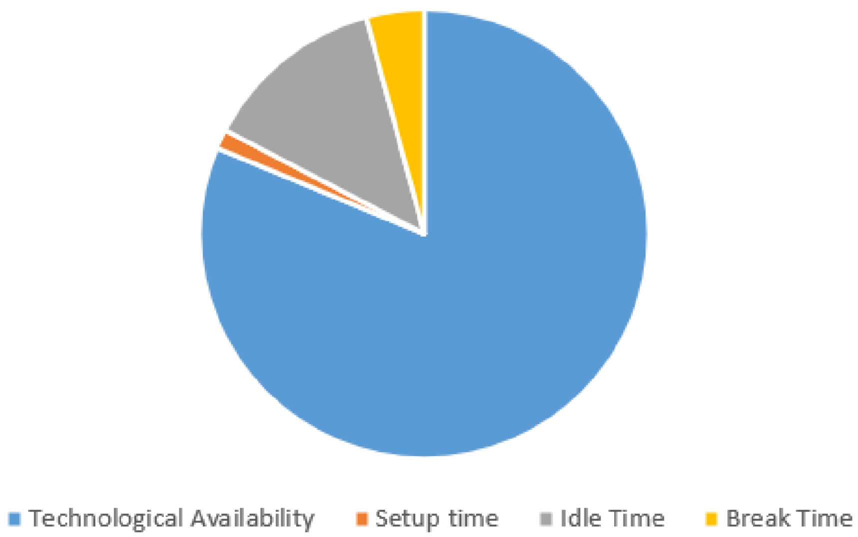


Figure 20: Time period of future suggestion cell [own]

The Figure 19 and Figure 20 shows the expected working time of the future layout suggestions and the time period per day.

As on the data analysis that was caried above and from, we can infer that,

- From the capacity point of view, it is possible to build up the lines together and make it as a universal line for the products SK326 and SK382.
- The technology matrix also depicts that the lines can be build up together on the technological point of view but with a limitation of hoisting crane for the SMED where the production method changes.
- The standard production processes would be the same with no changes and so the standard times will also be the same.

For the new suggestion of layout, the following are the requested values and the forecasted benefits,

Benefits	Current state	Requested state
Production space	278 sq. m	130 sq. m
Efficiency	1 shift idle in GEAF II 2 shifts idle in Schwalbach	No idling- 3 shift model
Savings on machines	No savings	Extra machines can be eliminated and the machine cost is saved

Table 9: Requested Benefits [own]

8.2 VALUE STREAM MAPPING

The cycle time (C/T), the change over time (C/O) and the waiting time are from the data obtained from the company. The value stream mapping is represented for the main edge processes such as HF welding, cutting and assembly that are carried out.

PLT for SK 382 = 22 + 3.37 + 6

PLT for SK 382 = 31.37

VA index for SK 382 = 3.37/31.37

VA index for SK 382 = 0.1074

The below figure shows the value stream mapping for the product SK382. The time prescribed are in minutes. The data is collected from the real system is reflected in the pictorial view and the calculation of the VA index is made according to the formula that are suggested. The dashed lines on the timeline of process denotes the changeover that occurs in the process phase.

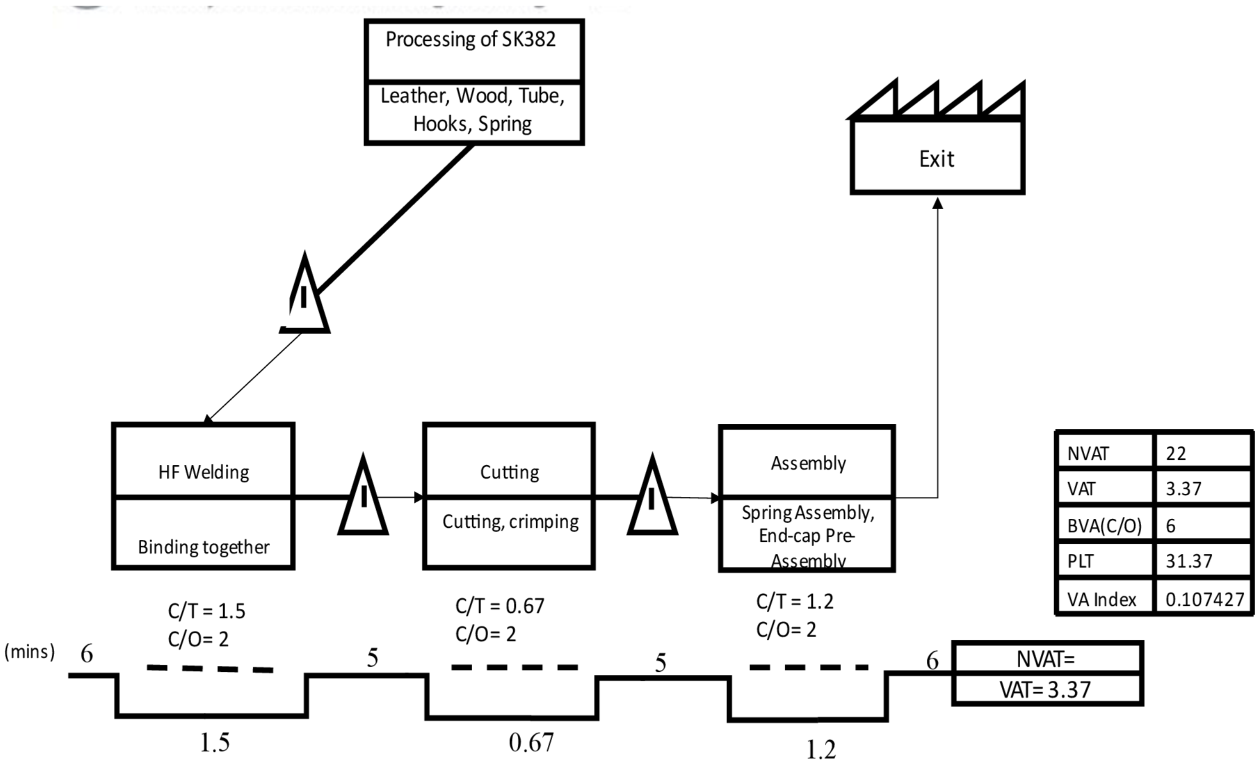


Figure 21: VSM for GEAF II [own]

The work in process is 5 products for each work station. Usually, the VA index value ranges around 0.004, but here the value is around 0.1074 which is slightly a higher value as the Production Lead Time value is comparatively less as it calculated for the three main processes.

The below picture shows the value stream mapping of the product SK326 in the Schwalbach cell. Since it operates only 1 shift with less than 5 hours, the change over time is null and the dashed lines are not drawn.

PLT for SK 326 = 22 + 3.79 + 0

PLT for SK 326 = 25.79

VA index for SK 326 = 3.79/25.79

VA index for SK 326 = 0.1469

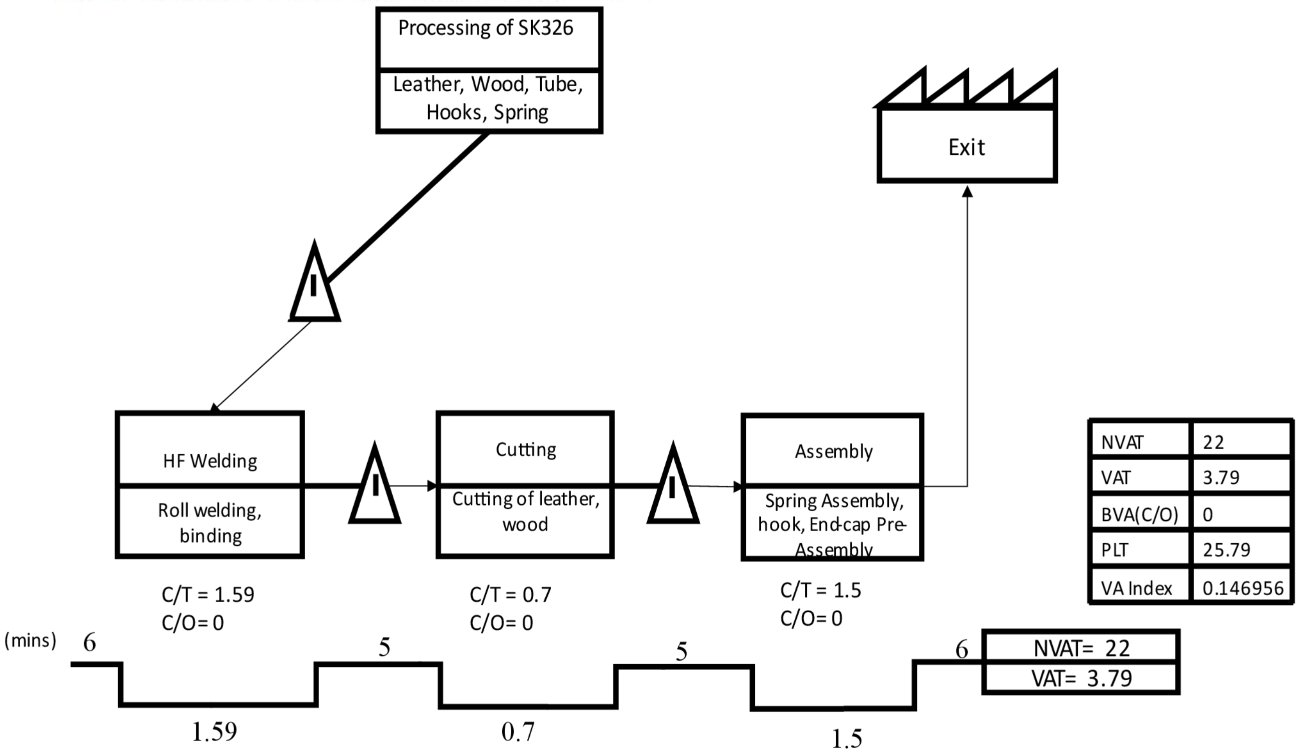


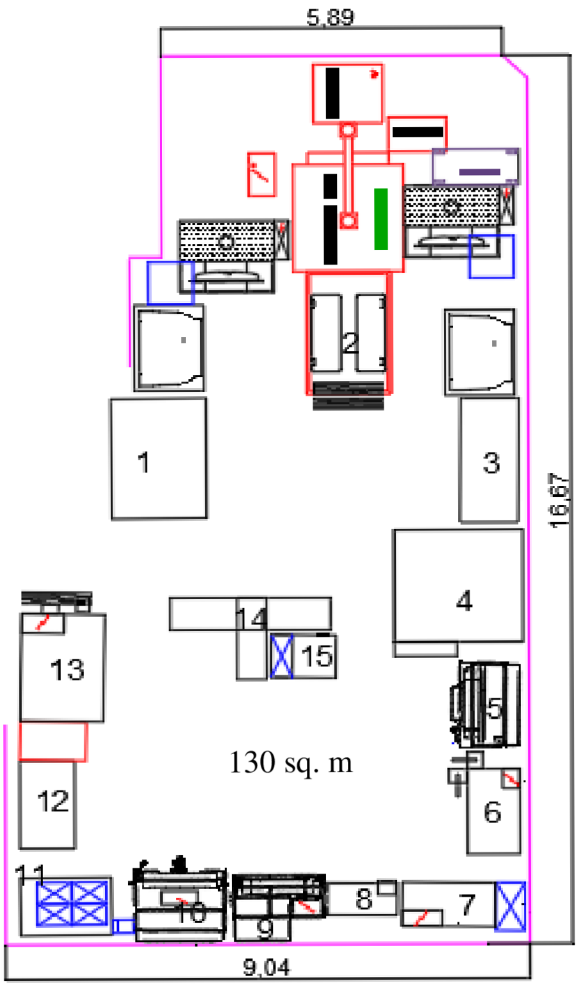
Figure 22: VSM for Schwalbach [own]

The work in process is 5 products on each work station. The value-added time is comparatively higher than that of the GEAF II.

The general range of VA index is 0.004, but here it is comparatively higher with value of 0.1469 as the there is no Change Over time and so the total Production Lead Time value got decreased.

8.3 SUGGESTION 1

The Figure 23 shows the shows the U- shaped cell suggestion. In this layout the similar operating machines for the products are clubbed and made as a universal line. The machines roll welding and hook assembly are kept separately in the appropriate positions of the cell, since it is used only for the third shift of production in a day. The distance between each work station is 3 feet distance.



1. Oven
2. HF-Welding
3. Crimping
4. Sand Cutting
5. Machine Pre-assembly
6. Tube Pre-assembly
7. Roll up table
8. Spacer wedge
9. Winding
10. Final assembly
11. Endcap Pre-assembly
12. Design check
13. Final check
14. Roll welding
15. Hook assembly

All dimensions are in m

Figure 23: Cell Suggestion 1 [own]

Spaghetti diagram

The spaghetti diagram Figure 24 indicates the flow of products from one stage to the other. The arrows indicate the flow of the model SK382, and the flow of the model SK326.

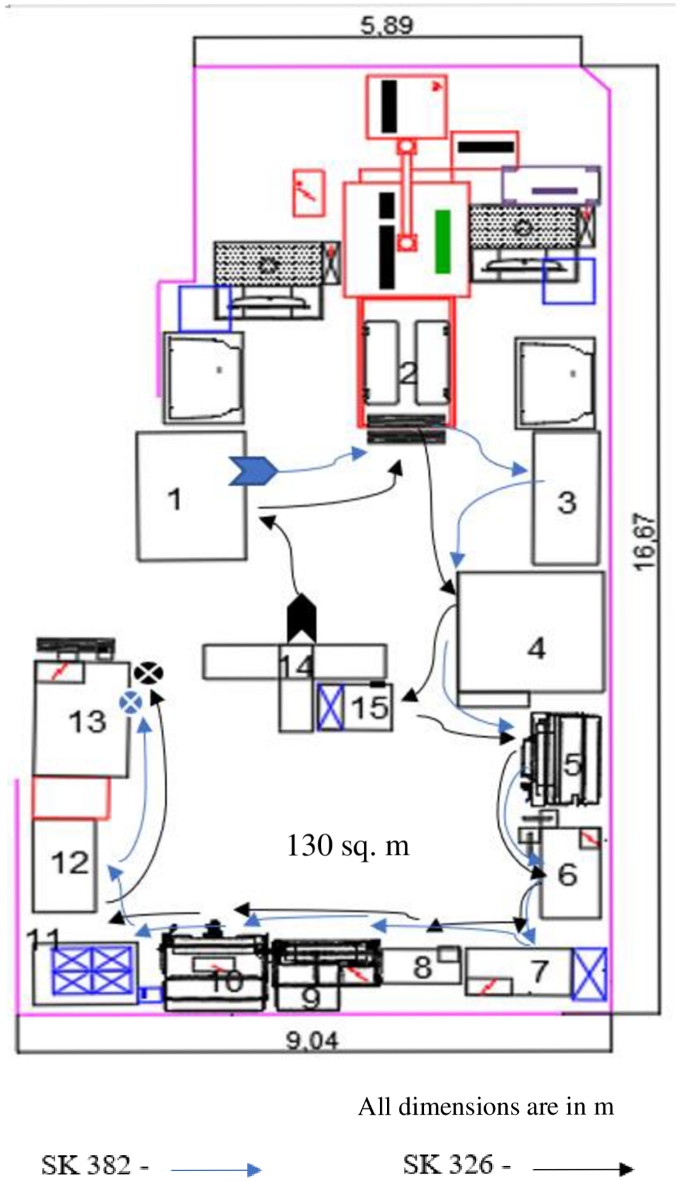


Figure 24: Spaghetti diagram of suggested cell 1 [own]

Advantages

- Production area is saved by eliminating one cell.
- Process flow is continuous.
- Process flow is one directional for SK382.
- Unnecessary movements are reduced comparatively.
- Working operators can be reduced.

Disadvantages

- Flow is discontinuous and in opposite direction for model SK326.
- The layout is vertical and so it only can be built in the area of original Karaq layout of the major layout.

8.4 SUGGESTION 2

The layout suggestion 2 is much like that of the suggestion 1 and the main difference is that it is designed to exactly fit in the original space of the pre-existing Octavia layout (GEAF II) and so the implementation of the new layout becomes easier. For this purpose, the workstation 5 has been placed separately and the workstations are placed accordingly.

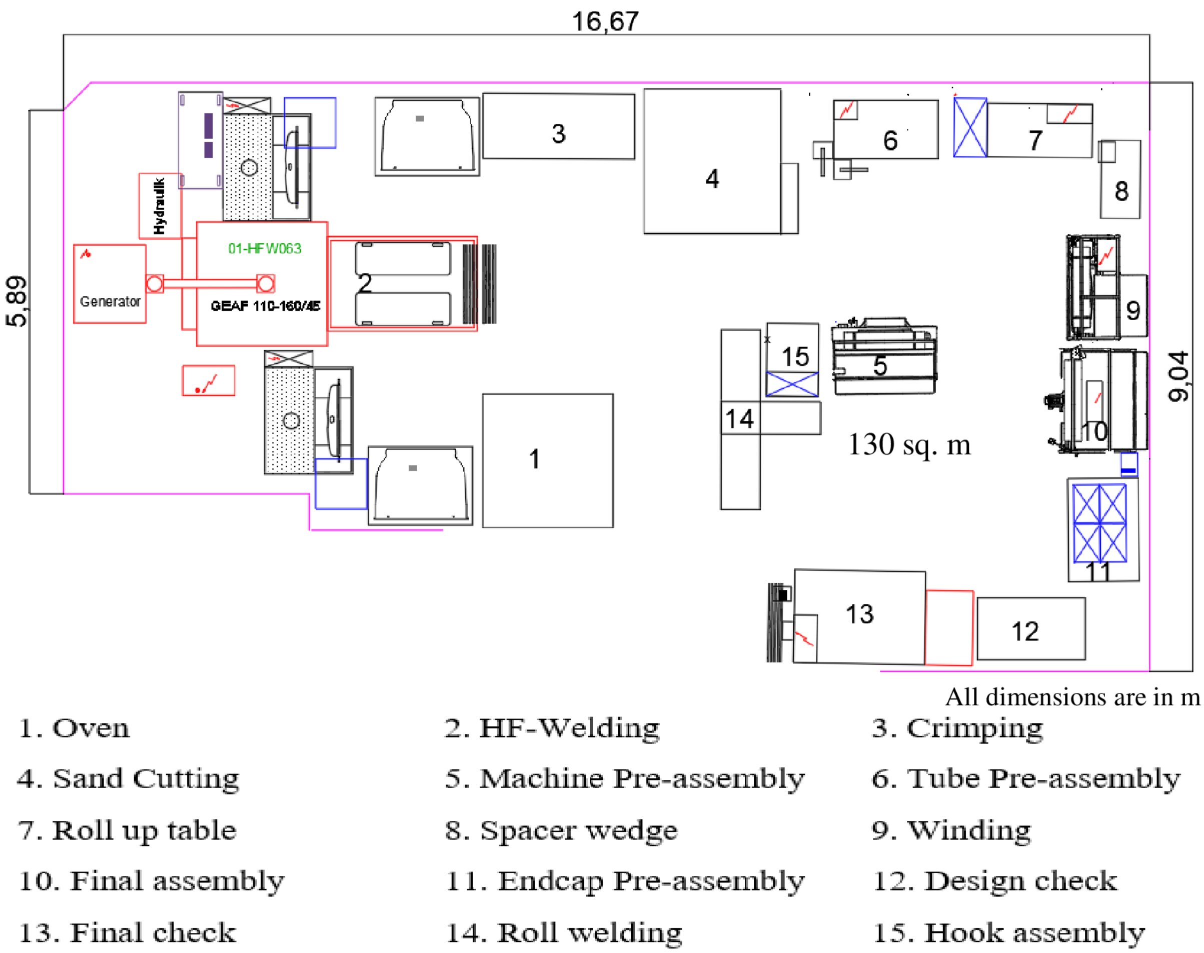


Figure 25: Cell Suggestion 2 [own]

Spaghetti diagram

The below Figure 26 shows the spaghetti of suggested cell 2, where the process for SK382 starts at oven machine (1) and the process for SK362 starts at the roll welding machine (14).

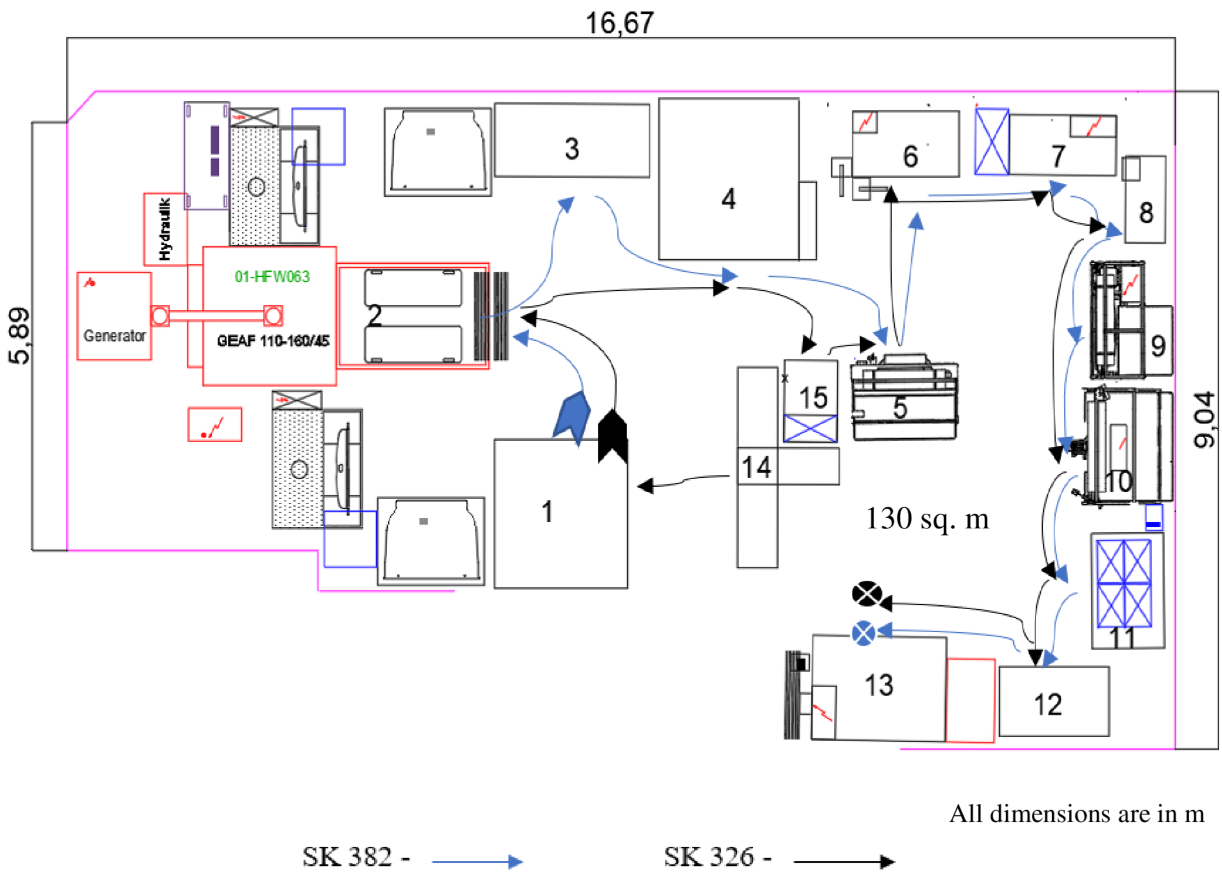


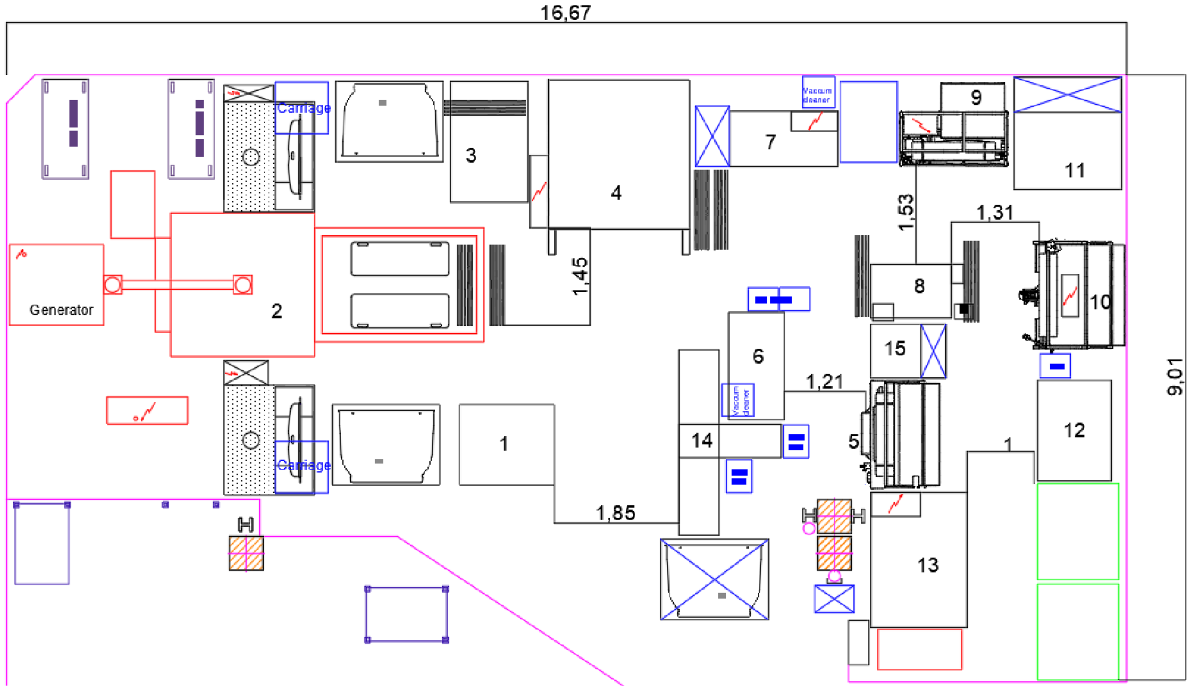
Figure 26: Spaghetti diagram for suggested cell 2 [own]

Advantages

- This layout has all most same merits as the previous one with an improvement as process flow is one directional for both the models.
- Also, it is placed on horizontal position with minor changes so that it can be built on the Octavia line which has same basic dimensions on the major layout. By this way the layout can be built up and fit easy and hazzle free on a pre-existing area.

8.5 SUGGESTION 3

The cell suggestion 3 given is a conventional type of cell rather than a U-shaped production line. this kind of cell is suggested in order to compare the work flow, motion of workers and other principles of production flow within a cell. Unlike the previously suggested cells this does not place the odd operations that run only for the third shift separately, but placed alongside of the day shift machines.



All dimensions are in m

1. Oven	2. HF-Welding	3. Crimping
4. Sand Cutting	5. Machine Pre-assembly	6. Tube Pre-assembly
7. Roll up table	8. Spacer wedge	9. Winding
10. Final assembly	11. Endcap Pre-assembly	12. Design check
13. Final check	14. Roll welding	15. Hook assembly

Figure 27: Cell suggestion 3 [own]

Process flow diagram

The below Figure 28 shows the spaghetti diagram of the suggestion 3. Since the machines are placed alongside each other the flow of direction of the process for both the products have been marked in the figure. The name of the machines was removed in all the layouts including the suggested ones, due to the security and privacy constrains of the company as directed.

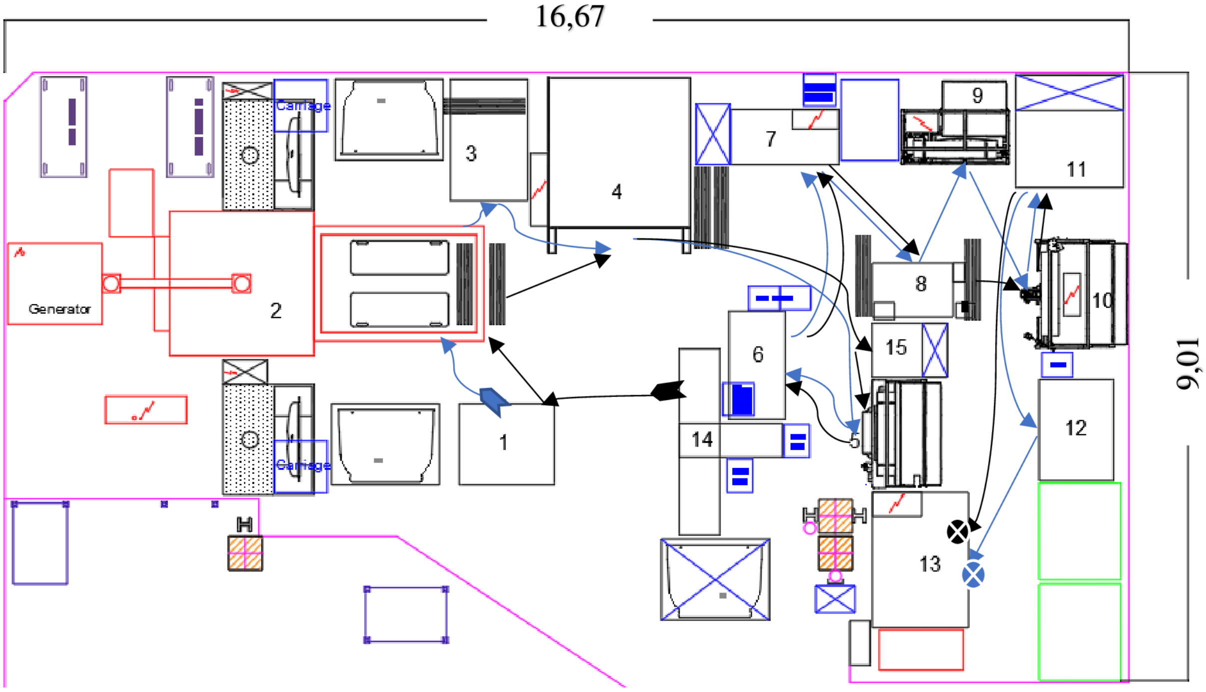


Figure 28: Process flow diagram of suggested cell 3 [own]

8.6 MULTI CRITERIA ANALYSIS

This is a vital step in choosing the layout from the suggested ones. It is important to analyze the pros and cons of each layout individually and select the best one by the specified criteria or the performance indicators.

Criteria	Suggestion 1	Suggestion 2	Suggestion 3	Units to measure
Production space	130	130	150	Sq. m
Movement of person	SK 382- 42 SK 326- 45	SK 382- 42 SK 326- 45	SK 382- 45 SK 326- 51	Total number of steps
Intersections	0	0	2	Number of intersections
Process distance	SK 382- 23.4 SK 326- 24.5	SK 382- 22.7 SK 326- 24.3	SK 382- 23.5 SK 326- 24.3	Meters

Table 10: Criteria measurements [own]

The above Table 10 shows the criteria which are measured for forming the evaluation matrix and chose the best variant among the suggested. The values of the criteria are measured so that the satisfying scores for the given weightage can be given.

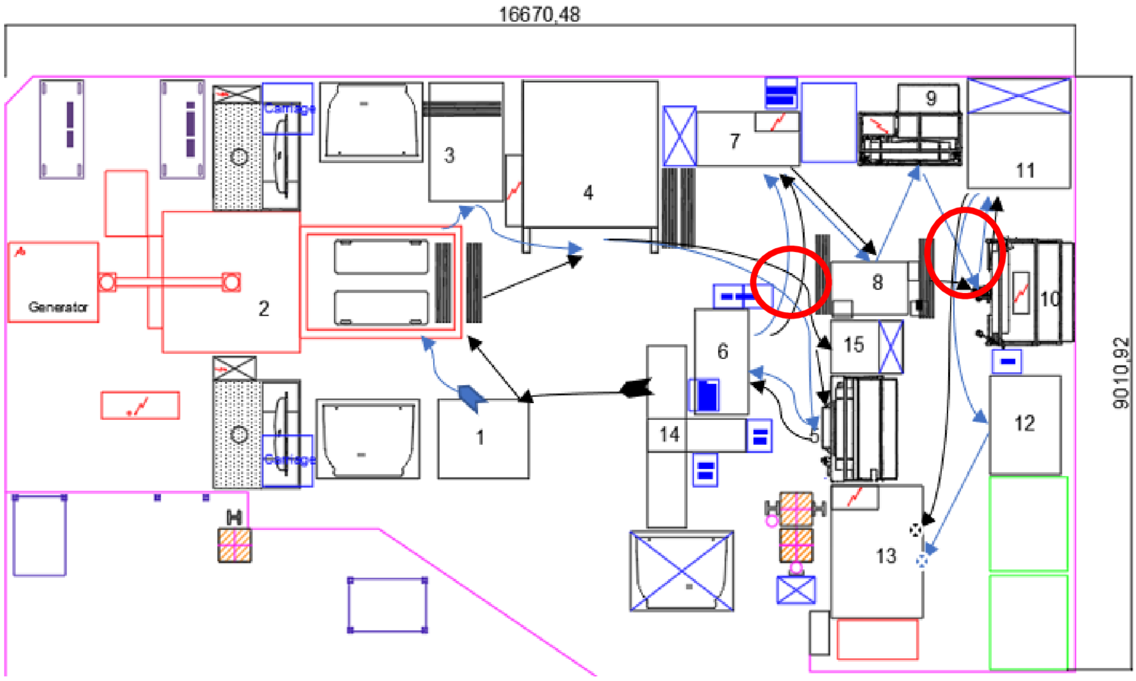


Figure 29: Intersections [own]

The below Table 11 shows the weightage- decision matrix that is formed using the criteria, weightage, and the suggested options. The weightage is set with values ranging from 1 to 5 (least important to most important). It is set by me according to the main objectives of this project which is given by the company that are to be attained.

Criteria	Weightage
Production space	5
Movement of person	4
Flow	5
Process distance	4

Table 11: Weightage decision matrix [own]

After forming the weightage decision matrix, the evaluation matrix is formed with the same scale of values ranging from 1 (least satisfying- very poor) to 5 (most satisfying – very good) for satisfying the given criteria.

Criteria	Suggestion 1	Suggestion 2	Suggestion 3
Production space	5	5	4
Movement of person	5	5	4
Flow	5	5	3
Process distance	4	5	4

Table 12: Evaluation matrix [own]

Then the weightage values are multiplied with the evaluation values to help us choose the best solution among the given variants. By, the weighted scoring method, the best solution is obtained. The below Table 13 gives the overall scores which is used to find out the best solution.

Criteria	Suggestion 1	Suggestion 2	Suggestion 3
Production space	25	25	20
Movement of person	20	20	16
Flow	25	25	15
Process distance	16	20	16
Sum	86	90	67

Table 13: Overall scores [own]

The layout 2 has scored the highest value among 3 suggested variants. We can infer that the suggested layout 2 meets the desired important criteria than the other suggested layouts and scored highest score among the variants. So, the layout 2 is selected as the most optimal choice from the given cell variants.

9. SIMULATION

In simulation, the futuristic suggested model is visually represented and verified using the capacity equations and Lanner Witness 14 simulation software. The machine utilization rates are calculated to ensure that the universal layout is possible in terms of capacity.

9.1 YAMAZUMI METHOD

This method is used to find the bottlenecks in a process remove this by line balancing and analyze the steps in the process where the cycle time taken is higher than the actual tack time.

$$\text{Takt time (TT)} = \frac{Net\ available\ working\ time\ per\ day}{Total\ daily\ customer\ request} \quad (3)$$

In our case, as the universal cell is formed the total available time per day will be 1170 minutes since the model SK382 will be run for 2 shifts for 7.5 hours each and SK326 will be run for the remaining 1 shift for 4.5 hours. The yearly demand for SK 328 is 142880 and for SK326 is 19635. The number of working days per year is 252. So, the daily combined demand of models will be 655.

$$\text{Takt time (TT)} = \frac{1170}{655} = 1.786$$

The Target Cycle Time (TCT) gives the time at which the processing of the product will be completed.

$$\text{Target Cycle Time (TCT)} = \frac{Net\ available\ working\ time\ per\ day}{Production\ capacity\ of\ line\ per\ day} \quad (4)$$

$$= \frac{1170}{164990/252} = 1.786*0.9895$$

$$\text{TCT} = 1.767$$

The number 0.9895 is the coefficient of lower limit for the annual production line capacity which is about 98.95%.

The below Figure 30 and Figure 31 shows the Yamazumi board where it consists of column bars of each process with their value-added time or the processing time and the necessary time to carry on the production operation (setup time). From the graph no process stations exceed its Target Cycle Time (TCT). So, we can conclude that there are no bottlenecks in the process.

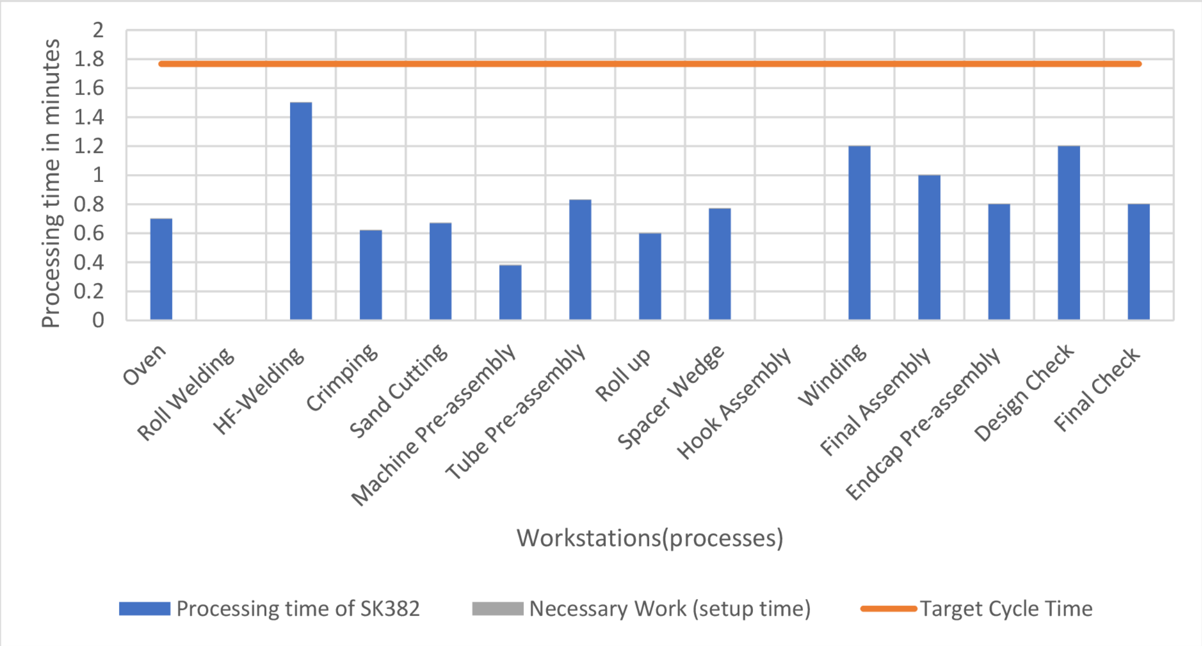


Figure 30: Yamazumi board for SK382 [own]

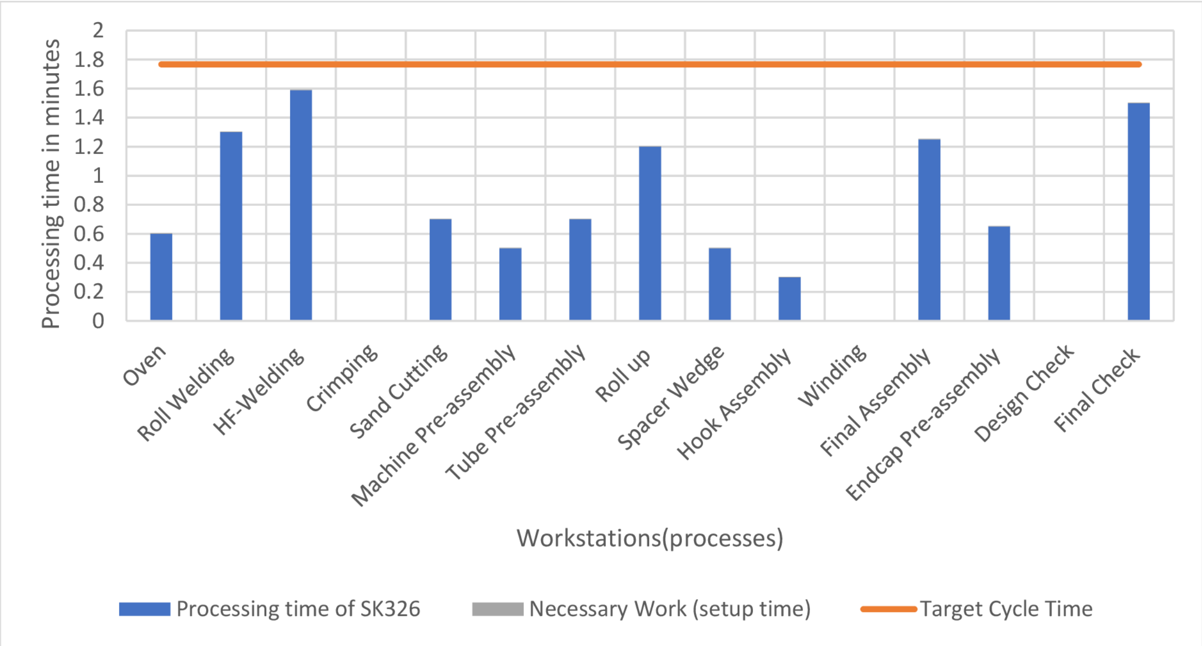


Figure 31: Yamazumi board for SK326 [own]

9.2 ECONOMIC MODEL – CAPACITY EQUATIONS

The economic model is the capacity equation calculations from which the utilization rates are calculated. In our economic model the products SK382, SK326 must be produced, which has its own technological processes.

Model	Demand/year	Number of shifts per day	Technological availability	Manufacturing Batch size	Transfer Batch size
SK 382	142,800	2	7.5 hours per shift	284/ shift	1(single piece flow)
SK 326	19,635	1	4.5 hours	78/shift	1(single piece flow)

Table 14: Economic model specifications [own]

- At first, the processing time (T_{ac}) and setup time (T_{bc}) for each process of the models are given accordingly. The $T_{ac}$and T_{bc} are specified as null for the processes where it does not involve in the production of that model.
- The duration of production for the batch is calculated using the formula given below,

$$\text{Duration of Batch} = (T_{ac} * \text{ Manufacturing Batch size}) + T_{bc} \quad (5)$$

- The number of batches is specified as 2 for the model SK 382 and 1 for SK 326 as the number of shifts operated to produce the models are 2 shifts and 1 shift respectively.
- The number of working days is 5 days per week.
- Now we get the total number of batches produced by multiplying the number of working days and the number of batches as shown in Table 15.

	SK 382	SK 326
Number of batches	2	1
Number of working days per week	5	5
Total number of batches per week	10	10

Table 15: Calculation of batches [own]

- The technology demand gives the total time required to produce the manufacturing batches, which is calculated using the formula given below,

$$\text{Technology demand} = \text{Number of batches} * \text{Duration per batch} \quad (6)$$

- Time fund is the total available time for the production process. It is the product of time available per shift, number of shifts and the total working days.

	Available time fund per week (minutes)
Machines that operate to produce both models	5850
Machines that operate to produce only SK 382	4500
Machines that operate to produce only SK 326	1350

Table 16: Time fund available [own]

- The work utilization is obtained by the ratio of total working time of the machine and the total available time fund.
- The utilization values of the workstations that are calculated using the capacity equations are given in the Table 17 and the Figure 32 shows the graphical representation of the obtained utilization values.

	Theoretical no. of m/c	Real no. of m/c	Time fund (minutes)	Utilization	Machine Utilization
Oven	0.3850	1	5850	38.50%	38.50%
Roll Welding	0.3830	1	1350	38.30%	38.30%
HF-Welding	0.8393	1	5850	83.93%	83.93%
Crimping	0.3957	1	4500	39.57%	39.57%
Sand cutting	0.3771	1	5850	37.71%	37.71%
Machine Pre-assembly	0.2229	1	5850	22.29%	22.29%
Tube Pre-assembly	0.4547	1	5850	45.47%	45.47%
Roll up	0.3764	1	5850	37.64%	37.64%
Spacer wedge	0.3772	1	5850	37.72%	37.72%
Hook Assembly	0.0941	1	1350	9.41%	9.41%
Winding	0.3831	1	4500	38.31%	38.31%
Final Assembly	0.5722	1	5850	57.22%	57.22%
Endcap Pre-assembly	0.4368	1	5850	43.68%	43.68%
Design Check	0.4652	1	4500	46.52%	46.52%
Final Check	0.4935	1	5850	49.35%	49.35%

Table 17: Utilization values of machines [own]

INFERENCE FROM CAPACITY EQUATION

- Two products are manufactured in three shift operations.
- It is evident that the merging of two lines is possible from the capacity point of view with one machine for each process.

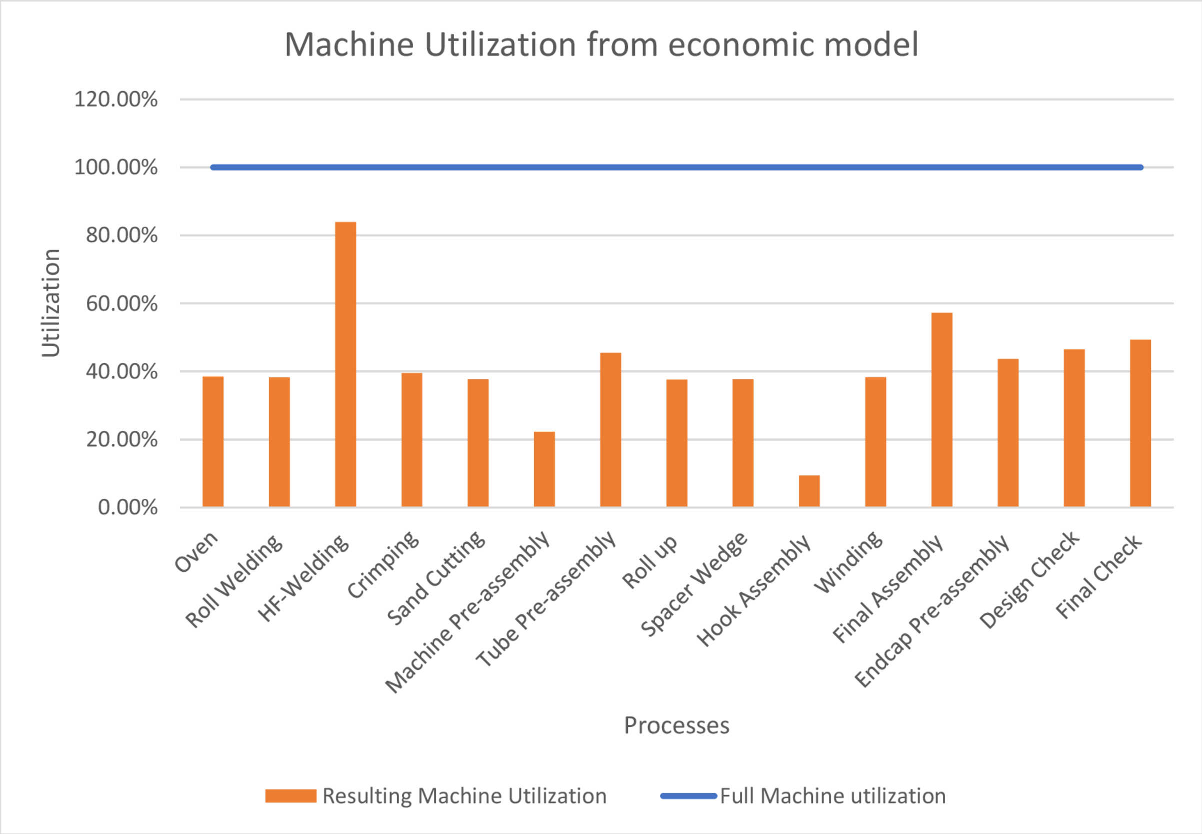


Figure 32: Machine utilization from economic model [own]

9.3 SIMULATION MODEL

The virtual visualization of the real time futuristic model of the merging of the two cells is done in the simulation process. The Lanner Witness 14 software has been used here in the simulation process.

- At first, the parts are placed to the simulation area from the “designer element” tab and defined by double clicking on them.
- The inter arrival time is set 2*60 which equals 120 minutes since the goods arrive every two hours for the production process. The lot size is the number of products that arrive every two hours for the production.

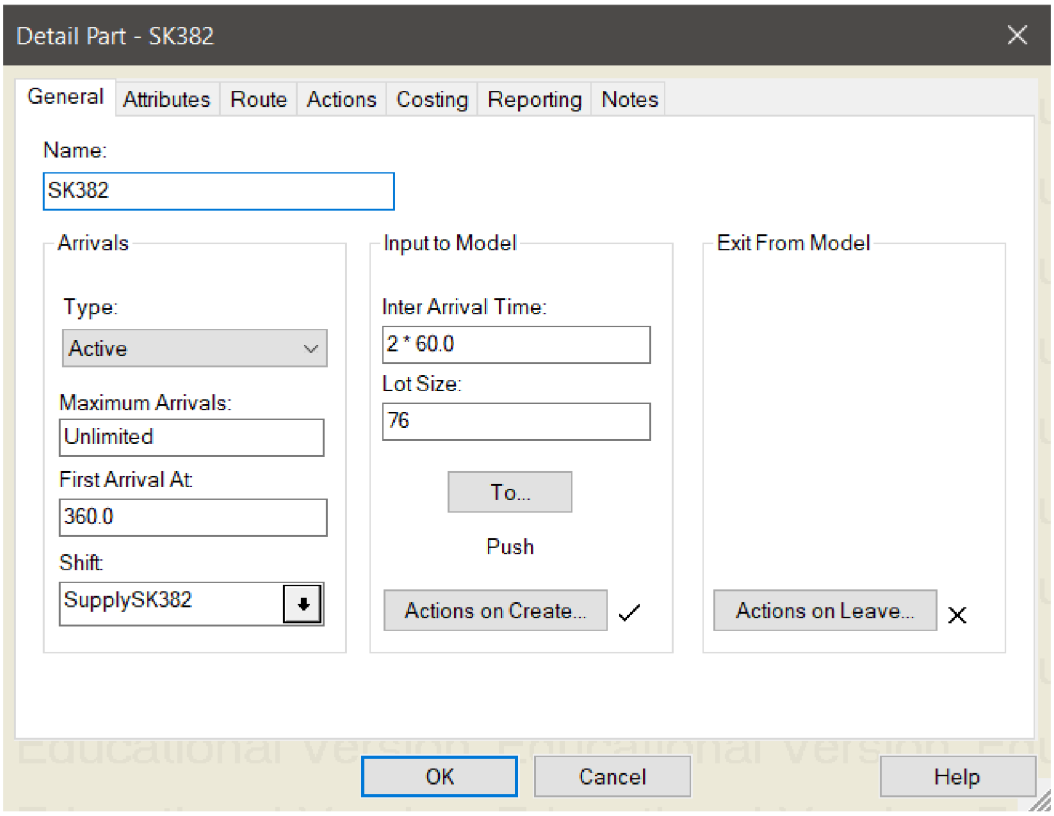


Figure 33: Part detail SK382 [own]

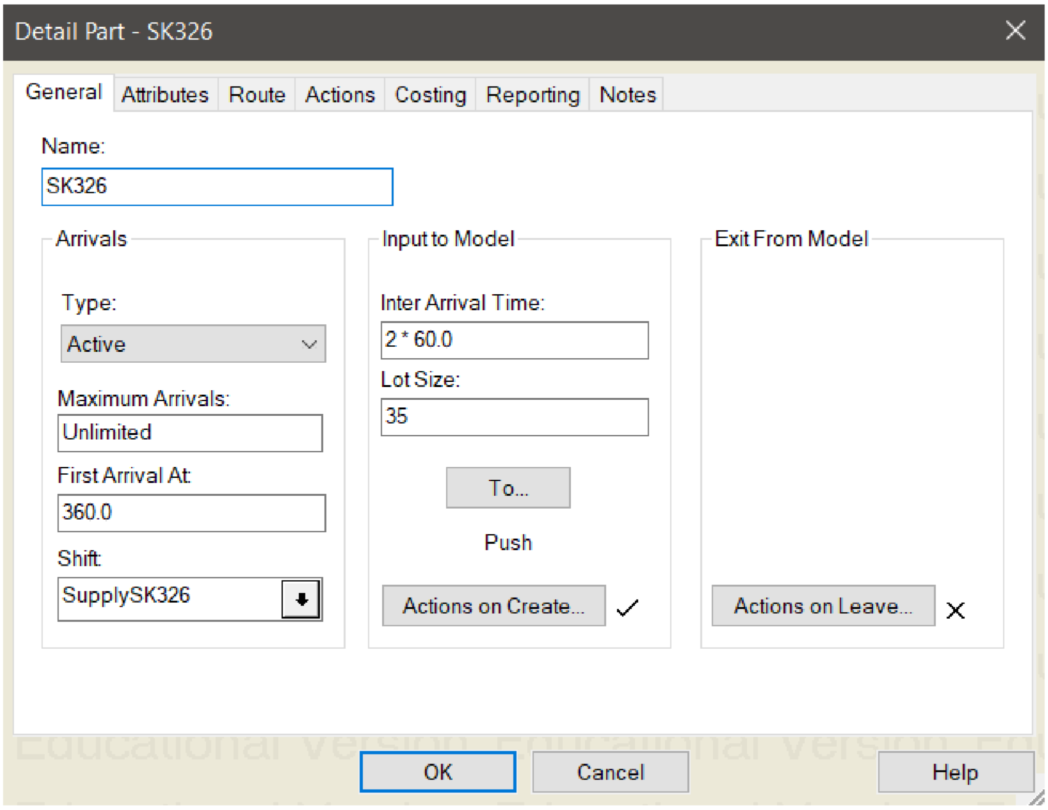


Figure 34: Part detail SK326 [own]

- Then the attributes for the processing time (T_{ac}) and the setup time (T_{bc}) are specified by placing it in the simulation area. Each machine has its own attributes for the processing time and the setup time.
- The values of the Tac and Tbc of each machine is specified on the "actions on create" in the machine detail window as given below in Figure 35,

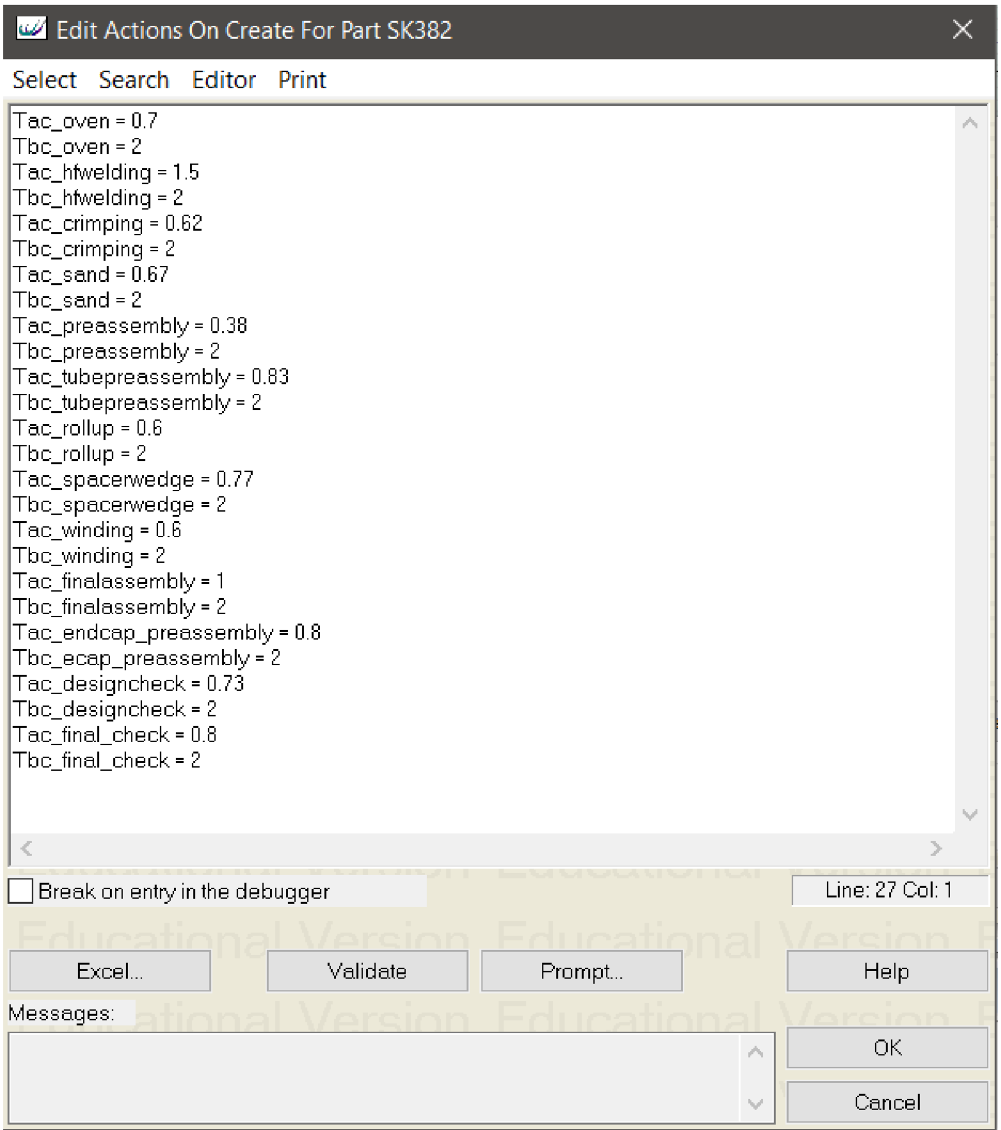


Figure 35: Actions on create [own]

- The machine detail is given by double clicking on the machine icon and the name of the machine can be changed accordingly. The type of machine is specified as "single" since it is a single piece flow process and so the transfer batch size is one.

- The cycle time is specified under the section "duration" where the value is defined before on the "actions on create" in part detailing. Each machine is specified with its pre-recorded processing time.

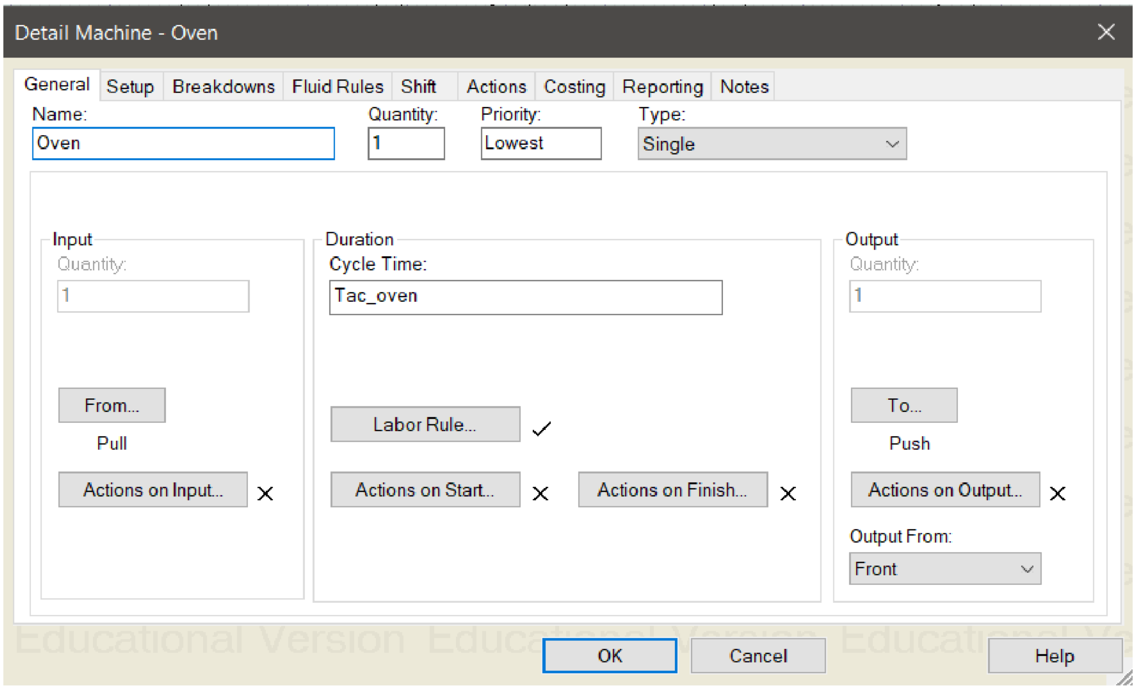


Figure 36: Machine detail [own]

- Then, the setup data for the machine is given with unique names for the setup description and the mode of setup is given as "part change" and the setup time is given according to the attribute name as specified before.

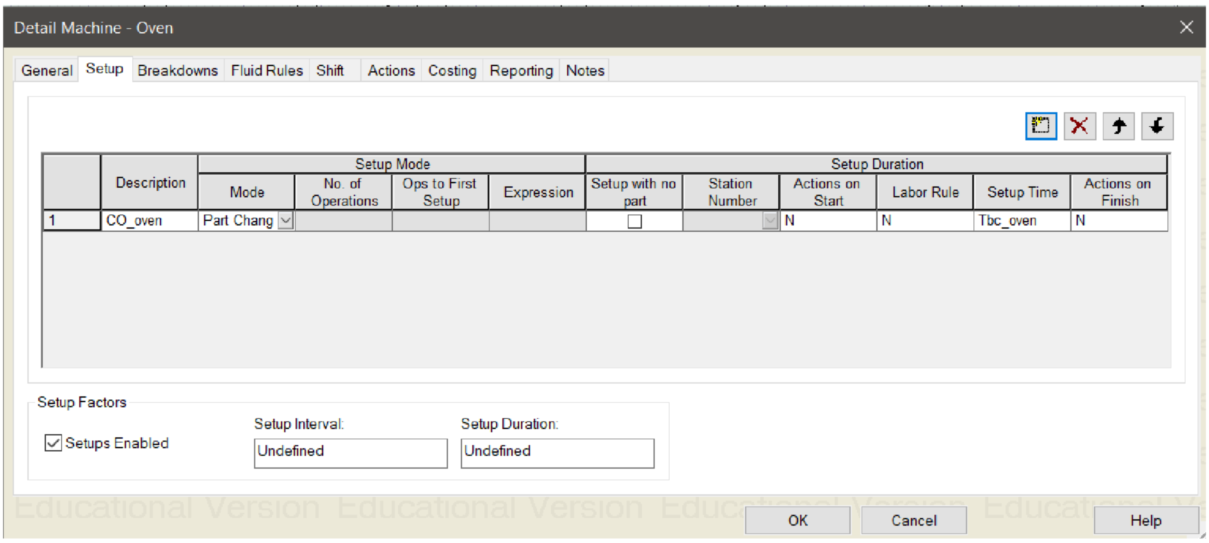


Figure 37: Setup detail [own]

- The simulation model for the future suggested layout is formed where the parts to produce the models SK382 and SK326 travels each stage of the machine accordingly in their pre-defined paths that are specified using the "push" and "pull" rule.

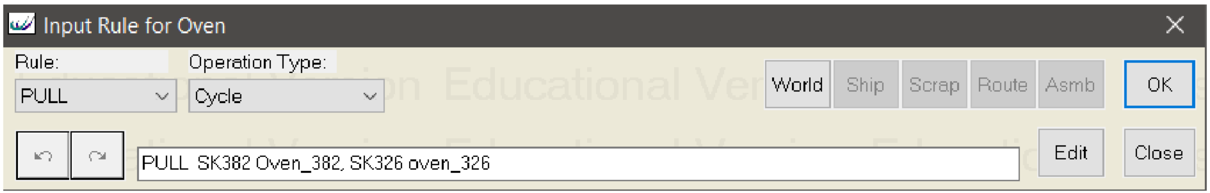


Figure 38: Pull rule [own]

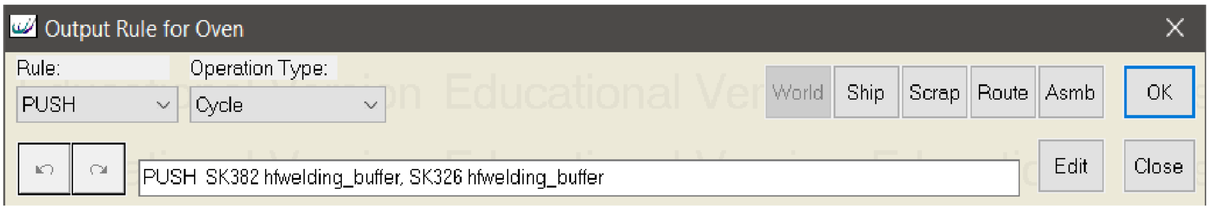


Figure 39: Push rule [own]

- The shifts are defined accordingly to the working time of the machines with the break times. Totally 3 kind of shift attributes are defined to assign the shifts to the machines for working.

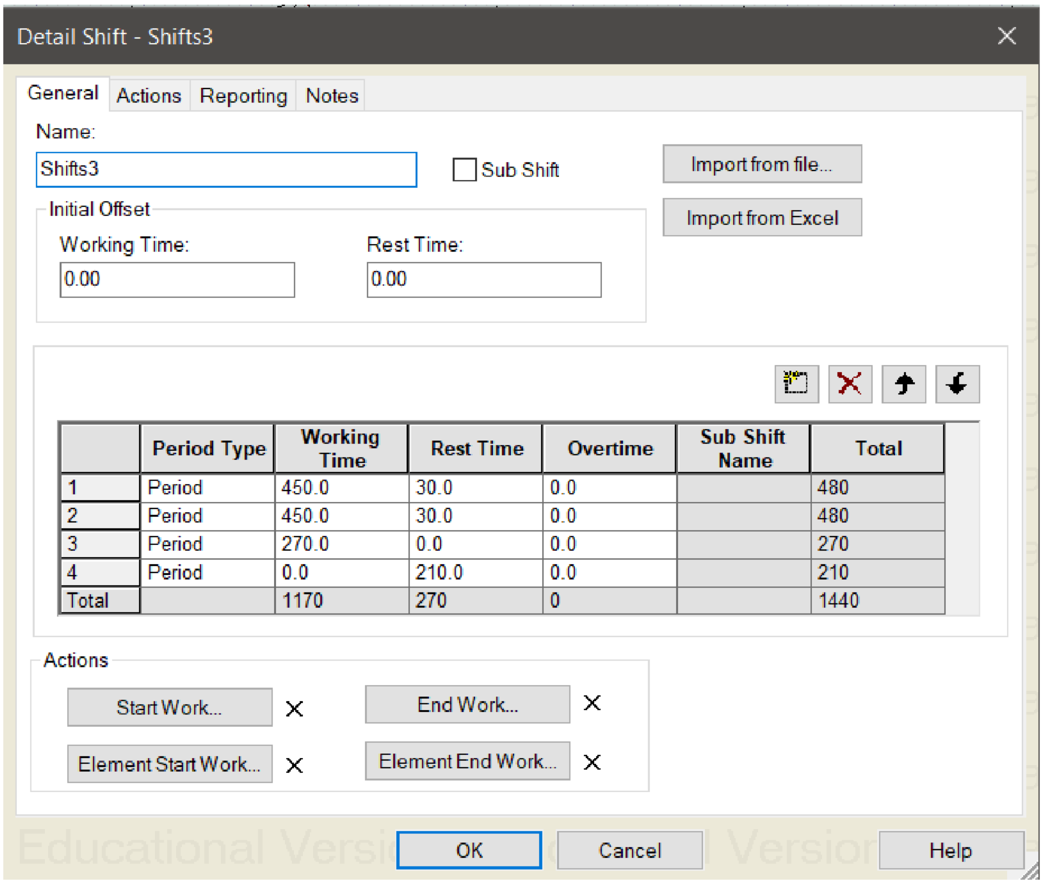


Figure 40: Shift detail [own]

- The defined shift elements are then assigned to the machines under the "shift" tab on the machine detail window.

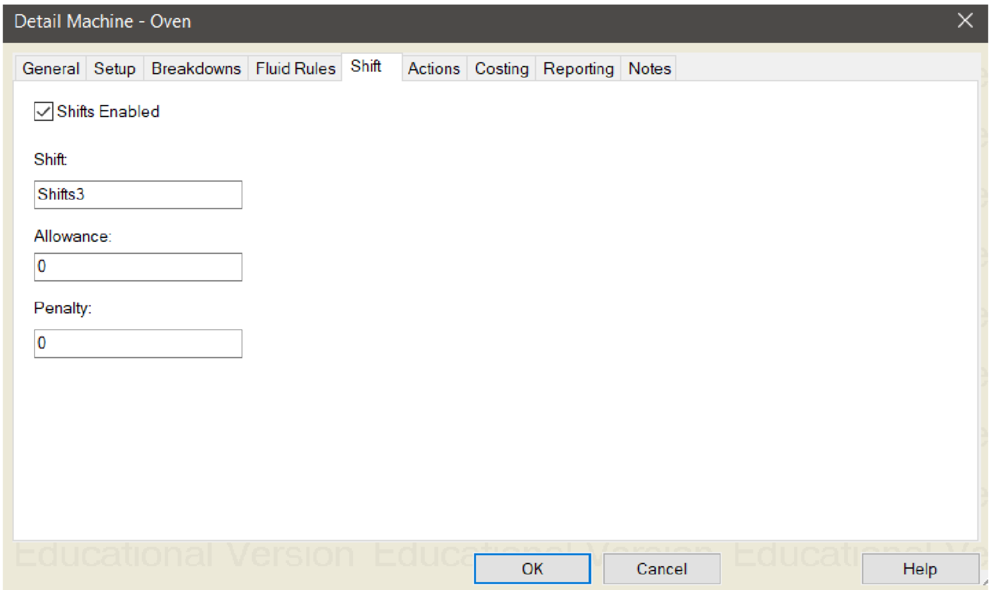


Figure 41: Shift setup [own]

- Now after finishing all the above steps, we get the simulation model as shown in the below picture. The simulation is run for a total of 282 days with 30 days is given as a warm up time period.

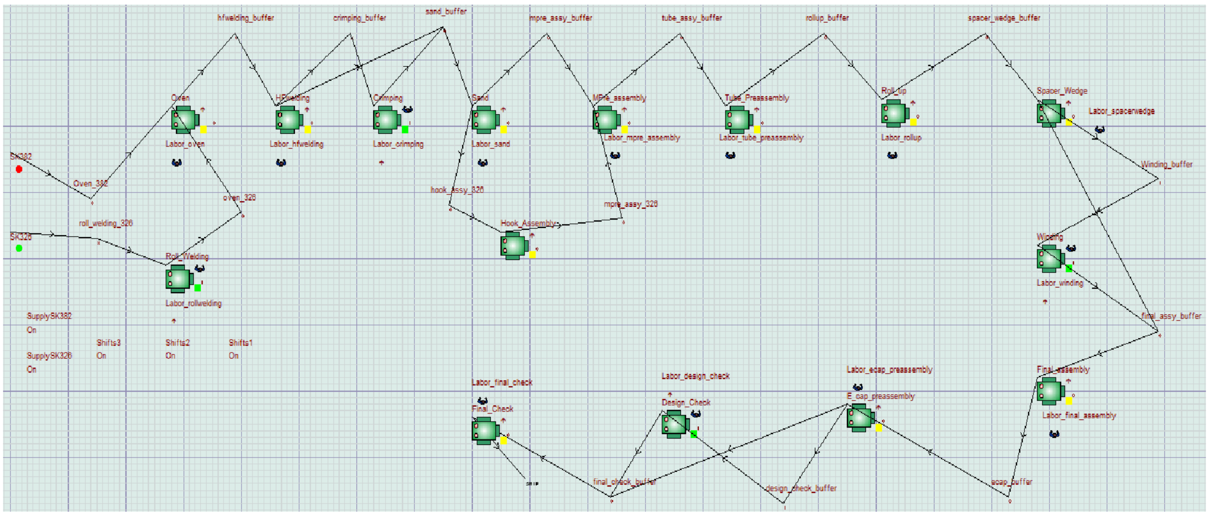


Figure 42: Simulation model [own]

- The below Figure 43 show the simulation result that is obtained. From the part statistics, the customer demand for the year has been fulfilled.
- The statistics shows that we produce higher quantities than the required customer demand, in real time the demand increases each year and can be balanced with the produced quantities accordingly.

Part Statistics Report by On Shift Time

Name	No. Entered	No. Shipped	No. Scrappe	No. Assembl	No. Rejected	W.I.P.	Avg W.I.P.	Avg Time	Sigma Rating
SK382	143736	143640	0	0	0	96	87.15	137.52	6.00
SK326	19880	19845	0	0	0	35	41.18	140.94	6.00

Figure 43: Part statistics [own]

- The machine statistics is shown in the Figure 44. There should be no machine blockage to carry on the production process smoothly as resulted in the statistics.

Machine Statistics Report by On Shift Time

Name	% Idle	% Busy	% Filling	% Emptying	% Blocked	% Cycle Wait	% Setup	% Setup Wait	% Broken Do	% Repair Wa	No. Of Operation
Oven	61.15	38.17	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	19480
Final_Check	42.26	49.15	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
HFwelding	15.46	83.86	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	19480
Crimping	60.73	39.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17100
Sand	54.02	37.39	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
Roll_Welding	61.80	38.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2380
MPre_assemb	69.50	21.90	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
Hook_Assem	91.19	8.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2380
Tube_Preasse	46.23	45.18	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
Roll_up	54.04	37.37	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
Spacer_Wedg	50.50	40.90	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
Winding	62.00	38.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17100
Final_assembl	34.21	57.19	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
E_cap_preass	48.03	43.38	0.00	0.00	0.00	0.00	8.59	0.00	0.00	0.00	19480
Design_Check	53.77	46.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17100

Figure 44: Machine statistics [own]

- The shift statistics below shows the percentage of working operations carried out as "on-shift" and the idle time with the "off-shift".

Shift Statistics Report by On Shift Time

Name	% On-Shift	% Off-Shift	Completed Shifts
Shifts3	81.25	18.75	30
Shifts2	62.50	37.50	30
Shifts1	18.75	81.25	30
SupplySK382	62.50	37.50	30
SupplySK326	18.75	81.25	30

Close
Help
<<
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Figure 45: Shift statistics [own]

- The worker for the machines is assigned in such a way, the working operations are balanced and the output satisfies the yearly customer demand. There are a total 10 workers assigned to the machines. In a precise manner, total of 9 workers are assigned to the production of SK 382 per shift and 8 workers are assigned to the production of SK 326 per shift. The below Figure 46 shows the labor statistics of the model.

Labor Statistics Report by On Shift Time

Name	No. Of Jobs	No. Of Jobs E	% Busy	% Idle	Quantity	No. Of Jobs	Avg Job Tim	No. Of Jobs
Labor_oven	163611	163611	38.14	61.86	1	0	0.69	0
Labor_rollweld_hookass	39691	39690	46.67	53.33	1	1	0.80	0
Labor_hfwelding	163989	163989	83.78	16.22	1	0	1.51	0
Labor_crimping	144019	144018	39.27	60.73	1	1	0.62	0
Labor_sand	163611	163611	37.35	62.65	1	0	0.67	0
Labor_mpre_tube_asse	327474	327474	67.03	32.97	1	0	0.60	0
Labor_rollup_spacerwed	327266	327265	78.15	21.85	1	1	0.70	0
Labor_winding_designc	287337	287336	84.16	15.84	1	1	0.66	0
Labor_final_assembly	163586	163586	57.08	42.92	1	0	1.03	0
Labor_finalcheck_endca	327253	327252	92.35	7.65	1	1	0.83	0

Figure 46: Labor statistics [own]

10. EVALUATION

- The merging of lines is possible from the technological point of view as suggested before in the production capacity analysis.
- From the capacity point of view, there is no problem and can be implemented as a result of the machine utilization rates obtained in the capacity equations.
- The model is simulated with the real time data as used in the capacity equations from the work floor and to virtually see whether it is possible to make out a universal line.
- From the result of the simulation model, it is possible to make out the universal line and fulfill the yearly customer demand.
- The Table 18 shows the comparison of the machine utilization rate obtained from the economic model and the simulation model. From the table, the machine utilization rates obtained from both the models are much like each other.
- So, the lines can be merged to form a universal line to produce both the products SK 382 and SK 362 in a three-shift operation without any constraints and meet the yearly customer demand.
- The layouts that are suggested are with optimized process flow and the machines arranged in a sequential manner to ensure the process flow is continuous with minimum amount of crossover.
- Therefore, the layout suggestion 2 which meets all the criteria will be the most suitable layout that we can use it as a universal layout for the production process.

	Machine Utilization rate (economic model)	Machine Utilization rate (simulation model)	Difference
Oven	38.50%	38.14%	0.36%
Roll Welding	38.30%	37.92%	0.38%
HF-Welding	83.93%	83.78%	0.15%
Crimping	39.57%	39.27%	0.30%
Sand cutting	37.71%	37.35%	0.36%
Machine Pre-assembly	22.29%	21.88%	0.41%
Tube Pre-assembly	45.47%	45.15%	0.32%
Roll up	37.64%	37.31%	0.33%
Spacer wedge	37.72%	40.88%	3.16%
Hook Assembly	9.41%	8.75%	0.66%
Winding	38.31%	38.00%	0.31%
Final Assembly	57.22%	57.13%	0.09%
Endcap Pre-assembly	43.68%	43.35%	0.33%
Design Check	46.52%	46.23%	0.29%
Final Check	49.35%	49.07%	0.28%

Table 18: Utilization Evaluation [own]

11. CONCLUSION

The objective of this thesis is to combine two manufacturing that produces two models of luggage cover SK 382 and SK 326 for car models Skoda Octavia and Karaq respectively in the company BOS Automotive Products CZ s.r.o. the universal line is proposed by designing and verifying by simulation.

In theoretical part, the manufacturing cell design and its methods was elaborated. The ways of improving a manufacturing environment were explained in brief under topics such as lean manufacturing, lean tools, six sigma and ergonomics, so that the manufacturing environment could be continuous and hassle free. The 5S and SMED were also explained as possible tools for the improvement of utilization.

The product that was manufactured was luggage cover, which was explained in words and visually represented using the pictures provided by the company. The transfer batch was a single piece flow and the description and advantages of a modern U-shaped cell was briefed.

In the analysis phase, the production technology matrix was formed to identify the processes that are carried out in the production of products SK 382 and SK326. The common operations and the extra working operations were identified. The production capacity analysis was done to identify the shift ideal time and production capacity of each cell and the swim lane diagram was constructed for the purpose of easy identification of the flow of process through various phases of the production.

The workshop phase included the future production capacity of the manufacturing cell. The value stream mapping was done for the 3 main phases of the processes. Then, the cell suggestions were proposed with their own advantages and disadvantages. The spaghetti diagram was drawn to analyze the product flow from one stage to other. By multi criteria method the suggestion 2 was selected as the best solution.

The requested objectives by the company BOS Automotive Products CZ s.r.o. such as the production space to 130 sq. m was met by the layout design. Secondly, the three-shift operation of the cell was achieved by combining and forming a universal cell. Finally, the cost savings on machine was obtained by eliminating the similar process machines.

Finally in the simulation part, the yamazumi board was drawn to visualize the line balancing and see the tact times. Economic model of the future state was formed and obtained the machine utilization values. Then using the Lanner witness 14 simulation software, the future model was constructed with all data obtained from the BOS Automotive Products CZ s.r.o. and the outcome was that the futuristic universal layout is possible in capacity point of view and technological point of view.

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