CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

MS:	Mixing Station
GS:	Grinding Station
FAST:	Field Assisted Sintering
CIPS/HIP:	Cold Isostatic Press Sintering - Hot Isostatic Press
HTS:	Heat Treatment Station
SFS:	Surface Finishing Station
CS:	Cutting Station
LS:	Labelling Station
Q:	Throughput
K:	Failure factor
V:	Availability
ρ:	Utilization
$M_{(w):}$	Waiting area
$T_{(wc):}$	Mean Waiting time
F_H:	Frictional resistance
$F_{(St)}$:	Slope resistance
$F_{(Acc)}$:	Acceleration resistance

ABSTRACT

The goal of this assignment was to design a factory layout for manufacturing metal stock bars through powder metallurgical processing, coupled with an automated material handling system featuring continuous conveying technology. The primary goal was to sustain a production rate of 90 bars per hour, excluding rejected items. Key workstations, including the mixing station, grinding station, compacting stations like field-assisted sintering processing (FAST), cold isostatic pressing-sintering-hot isostatic pressing (CIPSHIP), and quality check station, were strategically positioned for efficient processing. Additionally, a heat treatment station, cutting station, surface finishing station, and labeling station were incorporated for the automated post-processing of blanks, with the final product transported to the warehouse via a central conveyor.

Various material handling equipment, such as conveyors, diverters, accumulators, and sensors, was utilized. Comprehensive calculations and analyses, considering factors like $Q_{(limit)}$, $Q_{(required)}$, availability, mean waiting time M(W), and utilization (ρ), were conducted to meet specified constraints. Collaboration with other groups, including "Requirements, Consideration, and Selection of Materials Along with Engineering Chains (RECOM)" and "Establishing Digital Engineering Chains (EDEC)," contributed to the design process. Ultimately, two layouts were developed and compared, and the most suitable design was chosen.

1 INTRODUCTION:

1.1 Problem Statement:

A powder-metallurgical (PM) processing route for the production of metal stock products (bars) is to be planned. To improve the quality and efficiency of the process, the different production steps are to be linked with an automated material handling system (MHS) based on continuous conveying technology. The required total production rate of 90 products (bars) per hour (not including rejected products) is defined by the management which is to be achieved.

1.2 Considerations for design of Automated Material Handling System:

The general metal bar production by the powder metallurgical process can be described generally as follows:

A blank is created after mechanical alloying and compaction. Each blank may have its own mixtures and necessary compaction process parameters. As a result, each blank may differ significantly from the others. The blank undergoes postprocessing, where heat treatment, cutting, finishing, and labeling are undertaken.

The blanks have a size of 40 mm in diameter and 200 mm in length.

It is assumed that out of one blank, on average, three final stock products are created. Production time fluctuates and is dependent on the bar geometry and the required density of the products.

In detail, production requires the following three main steps:

1.2.1 Processing of blanks:

a) Powder preparation in a mixing station (MS): mixing the initial powders in the desired chemical composition and filling into the grinding tool (attritor made of stainless steel or tungsten; capacity: 5 l). Due to the reactivity of the powder, it is handled under a protective gas atmosphere in a glove box. The creation of the mixing takes approximately 10 minutes per set of four attritors.

b) Manual transport of the grinding tool to the grinding station (GS): 5 minutes for the set of 4 attritors.

c) Grinding/mechanical alloying in GS: The closed grinding vials must be fixed in the attritor mill (handwork). Each grinding station can mix four attritors simultaneously. The parameters for mechanical alloying are set (rounds per minute, rpm, and time) and will be discussed in more detail by the group RECOM. The grinding alloying process takes, on average, 2 hours per grinding tool.

d) Manual transport of grinded alloy to compaction station (CS): 5 minutes per set of 4 grinded alloys.

e) Compacting the milled powders to a blank in the compaction station (CS): Two different routes are available in general:

- Field-Assisted Sintering (FAST) or
- Cold Isostatic Pressing (CIP)—Sinter—Hot Isostatic Pressing (HIP) process.

The process steps on the FAST device take approximately 1.5 hours per blank. The CIPSHIP process takes approximately 2 hours per blank. FAST and CIPSHIP processes are equally used to create the blanks. The automated FAST and CIPSHIP stations can produce four blanks simultaneously.

f) Manual transport of the blanks to the quality check station (QS): 5 minutes per 4 blanks

g) Quality check of blank (inline CT) in QS: The quality check takes approximately 5 minutes per blank. 1% of all blanks are detected to not reach the porosity limit. They undergo a recompacting process. This re-compaction process is not taken separately and should not be further considered in this task.

The MS, GS, and CS should be treated as black boxes. The properties of the given workstations are assumptions and the basis for the further planning of the Material Handling System (MHS).

1.2.2 Automated postprocessing of blanks to generate certain product properties.

The main aim of this assignment was to create an automated material handling system which is to be used in post-processing of the raw material. The transport should be done with an automated continuous conveying system.

a) Heat treatment of the blanks to modify their mechanical properties takes place at the heat treatment station (HT). The heat treatment takes 30 minutes per blank. 50% of all blanks need to be heat-treated.

b) Cutting of the blanks to produce stock bars of the intended length at the cutting station (CS). 95% of all blanks need to be cut. The cutting takes approximately 2 minutes per cut. On average, three stock bars are created out of one blank.

c) Surface finishing of the stock bars (descaling and polishing) at the finishing station (FS): Surface finishing takes 65% of all stock bars that need to undergo the surface finishing process step. The surface finishing takes approximately 3 minutes per stock bar.

d) Labeling of 100% stock bars at the labeling station (LS). Labeling takes 1 minute.

1.2.3 Transport to the warehouse by a central conveyor.

The given times were approximated values for the first planning step. The precise times were determined by collaborating with the RECOM group based on the specific selection of blank manufacturing material. In order to achieve the desired quality of the selected material, specific process parameters and subsequent heat treatment processes have to be considered, which are finally realized by the related production system elements. A detailed prediction of the material characteristics was done by the "RECOM" group, and this data was collected from them. The resource structure of the powder metallurgical production route is developed by the EDEC Group.

Based on our assignment, we attempted to address the following points in this report:

- Solutions for identifying the steel bars. The benefits and drawbacks of the solutions.
- The various types of conveyors suitable for this particular application and the design we chose after careful consideration.
- Selected diverter, merger, and accumulation units are based on application.
- Design of two automated material handling system layouts.
- Technical block diagrams of designed layouts and their use.
- Calculation of throughput and identification of serving systems in our designed layouts.
- Calculation of utilization for the servers. Calculation of average elements in the waiting room as well as the waiting time along with the total time in the existing serving systems.
- Calculation of the number of waiting elements to allow a blocking-free operation in 80% of the time.
- Calculation of the reliability of the developed material handling system based on the given failure factors. Identification of the type of redundancy in the material handling system.
- Evaluation of both layouts based on their advantages and disadvantages. Selection of a favorable solution.
- Calculation of the approximated length and drive power of the components of the selected MHS.
- List of components with their properties according to the asset administration shell template provided by the EDEC group.
- Discussion of the detailed times required for postprocessing and quality control, which were collected from the RECOM group. Comparison of these times with the final layout and changes that were made accordingly.

2 IDENTIFICATION POSSIBILITIES:

A) Laser identification:

It is a method of marking or engraving identification marks onto steel bars using a laser. The Identification marks are created by directing a laser beam onto the surface of the steel bar, which melts or vaporizes the material to create the mark.

Figure 1: Laser identification

Advantages: Laser identification methods can produce precise and detailed identification marks, and they can be used to engrave complex patterns or logos. They are also suitable for small or thin steel bars.

Disadvantages: Laser identification methods may be expensive and require specialized equipment and personnel to perform. Additionally, Laser identification is not suitable for high-temperature applications, as the heat generated by the laser may cause damage or distortion to the steel bars.

B) Magnetic identification:

It is a method of marking or engraving identification marks onto steel bars using a magnetic pen or ink. The identification marks are created by applying magnetic ink or paint on the steel bar, which can be read using a magnetic reader.

Advantages: Magnetic identification methods are quick and easy to perform, and they do not cause any damage to the steel bars. They are also suitable for small or thin steel bars.

Disadvantages: Magnetic identification marks may be difficult to read or may fade over time, making them less durable than other identifications methods. Additionally, magnetic ink or paint may not be suitable for high temperature applications, as the magnetic properties may degrade or disappear at high temperatures.

C) Chemical identification:

It is a method of marking or engraving identification marks onto steel bars using chemicals. This method typically involves using chemical etching or marking to create identification marks on the steel bars.

Figure 2: Chemical identification

Advantages: Chemical identification methods such as chemical etching or marking can produce detailed and precise identification marks. They are also suitable for small or thin steel bars.

Disadvantages: Chemical identification methods may be time-consuming and may require specialized equipment and personnel to perform. Additionally, the chemicals used in chemical etching may be dangerous, so safety measures and equipment should be in place when using this method.

D) Barcode Identification:

Barcodes: Unique barcodes printed on labels or directly on steel bars.

Barcode Scanners: Optical scanners to read barcode information.

Processing Unit: Barcode decoding software.

Workflow:

Steel bars are labeled with unique barcodes and barcode scanners capture information from the labels. Barcode decoding software interprets the scanned data. The system automatically diverts steel bars based on the identified information.

Advantages: Cost-effective and widely used. Can handle various steel bar sizes.

Disadvantages: Prone to damage or wear on labels and requires line-of-sight for scanning.

E) Mechanical identification:

It is a method of marking or engraving identification marks onto steel bars using mechanical devices. This method typically involves using punches stamps, or roll markers to physically engrave or stamp identification marks on the steel bars.

Advantages: Mechanical identification methods such as punches, Stamps, or roll markers, are durable and can withstand harsh conditions. They can also be used to engrave complex and detailed identifications marks.

Disadvantages: Mechanical identification methods may cause some damage to the surface of the steel bars, and they may not be suitable for small or thin steel bars.

F) Ultrasonic Identification:

Ultrasonic Transmitters: Devices emitting ultrasonic signals.

Ultrasonic Receivers: Sensors to detect reflected ultrasonic signals.

Processing Unit: Ultrasonic signal analysis software.

Workflow:

Ultrasonic transmitters emit signals onto steel bars. Ultrasonic receivers detect reflected signals, creating a unique identification pattern and then ultrasonic signal analysis software interprets this pattern. The system automatically diverts steel bars based on the identified information.

Advantages: Non-contact identification. Suitable for harsh environments.

Disadvantages: Requires a clear path for ultrasonic signals. Limited range compared to other methods.

2.1 Selected combination of Identification Method:

A. Barcode Application:

Thermal Transfer Printing Method with Resin-Based Ribbon:

Thermal Transfer Printing Method with Resin-Based Ribbon: Barcodes are applied at 3 strategically selected locations on the blank using a thermal transfer printing method. A resin-based ribbon ensures durability and resistance to high temperatures during next step of heat treatment.

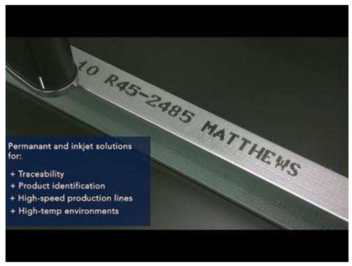


Figure 3: Thermal transfer printed method with Resin Based Ribbon

Due to the placement of these, very small codes at strategic positions on the blank they will be visible irrespective of its rotational motion. It is evident that because of the small size of blank, printing of code at multiple locations is problematic, but because all three codes are in different lines or at different sides of blank, there will be sufficient space for printing. We have selected a simple 3-digit code scheme in order to avoid any issues while printing. We were able to do this because we are also using color coding in combination, as our identification method before heat treatment, length measurement before cutting and surface quality inspection before surface finishing.

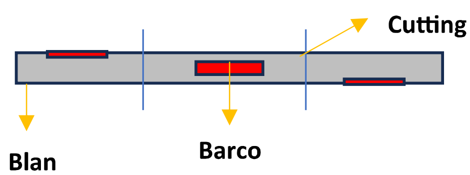


Figure 4: Illustration of placement of bar codes.

B. Color Coding:

1. **Paint or Marking:**
   Dual color coding is applied on the faces of the blank in such a way that each color represents a decision to be taken while sorting at coming stations. Blue – Need to be Heat Treated & Pink – Need to be sent for cutting. Use high-visibility and durable paints that adhere well to aluminum surfaces. VHT (Very High Temperature) Engine Enamel Paint is used for this purpose.

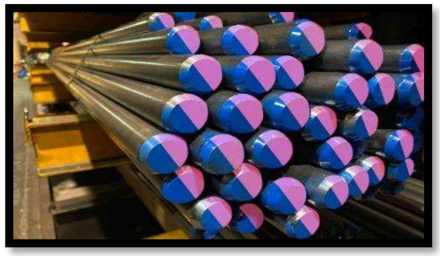


Figure 5: Dual color-coding method

2. VHT (Very High Temperature) Engine Enamel Paint:

1. Brand: VHT (Very High Temperature):
    - VHT is a well-known brand that produces high-temperature engine enamel paints.
2. Product: VHT Engine Enamel:
    - Choose a specific product within the VHT Engine Enamel range that meets your requirements.
3. Features:
    - VHT Engine Enamel paints are designed to resist high temperatures, making them suitable for applications where aluminum parts are exposed to heat.
4. Adhesion to Aluminum:
    - These paints typically adhere well to aluminum surfaces, providing a durable and long-lasting finish.
5. Color Options:
    - VHT offers a wide range of color options, allowing you to choose colors that provide good visibility and contrast for your color-coding needs.

Disadvantages: Difficult to implement initially because of complexities related to position of barcodes and dual color coding.

3 SELECTION OF CONVEYOR:

To finalize the conveyor suitable for the required process, it is important to understand the profile of the product i.e. blank which is in form of cylindrical rod with 40mm diameter and 200mm length.

Requirements for conveyor can be stated as follows:

- Requirement of support for product within the conveyor
- Conveyor must be able to withstand heat
- Power consumption should be less
- Easy transport of product.

Also, the blank is oriented on the conveyor perpendicular to the direction of flow. It should be in such a way that the product must remain on the conveyor throughout the process without any slippage or roll back.

3.1 Type of conveyors:

- ***Chain conveyors:*** These use a chain and a series of sprockets to move the steel bars along the conveyor. They are commonly used for heavy-duty applications and can handle large and long steel bars.
- ***Roller conveyors:*** These use a series of rollers to support and move the steel bars along the conveyor. They can be powered or gravity-driven and can handle long steel bars.

Figure 6: Example of roller conveyor

- ***Monorail conveyors:*** These use a single rail to move steel bars along the conveyor. They are commonly used for long and heavy steel bars and can handle high capacities.
- ***Overhead conveyors:*** These use an overhead rail to move the steel bars along the conveyor. They are commonly used for long and heavy steel bars and can handle high capacities. They can also be used to suspend the steel bars in the air during the cooling process.

- ***Belt conveyors:*** A belt conveyor is a mechanical system used for efficient material transportation in various industries. It consists of a continuous loop belt, motorized pulleys, support rollers, and a sturdy frame. The motor provides power to move the belt, while idlers reduce friction and maintain tension. Belt conveyors are versatile, cost-effective, and reliable, accommodating a wide range of loads and applications. Their design and specifications depend on factors like material type, distance, and required throughput.

Figure 7: Example of belt conveyor

- ***Pusher conveyors:*** These use a series of pushers to move the steel bars along the conveyor. They are commonly used for long and heavy steel bars and can handle high capacities.

All of these conveyors are typically built to handle the weight and size of long steel bars, as well as any potential heat generated from the casting process. But in our case, due to the small size of blanks that are to be transported, we had to go for a customized solution.

3.2 Selection of customized conveying units for our specific application:

For our particular case, we have decided to use Belt Conveyor with Enclosed Sidewalls and Low-Profile Cleats to provide proper Containment, Gentle Handling and have high level of Versatility.

3.2.1 Belt Conveyor with Enclosed Sidewalls and Low-Profile Cleats:

A belt conveyor with enclosed sidewalls features vertical barriers along the edges, preventing material spillage. Low-profile cleats on the belt provide efficient material containment and transportation, making it suitable for industries with specific handling requirements.

This design enhances both safety and productivity in material conveying applications.

Figure 8: Low profile cleated conveyor with side walls and cleated conveyor with retaining walls

• *Enclosed Sidewalls:* The conveyor is equipped with enclosed sidewalls on both sides. Sidewalls prevent blanks from falling off the conveyor during transportation.

• *Low-Profile Cleats:* Cleats are attached to the conveyor belt at regular intervals. Low-profile cleats ensure proper grip on the blanks without causing interference or damage.

• *Adjustable Cleat Spacing*: Cleats are designed with adjustable spacing to accommodate different blank sizes if required.

• *Flat Conveyor Surface:* The majority of the conveyor surface is flat, allowing for smooth and continuous movement of blank.

• *Belt Material Selection*: Belt material suitable for the application, ensuring it provides sufficient grip and durability for the specific characteristics of the blanks.

3.2.2 Benefits:

• *Containment*: Enclosed sidewalls prevent blanks from falling off, ensuring a secure and contained transport.

• *Gentle Handling:* Low-profile cleats provide a gentle and controlled grip on blanks without causing damage.

• *Versatility:* Adjustable cleat spacing allows the conveyor to handle a variety of blank sizes.

• *Smooth Operation:* The flat conveyor surface ensures a smooth and consistent flow of blanks.

• *Adaptability:* Suitable for applications where precise positioning and control are essential.

4 SELECTION OF DIVERTER, MERGER AND ACCUMULATION UNIT:

4.1 Accumulation conveyor:

- Create a helpful buffer zone between processes that require different lengths of time to complete. In picking and packing facilities for example, it can sometimes be difficult for packers to load product at the rate in which it flows into their station; therefore, accumulation conveyors are used to slow the stream, and to create a collection pool that they can grab from.
- Allow operators to oversee multiple stations at once. Strategically timing production flows at specific intervals gives operators the chance to move in-between work areas.
- Create an efficient que for feeding products through machines on the production line. This is useful for both last in, first out (LIFO) and first in, first out (FIFO) applications. Prevent congestion or damage on inclines, declines, and spirals.

4.1.1 Selection of customized accumulation unit for our specific application:

Zero-Pressure Accumulation Conveyor with Belt Integration:
A zero-pressure accumulation conveyor seamlessly integrates a belt system with controlled zones, allowing products to accumulate without contact or pressure. This technology ensures smooth material flow and prevents product damage, making it ideal for high-throughput and precision handling in various industries.

a) Belt Conveyor with enclosed sidewalls and grooved pattern:
Use a belt conveyor with grooved pattern to prevent blanks or bars from rolling and enclosed side walls for preventing it from falling.

b) Zero-Pressure accumulation conveyor:
Integrate zones of rollers or accumulation zones along the belt conveyor. Sensors or photo eyes to detect the presence of blanks or bars in each accumulation zone.

c) Slip-Torque Rollers:
Slip-torque rollers that allow free movement when accumulation is not needed. These rollers have the ability to slip, enabling accumulation without creating back pressure.

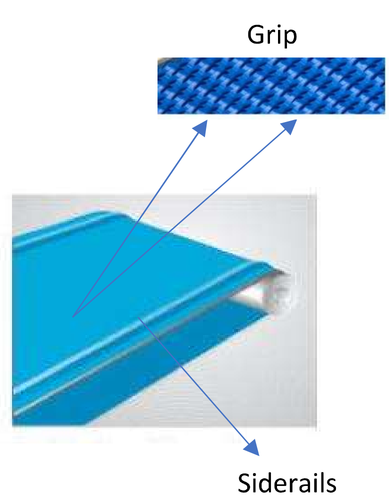


Figure 9: Accumulation grooved belt conveyor with retaining walls

Benefits:

• *Zero-Pressure Accumulation:* Blank accumulation occurs without creating back pressure or causing damage.

• *Flexible and Adaptable:* The system is designed to handle varying sizes and production rates, adapting to changing requirements.

• *Enhanced Control:* PLC-based control provides precise management of accumulation zones, optimizing the flow of blanks and bars.

4.2 Diverter and Merger:

A diverter lifts the material to be conveyed and diverts it in the desired direction, thereby changing the direction of conveyance. The lift is carried out pneumatically by bellows cylinders or electro-mechanically by an eccentric lifter. The conveying height and the conveying direction remain the same when moving by means of a turntable or carriage. Depending on the conveying solution, pushers, linear units or gantry systems for shifting the conveyed material are also available.

4.2.1 Selection of customized diverter unit for our specific application:

Integrated Belt Diverter with cleats and Adjustable contoured Side Rails:
An integrated belt diverter incorporates cleats for effective material control and adjustable contoured side rails for versatile handling. This design allows precise sorting and diversion of conveyed items while ensuring optimal containment and adaptability to different product sizes on the conveyor system.

Grooved belt

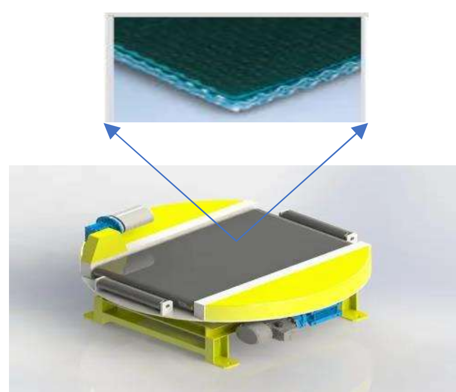


Figure 10: Belt turntable with adjustable side rails

Features:
• Powered Belt with grooves and anti-slip coating
• Adjustable Side Rails with Contoured Surface
• Powered Belt Diverter Mechanism

Working:

• The grooves on the belt provide positive engagement with the conveyed items, preventing sliding during diverting.
• Adjustable contoured side rails having a contoured surface that matches the shape of the blanks are positioned to guide and support the items, minimizing lateral movement.
• The anti-slip coating enhances traction on the belt, further preventing any unintended slipping of items during the diverting process.

Benefits:

• *Enhanced Traction:* The combination of an anti-slip coated belt and adjustable contoured side rails ensures enhanced traction for secure diverting.
• *Coordinated Diverting:* The powered belt diverter mechanism and adjustable side rails work in coordination to ensure controlled and precise diverting.

5 SELECTION OF SENSORS AND THEIR POSITION:

5.1 Visual Recognition System:

Implementing visual recognition involves installing high-resolution cameras along the conveyor, capturing images from multiple angles. Image processing software with feature extraction, pattern recognition, and classification algorithms is used to analyze the blanks. Thermal print code readers scan the codes on each blank and bar with extra aid of visual recognition.

We will be using this visual recognition system to scan the thermal printed code and take high resolution images for analysis. This will also help in creating database by combining results of all sensors for every single blank or bar. This data will be stored and thus, will have record encrypted in codes.

We will be specifically using Cognex In-sight 2000 vision sensor because of below mentioned advantages:

Robustness, diverse training data, real-time processing, seamless integration with the conveyor system, and adaptability to changing production requirements.

This special purpose high resolution visual recognition system will be located on the divertors from where blanks are to be sorted and sent for either heat treatment or directly to the next step by skipping heat treatment.

Figure 11: Visual Recognition System (Cognex In-sight 2000)

5.2 Sorting based on color sensing (Color coding identification):

5.2.1 *Color Sensors:*

These sensors are specifically designed for color detection and recognition. They can be programmed to recognize specific colors and trigger actions accordingly.

They will be located before and after the heat treatment section to identify blanks or bars requiring further sorting. Integrated into the visual recognition system for color-based identification. Due to the use of dual color-coding method, these sensors will help in sorting for both heat treatment and cutting. For example, Blue – Need to be Heat Treated & Pink – Need to be sent for cutting.

5.3 Sorting based on length of blanks (Length Measurement):

5.3.1 Ultrasonic Length Sensor:

Ultrasonic length sensors utilize ultrasonic waves for non-contact distance measurement, calculating distance based on wave travel time. An ultrasonic length sensor measures the initial length of each blank before the cutting operation with high precision.

We will be using this sensor to identify blanks which require cutting operation.

1. Key features: non-contact operation, compatibility with various materials, and cost-effectiveness.
2. Advantages: Relatively cost-effective when compared with laser sensors. If extremely high precision is crucial, a laser length sensor may be preferred.

These sensors will be located at the divertor before cutting station where sorting is done based on length of blank and it is finalized weather cutting operation is needed or not.

5.4 Sorting based on quality of surface (Surface quality inspection):

5.4.1 Eddy Current Sensors:

Detect minor surface defects, cracks, or irregularities. Positioned after the cutting operation.

Figure 12: Eddy current sensor for surface evaluation

5.4.2 Laser Profilometer:

Measure surface roughness and detect any deviations from the desired smoothness.

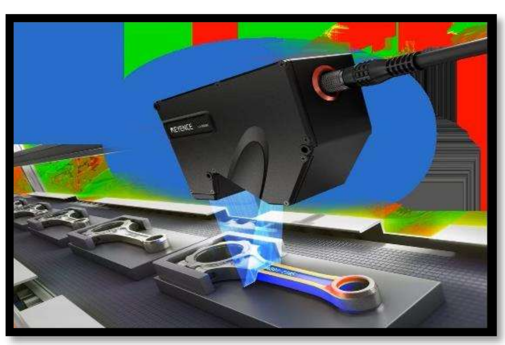


Figure 13: Laser Profilometer for detecting surface roughness

We will be using combination of both these sensors in order to identify weather surface finishing is required or not. These sensors will be located at the divertor before surface finishing stations to identify bars, that require final finishing because of surface quality.

5.5 Identification of Blank or Bar position:

5.5.1 Photoelectric Sensors:

- Through-beam Sensors: These sensors consist of a transmitter and a receiver. When the beam is interrupted by a steel bar, it indicates the presence of the object.
- Reflective Sensors: These sensors use a reflective surface to bounce the light beam back to the sensor. When the beam is interrupted by a steel bar, it signals the presence of the material.
- Diffuse Sensors: These sensors detect the presence of an object based on the amount of light reflected back. They can be used for detecting steel bars in the material handling system.

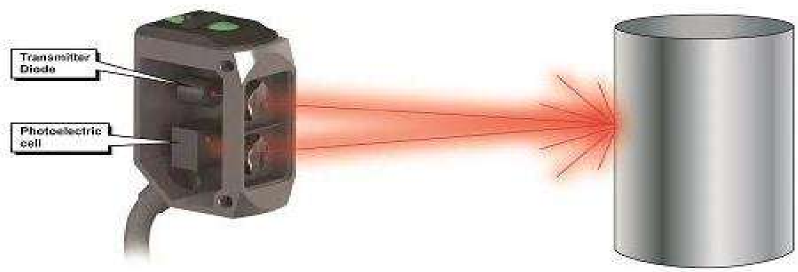


Figure 14: Photoelectric sensor used for detecting presence of blanks

We will be using trough-beam sensor in order to detect the presence of blanks and bars in our material handling system. The sensors will be located at multiple locations throughout of system in order to detect the presence and coordinate the movement of material.

6 LAYOUTS:

6.1 Layout 1:

The layout features a central conveyor that evenly divides machines, with half above and half below. This design minimizes serial connections and maximizes parallel connections, ensuring that a machine failure does not disrupt material flow. The quality station supplies blanks; 50% of non-heated blanks go directly to cutting, while the remaining 50% are equally distributed to upper and lower heat treatment stations. Additionally, 5% of blanks do not require cutting, and 35% of bars do not need surface finishing to pass through the central conveyor connecting the stations.

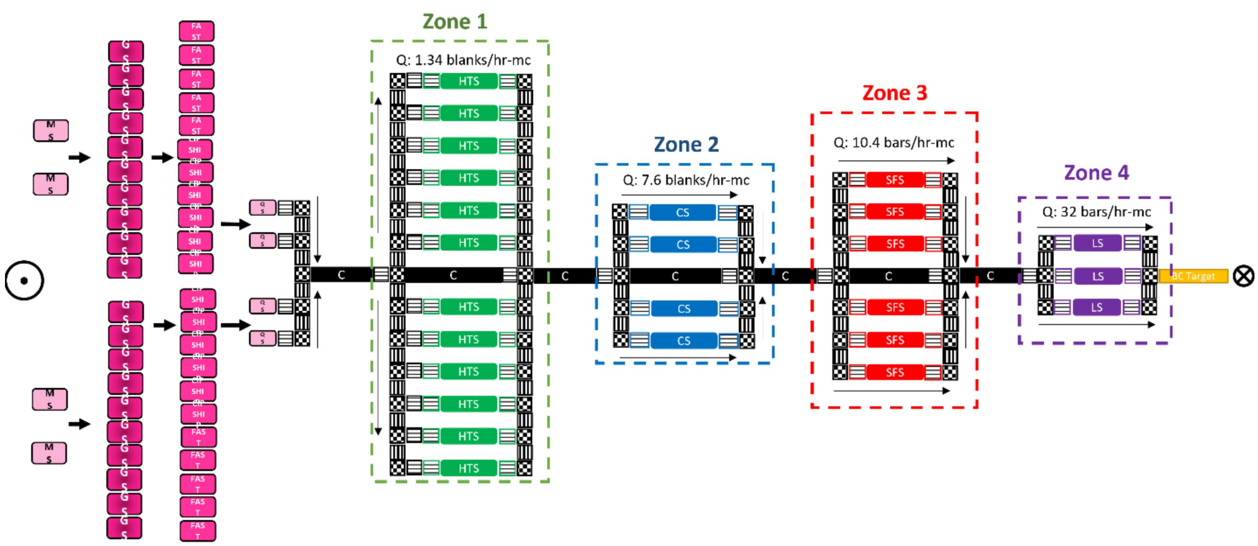
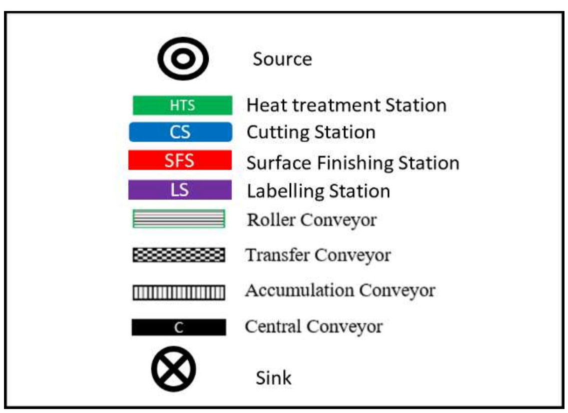


Figure 15: Layout 1

The following are the components of the layouts:



6.1.1 Redundancy of the system:

The parallel connections of the machines make it hot-redundant. However, a centralized conveyor can create a problem as it is the only source of transport to all the stations. Therefore, the failure of the centralized conveyor will affect the whole operation.

6.1.2 Block Diagram:

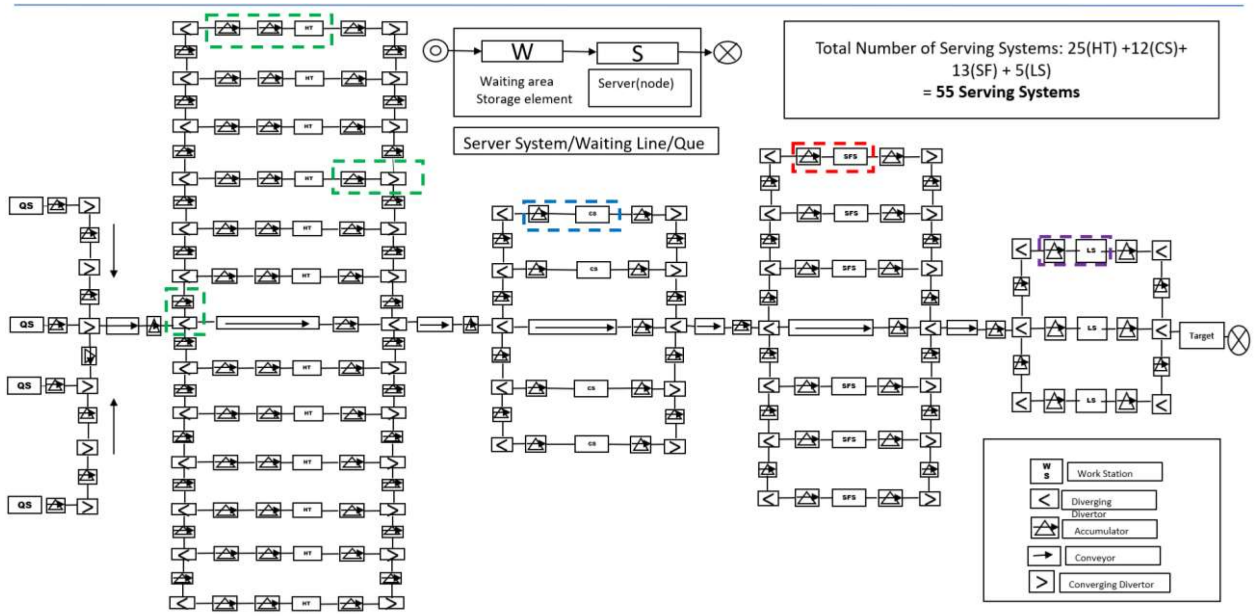


Figure 16: Technical Block Diagram -Layout 1

6.2 Layout 2:

In this layout, two independent lines are developed and connected to labeling stations for equal distribution of blanks, achieving a throughput of 90 bars/hour while maintaining the same number of machines.

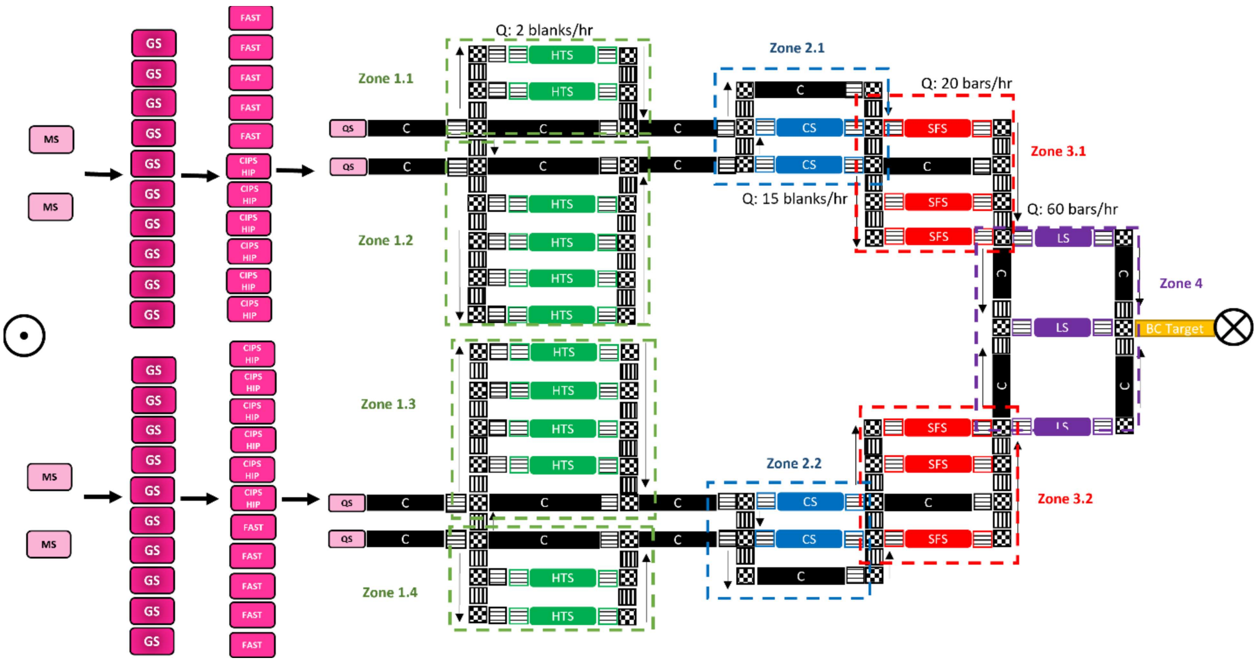


Figure 17: Layout 2

Flow sequence 1: 50% of the blank that requires heat treatment:

QS 1 supplies blanks to 2 upper heat treatment stations and 4 lower quality stations connected to QS 2 via an accumulator. QS 2 cannot supply blanks upwards. With a total throughput of 30 blanks per hour, each quality station facilitates 3.75 blanks per hour in two lines.

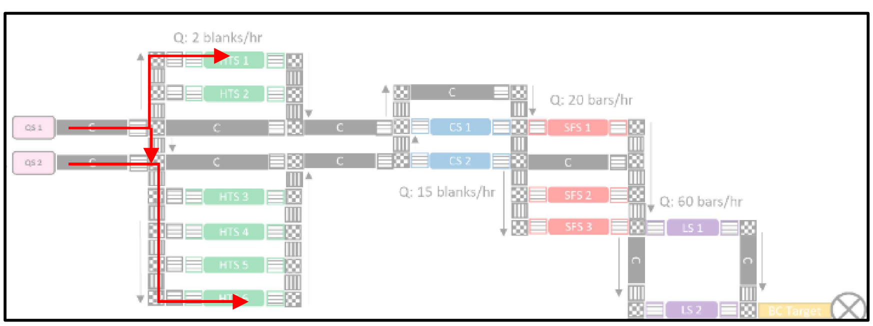


Figure 18: Flow sequence (50% heat treated material)

Each centralized conveyor at CS is attached to one CS, allowing direct material supply. CS machines are strategically placed for material flow priority. In the case of CS 2 failure, material can move upwards, but a failure of CS 1 prevents downward movement. Despite setbacks, excess machines attached to CS 2 ensure the layout meets demand. Furthermore, the second line mirrors the first line's material flow.

Flow sequence 2: 50% of blanks not requiring heat treatment:
Four separate centralized conveyors between QS and CS reduce traffic and waiting time for non-heat-treated blanks. With a total throughput of 90 bars, each line receives 7.5 blanks per hour, and each central conveyor line handles 3.75 blanks per hour of non-heat-treated blanks.

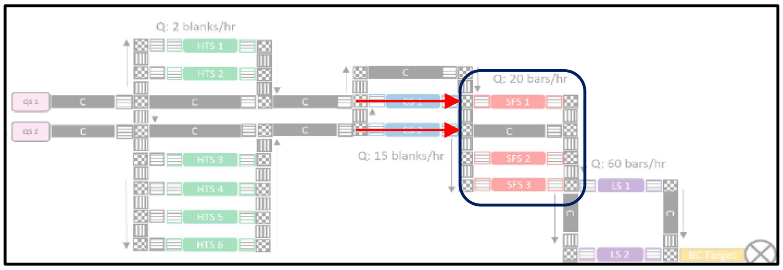


Figure 19: Flow sequence (50% blanks not heat treated)

Flow sequence 3: 5% of blanks not requiring cutting:
Blanks not requiring cutting pass-through conveyors positioned above and below CS. With a 5% ratio, 1.5 blanks per hour out of 30 blanks per hour pass through these conveyors.

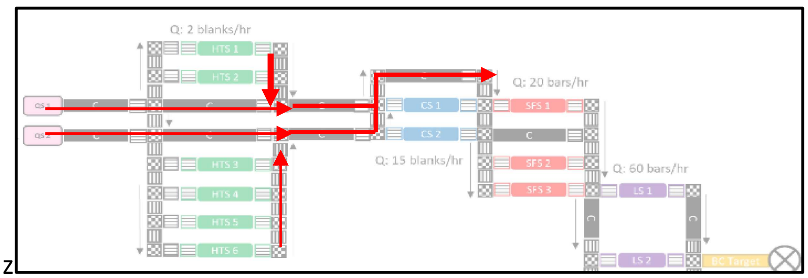
Z


Figure 20: 5% of blanks not requiring Cutting

Flow sequence 4: 35% of the Blanks that do not require surface finishing:
After cutting, 35% of bars not requiring surface finishing are directed to the LS. Each line facilitates 15.75 bars per hour, totaling 31.5 bars per hour for both lines.

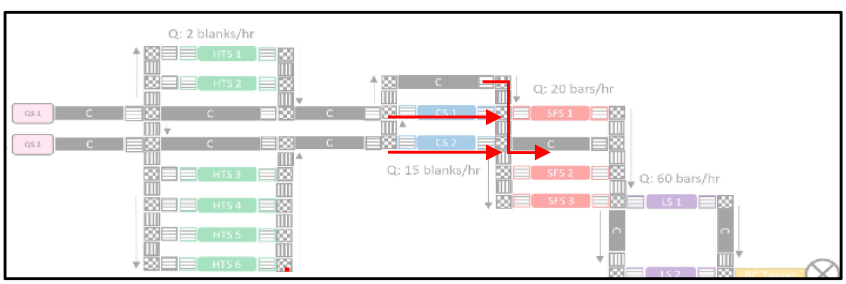


Figure 21: 35% blanks not requiring SF

After surface finishing, 100% of the material goes to the LS for further processing.

6.2.1 Redundancy of the system:

Due to the high number of parallel systems depicted below through various zones in the layout, the system is hot redundant. Furthermore, each line has its centralized conveyor which will not halt the operation.

6.2.2 Block Diagram:

Block Diagrams are drawn for the easy understating of the serving systems and easy representation of the actual mechanical equipment and machinery in a pictorial way for interpreting the data and performing calculations.

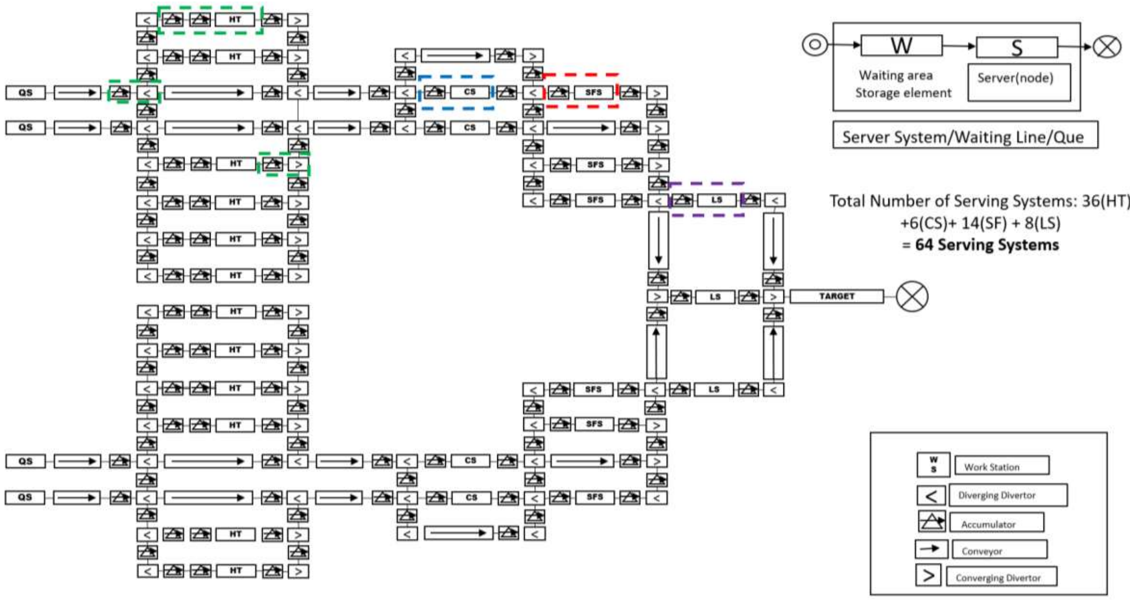


Figure 22: Technical Block Diagram Layout -2

7 AVAILABILITY CALCULATIONS:

According to VDI 3581 guidelines, the availability of an element or sub-element in a system can be defined as the probability of finding a given unit functioning properly at any given time during the operation period.

Layout 1 consists of various series and parallel systems. We have calculated the subsequent failure factors ĸ and availability V based on the below mentioned formulas.

Parallel system:

$$V_{total} = 1 - \prod_{i=1}^{n}(1 - V_i) = 1 - \prod_{i=1}^{n}(1 - \frac{1}{1 + \kappa_i})$$

Series system:

$$V_{total} = \frac{1}{1 + \sum_{i=1}^{n} \kappa_i}$$

Table 1: Given failure factors

Component	Failure Factor
Heat Treatment station	$k_{\mathrm{HTS}} = 0.08$
Cutting station	$k_{\mathrm{CS}} = 0.04$
Surface finishing station	$k_{\mathrm{SFS}} = 0.05$
Labelling station	$k_{\mathrm{LS}} = 0.03$
Conveyor	$k_{\mathrm{C}} = 0.005$
Accumulator	$k_{\mathrm{A}} = 0.08$
Non-Stopping Divertor	$k_{\mathrm{D}} = 0.08$
Sink	$k_{\mathrm{S}} = 0.005$

7.1 Layout -1:

The overall failure factor for this line was calculated as:

$$k_{eqtotal} = k_{eq(source)} + k_{(diverter)} + k_{eq\,(\text{accumulator})} + k_{eq(conveyor)}$$

$$or, k_{eqtotal} = (0.08+0.08) \parallel (0.08+0.08+0.08) \parallel (0.08+0.08+0.08+0.08+0.005) \parallel (0.08+0.08+0.08) \parallel (0.08+0.08)$$

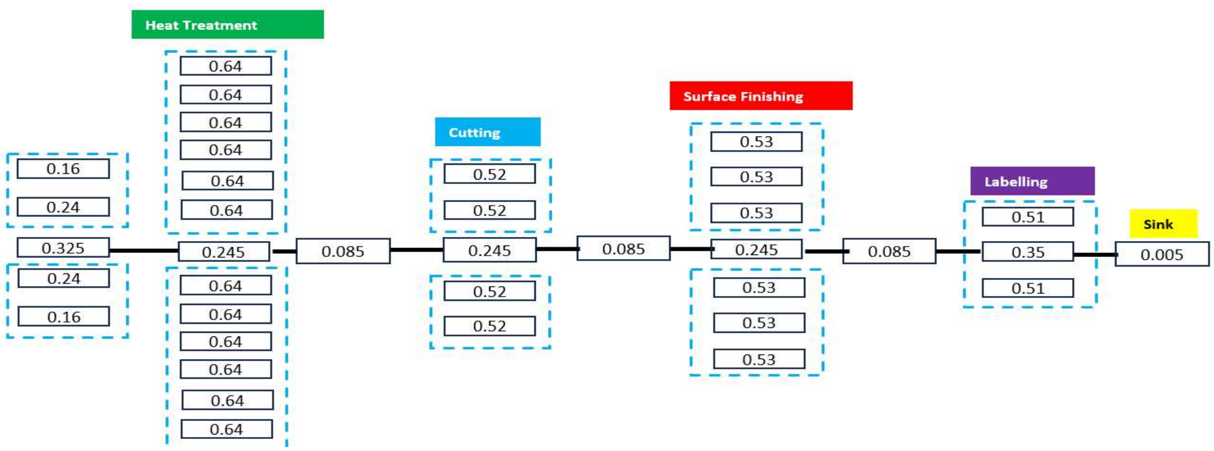
$$k_{eqtotal} = (0.16 \parallel 0.24) \parallel (0.325) \parallel (0.24 \parallel 0.16)$$

$$Hence, k_{eqLine} = \frac{k_1 \times k_2}{1+k_1+k_2} \text{ (Simplified equation when two components are in parallel, cold redundancy)}$$

$$\therefore k_{eqLine_2} = 0.0274$$

$$We\ know, availability = \frac{1}{1+k_{eq}}$$

$$\therefore availability\ of\ this\ line = 97.33\%$$



Following the Same approach, we get the values of Equivalent Failure Factors (Values shown in the diagram) of Heat Treatment Stations, Cutting Stations, Surface Finishing and Labelling Stations.

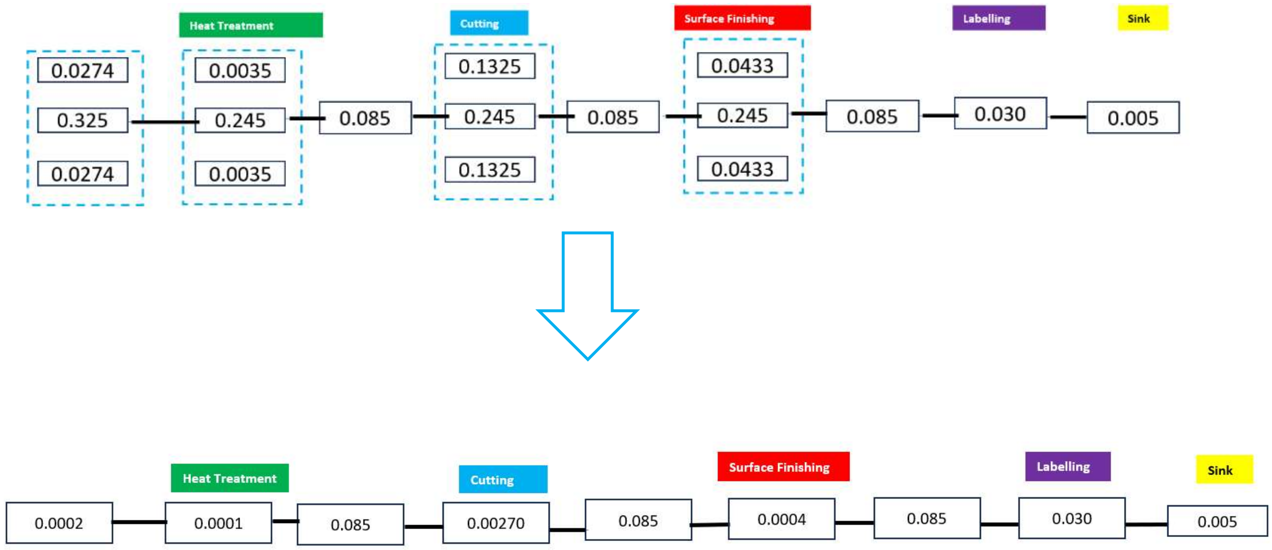


Figure 23: Availability calculation of Layout-1

After further simplification, the failure Factors of the all stations are in serial Connection with each other. The sum off all the failure Factors is added up and the formula for the total Availability is applied and the final Availability is Calculated.

$$\sum \mathrm{K(total)} = 0.2934$$

$$\mathrm{V} = \frac{1}{1+k}$$

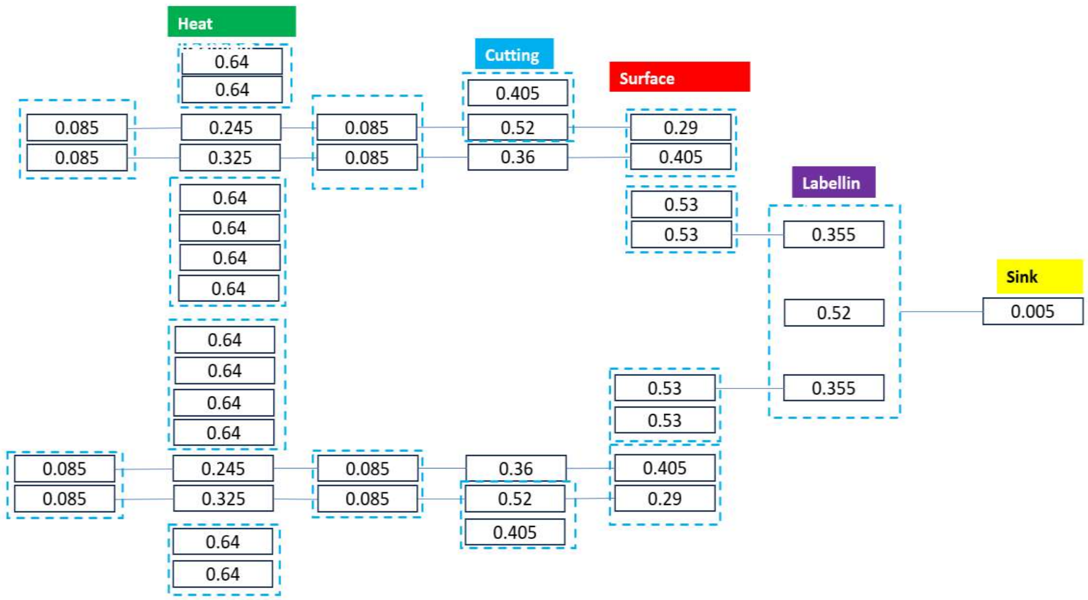
$$\mathrm{V} = \frac{1}{1+0.2934}$$

$$\mathrm{V} = 0.773$$

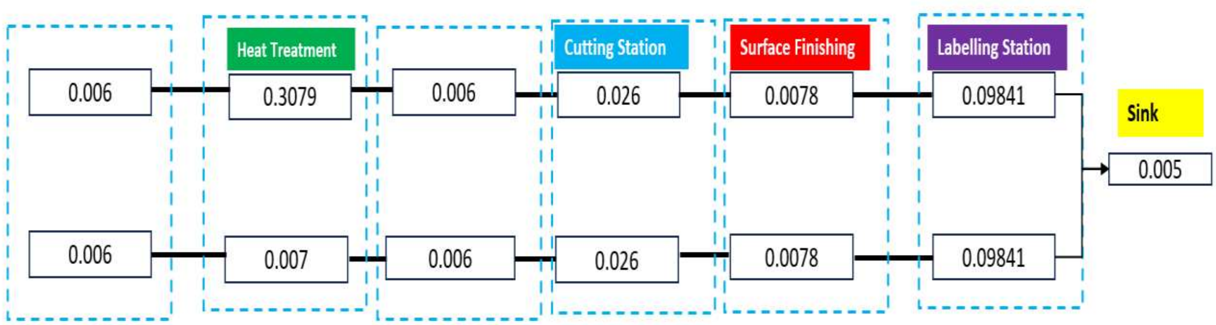
$$\mathrm{V} = 77.31\%$$

The Availability of the system **is 77.31%.**

7.2 Layout-2:



Following the Same approach as in Layout -1, we get the values of Equivalent Failure Factors (Values shown in the diagram) of Heat Treatment Stations, Cutting Stations, Surface Finishing and Labelling Stations.



After further simplification, the failure Factors of the all stations are in serial Connection with each other. The sum off all the failure Factors is added up and the formula for the total Availability is applied and the final Availability is Calculated.

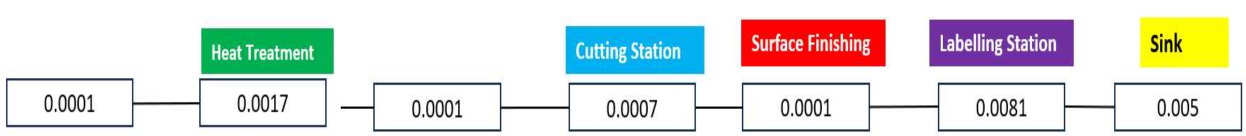


Figure 24: Availability calculations of Layout -2

$$\sum K(\text{total}) = 0.0158$$

$$V = \frac{1}{1+k}$$

$$V = \frac{1}{1+0.0158}$$

$$V = 0.9844$$

$$V = 98.44\%$$

The Availability of the system is **98.44%.**

8 TECHNICAL CALCULATIONS:

The number of machines and utilization can be calculated by using the processing times and quantity produced per hour. Moreover, the problem statement also defines the random distribution of blanks. After pre-processing 50% of the blanks will be heat treated, 95% will be cut into bars and only 65% of the bars move onto the surface finishing process.

8.1 Throughput Calculations:

The throughput (Q_{limit}) is the rate at which the machine produces the good within a specified period of time. Below is the formula for calculating the throughput;

$$\text{Throughput of } GS\ (Qlimit) = \left(\frac{60 \text{ mins}}{120 \text{ mins}}\right) \times 4 \text{ attritors}$$

$$\text{Throughput of } GS\ (Qlimit) = 2 \text{ attritors}$$

8.2 Number of Machines:

Therefore, in an hour GS produces 2 attritors. Furthermore, we also need required throughput ($Q_{Required}$); which is the total number of blanks/bars we need to produce per hour. Thus, the number of machines that are required can be calculated by;

However, they do not fulfill the required throughput of 30 blanks /hour or 90 bars/hour. Also, it is assumed that 1 attritor will produce 1 blank therefore;

$$Number\ of\ Grinding\ stations\ (GS) = \frac{Q_{Required}}{Q_{limit}} = \frac{32\ blanks/hour}{2\ attr/hour}$$

However, they do not fulfill the required throughput of 30 blanks /hour or 90 bars/hour. Also, it is assumed that 1 attritor will produce 1 blank therefore;

$$Number\ of\ Grinding\ stations\ (GS) = 16\ machines\ (20\ machines)$$

8.3 Utilization Calculations:

As a result, 16 machines are required for grinding stations. However, having exactly 16 machines would result in 100% utilization, meaning that the failure of any machine could lead to a loss of throughput. To mitigate this issue, extra machines are added. Consequently, the utilization is:

$$Utilization\ of\ GS = \frac{Q_{Required}}{Q_{limit} \times No.of\ machines} = \frac{32}{2 * 20} \approx 0.8$$

The calculation for the rest of machines is done in the same way and given in below table:

Table 2: Calculation of throughput, number of machines and utilization

Machines	Quantity produced	Processing Time (mins)	Throughput Q_{limit}	$Q_{(Required)}$	No. of machines required	Utilization
MS (attr/hr.)	4	10	24	32	4	0.33
MT (attr/hr.)	4	10	24	32	2	0.67
GS (attr/hr.)	4	120	2	32	20	0.80
MT (attr/hr.)	4	10	24	32	2	0.67
FAST (blanks/hr.)	4	90	3	16	10	0.60
CIPSHIP (blanks/hr.)	4	120	2	16	12	0.67
MT (blanks/hr.)	4	10	24	32	2	0.67
QS (blanks/hr.)	1	5	12	32	4	0.67
HT (blanks/hr.) (50% blanks)	1	30	2	16	12	0.67
CS (blanks/hr.) (95% blanks)	1	4	15	30	4	0.51
SFS (bars/hr.) (65% bars)	1	3	20	62	6	0.52
LS (bars/hr.)	1	1	60	96	3	0.53

Since the Utilization of the Heat Treatment machine is higher than most of all the post processing machines. Therefore, throughput of the system will be the throughput of the Heat Treatment system which is 1.3 blanks/hour.

8.4 Waiting elements calculations:

Numbers of waiting elements are calculated for all the serving systems which are diverters and Processing stations. For this purpose, utilization which was calculated previously was used.

For Processing Stations:

Table 3: Utilization of machines.

Machines	Utilization (P)
MX (attr/hr.)	0.33
MT (attr/hr.)	0.67
GS (attr/hr.)	0.80
MT (attr/hr.)	0.67
FAST (blanks/hr.)	0.60
CIPSHIP (blanks/hr.)	0.67
MT (blanks/hr.)	0.67
QS (blanks/hr.)	0.67
HT (blanks/hr.)	0.67
CS (blanks/hr.)	0.51
SFS (bars/hr.)	0.52
LS (bars/hr.)	0.53

Following formula is used to calculate the waiting area for the stations;

$$\mathbf{P(n = k) = P^k . (1 - P)}$$

Table 4: Calculation of waiting area for post-processing.

Machines	K	0	1	2	3	4
HT (blanks/hr.)	P(n=k)	0.33	0.22	0.15	0.10	0.07
	cumulative P(n=k)	0.33	0.56	0.70	0.80	0.87
CS (blanks/hr.)	P(n=k)	0.49	0.25	0.13	0.06	0.03
	cumulative P(n=k)	0.49	0.74	0.87	0.93	0.97
SFS (bars/hr.)	P(n=k)	0.48	0.25	0.13	0.07	0.04
	cumulative P(n=k)	0.48	0.73	0.86	0.93	0.96
LS (bars/hr.)	P(n=k)	0.47	0.25	0.13	0.07	0.04
	cumulative P(n=k)	0.47	0.72	0.85	0.92	0.96

Since, we require 80% blockage free. Therefore, the waiting area value will be is k – 1. Green highlighted are the waiting areas for the respective system.

8.5 Calculation of Waiting Rooms for Diverters:

8.5.1 Layout 1 Diverters:

As the layout is Symmetrical, so considering just the above portion of the central conveyor for calculation of diverter waiting room. As some of the diverters have same calculations so just considering one of them and considering only the diverters which have different utilization have been considered. For example, only the diverters at the input of the heat treatment stations are considered and not the diverters at out.

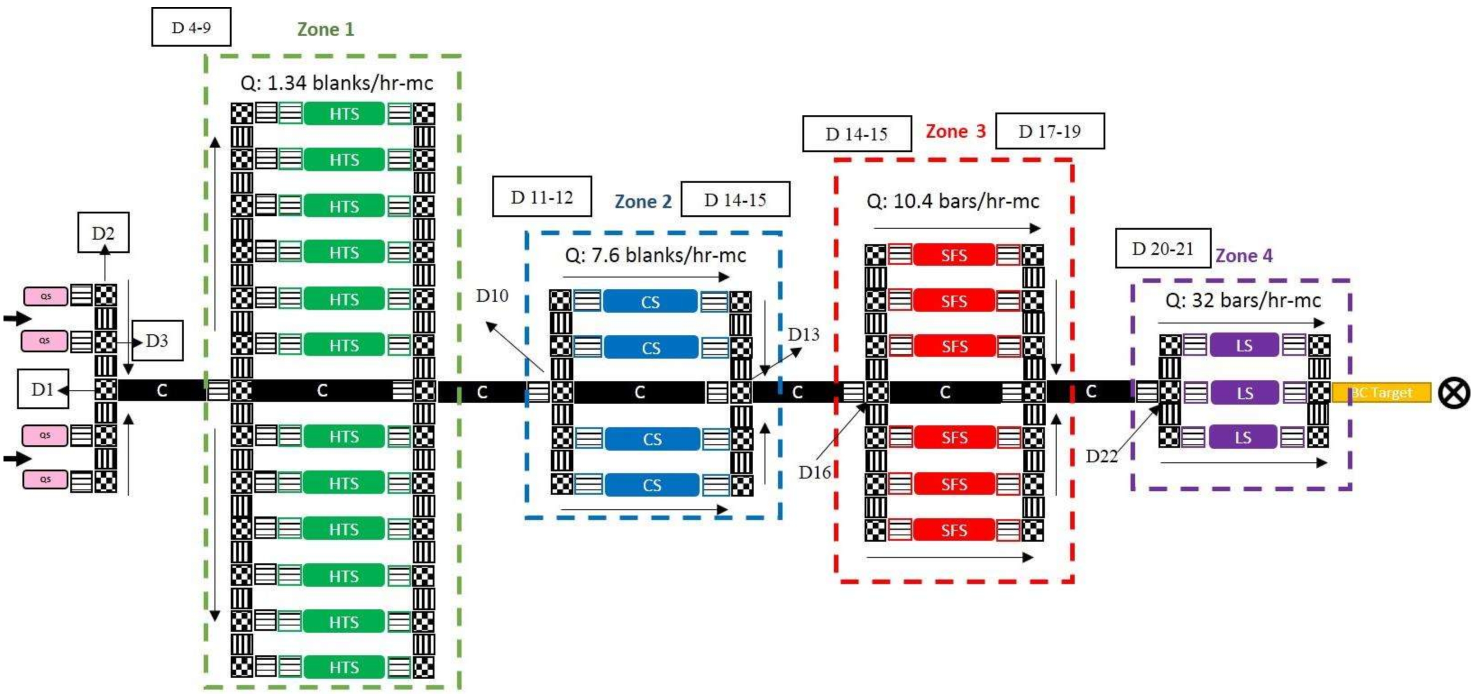


Figure 25: Identification of diverters for waiting area calculation (Layout 1).

Table 5: Calculation of utilization and waiting area for diverters (Layout – 1)

Diverters	Diverting Time (sec)	Throughput Limit $Q_{(Limit)}$	Required Throughput $Q_{(Required)}$	Utilization ρ	Waiting Room (80% blockage free) $\rho^k(1-\rho)$	For Value of "K"	Waiting Room (k-1)
D1	2	1800	32	0.0178	0.982	0	NA
D2	4	900	8	0.0089	0.991	0	NA
D3	3	1200	32	0.0267	0.973	0	NA
D4	3	1200	8	0.0067	0.993	0	NA
D5	3	1200	7	0.0058	0.994	0	NA
D6	3	1200	6	0.0050	0.995	0	NA
D7	3	1200	4	0.0033	0.997	0	NA
D8	3	1200	3	0.0025	0.998	0	NA
D9	4	900	2	0.0022	0.998	0	NA
D10	3	1200	32	0.0267	0.973	0	NA
D11	3	1200	7.5	0.0063	0.994	0	NA
D12	4	900	7.5	0.0083	0.992	0	NA
D13	3	1200	96	0.0800	0.92	0	NA
D14	4	900	22.5	0.0250	0.975	0	NA
D15	3	1200	22.5	0.0188	0.981	0	NA
D16	3	1200	96	0.0800	0.92	0	NA
D17	3	1200	10.4	0.0087	0.991	0	NA
D18	3	1200	10.4	0.0087	0.991	0	NA
D19	4	900	10.4	0.0116	0.988	0	NA
D20	3	1200	32	0.0267	0.973	0	NA
D21	4	900	32	0.0356	0.964	0	NA
D22	2	1800	96	0.0533	0.947	0	NA

We don't need waiting areas for any diverters for 80% blockage free operation. We have used one waiting area as a precaution in order to ensure proper functioning.

8.5.2 Layout 2 Diverters:

As the layout is Symmetrical, so considering just the above portion of the central conveyor for calculation of diverter waiting room. As some of the diverters have same calculations so just considering one of them and considering only the diverters which have different utilization have been considered. For example, only the diverters at the input of the heat treatment stations are considered and not the diverters at out.

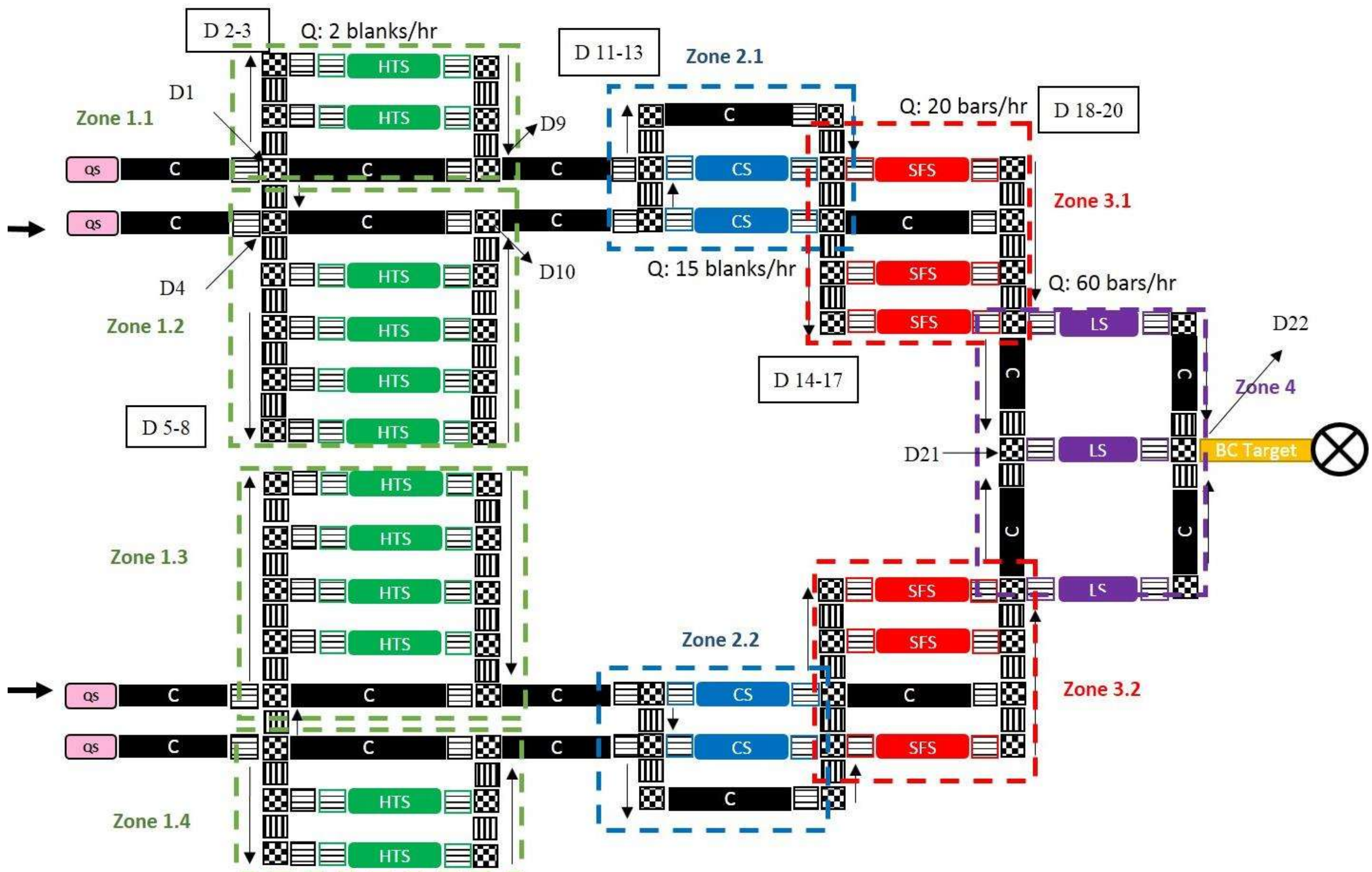


Figure 26: Identification of diverters for waiting area calculation (Layout 2)

Table 6: Calculation of utilization and waiting area for diverters (Layout – 2)

Diverters	Diverting Time (sec)	Throughput Limit $Q_{(Limit)}$	Required Throughput $Q_{(Required)}$	Utilization ρ	Waiting Room (80% blockage free) $\rho k(1-\rho)$	For Value of "K"	Waiting Room (k-1)
D1	3	1200	8	0.0067	0.993	0	NA
D2	3	1200	4	0.0033	0.997	0	NA
D3	2	1800	2	0.0011	0.999	0	NA
D4	3	1200	8	0.0067	0.993	0	NA
D5	3	1200	8	0.0067	0.993	0	NA
D6	3	1200	6	0.0050	0.995	0	NA
D7	3	1200	4	0.0033	0.997	0	NA
D8	2	1800	2	0.0011	0.999	0	NA
D9	4	900	8	0.0089	0.991	0	NA
D10	4	900	8	0.0089	0.991	0	NA
D11	3	1200	7.5	0.0063	0.994	0	NA
D12	3	1200	7.5	0.0063	0.994	0	NA
D13	2	1800	3	0.0017	0.998	0	NA
D14	3	1200	22.5	0.0188	0.981	0	NA
D15	3	1200	22.5	0.0188	0.981	0	NA
D16	3	1200	11.25	0.0094	0.991	0	NA
D17	2	1800	11.25	0.0063	0.994	0	NA
D18	4	900	16	0.0178	0.982	0	NA
D19	3	1200	27.25	0.0227	0.977	0	NA
D20	3	1200	48	0.0400	0.96	0	NA
D21	2	1800	32	0.0178	0.982	0	NA
D22	2	1800	96	0.0533	0.947	0	NA

We don't need waiting areas for any diverters for 80% blockage free operation. We have used one waiting area as a precaution in order to ensure proper functioning.

8.6 Waiting Time and Number of tasks in the waiting area:

Furthermore, the Total waiting time of the element and number of tasks in the waiting area are calculated below:

Table 7: Waiting time and number of tasks in the waiting room.

Stations	No. of Taks in waiting area M(w)	t (arrival) t arrival = 1 / Q req	Mean waiting time in waiting area T(w) Sec T(w) = M(w) * t arrival	Mean Waiting time in system T(wc) sec
HT	1.33	0.021	100.8	153.49
CS	0.520	0.011	21.4	42.15
SFS	0.563	0.016	32.4	62.40
LS	0.610	0.010	21.9	41.14

The total time in the existing system can be calculated by adding Mean waiting time in waiting area and mean waiting time in system which is **299.18 sec**.

8.7 Power Calculations:

After creating layouts, power calculations were initially performed for steel. However, following discussions with the RECOM group, these calculations were modified for aluminum material. Additionally, power calculations for diverters and accumulators were also conducted.

A: Meter Weight of Goods:

The conveyor is responsible for carrying blanks, and it must withstand the force applied by the blanks. The material of the blanks is a critical factor, as the mass of the blanks directly influences the pressure exerted. The formula used for this purpose is:

$$q_{goods} = \frac{m_{goods \times g}}{l_{goods}}$$

Initially, we selected steel as the material with the density of 7800 kg/m^3. The volume of the steel blanks can be determined using the radius (r) of 0.02 m and length (l) of 0.4 m. Therefore, mass can be calculated using the following formula.

$$m = volume \ \times density$$

$$volume = \pi \times r^2 \times l$$

$$m = 1.96 \ kg$$

B: Meter weight of tension device:

The meter weight of the tension device which is calculated by the mass of the belt (m_{belt}); which is identified by the material of the selected belt. Since we have chosen a belt conveyor, its mass is measured in kg/m^2 therefore, the width of the belt (B) is also considered. Followed by the value of gravitational acceleration (g). All the units are taken in SI system.

$$q_{belt} = m_{belt} \times B \times g$$

$$q_{belt} = 22.07 \frac{N}{m}$$

C: Meter weight of Idler:

The meter weight of idler is calculated by the mass of idler, gravitational acceleration and distance between the two idlers (l_{idler}).

$$q_{idler} = \frac{m_{idler} \times g}{l_{idler}}$$

D: Resistance force calculations:

All the previously calculated values will be utilized to compute various resistance forces acting on the conveyor, including Main resistance (running or frictional resistance) (F_H), slope resistance (F_{st}), and Acceleration resistance (F_{Acc}).

The following formulas are employed to calculate motion resistance for the return belt stand. In our scenario, the slope resistance F_{st1} will be zero as there is no inclination in the conveyor.

$$F_{H1} = q_{belt} . L .cos\, cos\, (\delta) . \mu_g + q_{idler} . L . 0.02$$

$$F_{st1} = q_{belt} . L .sin\, sin\, (\delta)$$

The following formulae is used to calculate the motion resistance in conveying stand. In our case, the F_{st2} will be zero as there is no inclination in the conveyor.

$$F_{H2} = (q_{good} + q_{belt}) . L .cos\, cos\, (\delta) . \mu_g + q_{idler} . L . 0.02$$

$$F_{st2} = (q_{good} + q_{belt}) . L .sin\, sin\, (\delta)$$

After calculating all the necessary forces, a total force is calculated;

$$F_{total} = F_{H1} + F_{H2} + F_{st1} + F_{st2}$$

Now, Acceleration resistance ($a_{a,b}$) is calculated, by taking the startup (t_a) and braking time (t_b) and given velocity of the conveyor.

$$F_{Acci} = L_i . a_{a,b} . \left(c_R . \frac{q_{idler}}{g} + \frac{q_{belt}}{g} + \frac{q_{good}}{g} \right)$$

Starting factor K_A is determined using the formula;

$$\frac{F_{Total} + F_{Acc}}{F_{Total}} < K_A$$

If the value of $K_{A\ present}$ is ≤ K_{Areq} then we have to use the formula, where η_{drive} is the efficiency of the drive of the motor which in our case it is $\eta_{drive} = 0.91$;

$$P_M = \frac{F_{Total} \cdot v}{\eta_{drive}}$$

8.7.1 Power calculation for Layout 1:

Using the above formulas, the power calculation for layout 1 was determined. Due to the varying sizes of conveyors, necessary adjustments were made (see appendix for reference). Below is a summary of the power calculation for layout 1.

Table 8: Power calculation for conveyors - Layout 1

Location	Number of Conveyor	Length of Conveyor (m)	Idler Spacing (l)	Num of Idlers	Idler spacing actual (m)	Power for one Conveyor (Watt)	Total Power Consumption (Watt)
STEEL							
Heat Treatment	1	3.556	1.45	3	1.05	101	101
Before CS	2	1.778	1.45	2	0.80	51	102
CS	1	2.794	1.45	3	0.98	80	80
After CS	2	1.778	1.45	2	0.80	21	42
SFS	1	2.794	1.45	3	0.98	32	32
Total Power required by all the conveyors to carry steel blanks/bars							**357**
ALUMINUM							
Heat Treatment	1	3.556	1.45	3	1.05	43	43
Before CS	2	1.778	1.45	2	0.80	22	44
CS	1	2.794	1.45	3	0.98	34	34
After CS	2	1.778	1.45	2	0.80	11	22
SFS	1	2.794	1.45	3	0.98	17	17
Total Power required by all the conveyors to carry Aluminum blanks/bars							**160**

Table 9: Power calculation for divertors and accumulators – Layout 1

Number of elements	Length of elements (m)	Power for one Conveyor (Watt)	Total Power Consumption (Watt)
STEEL			
36	0.5	14	504
80	0.5	14	1120
25	0.5	6	150
46	0.5	6	276
Total Power required by the accumulators and diverters (steel)			**2050**
ALUMINUM			
36	0.5	6	216
80	0.5	6	480
25	0.5	3	75
46	0.5	3	138
Total Power required by the accumulators and diverters (Aluminum)			**909**

Table 10: Power calculation summary- Layout 1

Power Calculation Summary (Layout 1)			
Elements	**Total Elements**	**Length (m)**	**Power of elements (Watts)**
STEEL			
Conveyors	7	16.26	417
Diverters	61	30.5	654
Accumulators	126	63	1396
Total Power Watts (STEEL)			**2467**
ALUMINUM			
Conveyors	7	16.26	160
Diverters	61	30.5	291
Accumulators	126	63	618
Total Power Watts (ALUMINUM)			**1069**

8.8 Power calculation for Layout 2:

There are conveyors of different sizes that are used in the layout therefore it will have a different power consumption.

Table 11: Power calculation of conveyors - Layout 2

Location	Number of Conveyors	Length of Conveyor (m)	Idler Spacing (m)	Num of Idlers	Idler spacing actual (m)	Power for one Conveyor (Watt)	Total Power Consumption (Watt)
STEEL							
Heat Treatment	4	3.556	1.45	3	1.03	101	404
QS and after Heat Treatment	8	1.778	1.45	2	0.80	51	408
CS	2	2.794	1.45	3	0.95	80	160
SFS	2	2.794	1.45	3	0.95	32	64
LS	4	1.778	1.45	2	0.80	21	84
Total Power required by all the conveyors to carry steel blanks/bars							**1120**
ALUMINUM							
Heat Treatment	4	3.556	1.45	3	1.03	43	172
QS and after Heat Treatment	8	1.778	1.45	2	0.80	22	176
CS	2	2.794	1.45	3	0.95	34	68
SFS	2	2.794	1.45	3	0.95	17	34
LS	4	1.778	1.45	2	0.80	11	44
Total Power required by all the conveyors to carry aluminum blanks/bars							**494**

Table 12: Power calculations for accumulators & divertors -Layout 2

Number of elements	Length of elements (m)	Power for one Conveyor (Watt)	Total Power Consumption (Watt)
STEEL			
40	0.5	14	560
86	0.5	14	1204
20	0.5	6	120
40	0.5	6	240
Total Power required by the accumulators and diverters (steel)			**2124**
ALUMINUM			
40	0.5	6	240
86	0.5	6	516
20	0.5	3	60
40	0.5	3	120
Total Power required by the accumulators and diverters (Aluminum)			**936**

Table 13: Power calculation summary - Layout 2

Power Calculation Summary (Layout 2)			
Elements	**Total Elements**	**Length in (m)**	**Power of elements**
STEEL			
Conveyors	20	46.7	1120
Diverters	60	30	680
Accumulators	126	63	1444
Total Power Watts (Steel)			**3244**
ALUMINUM			
Conveyors	20	46.7	494
Diverters	60	30	300
Accumulators	126	63	636
Total Power Watts (Aluminum)			**1430**

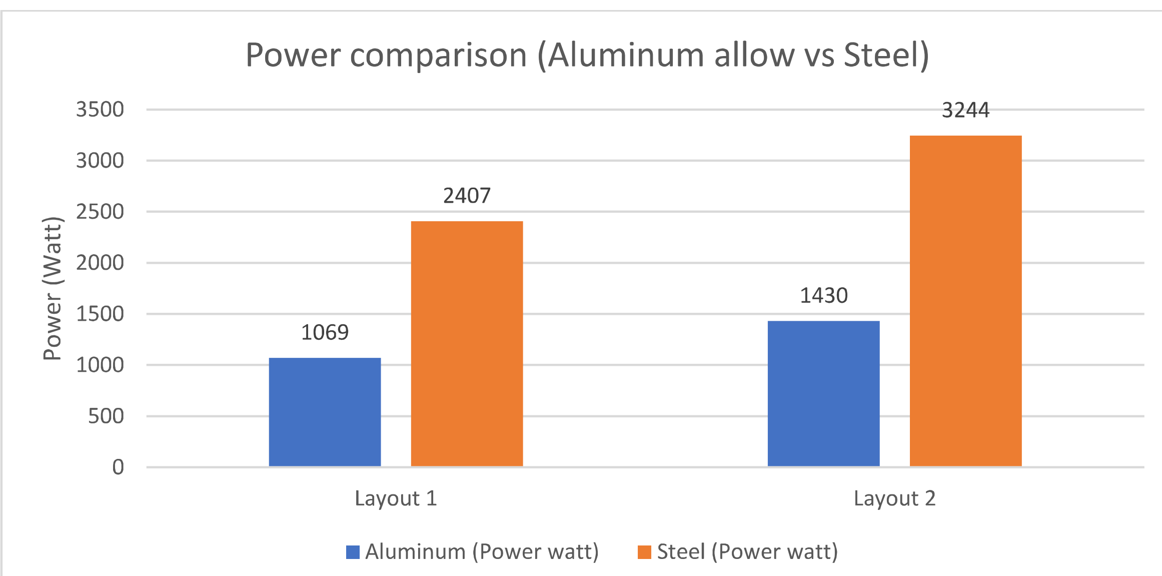


Figure 27: Comparison of power consumption

Below is the power calculation for conveyor, accumulators and diverters are done on Smath Studios.

Calculation Example 1: ROLLER AND BELT CONVEYOR FOR GENERAL CARGO (conveyors)

Conveyor length: $L_{BC} := 1.778\ \mathrm{m}$

Inclination: $\delta_{BC} := 0\ °$

Speed: $v_{BC} := 0.2\ \frac{\mathrm{m}}{\mathrm{s}}$

Startup time: $t_{aBC} := 3\ \mathrm{s}$

Data belt conveyor:

Belt properties: $m_{belt} := 4.5\ \frac{\mathrm{kg}}{\mathrm{m}^2}$ $\quad B := 500\ \mathrm{mm}$ $\quad \mu_g := 0.3$

Moving masses in return strand of belt conveyor:

$m_{idlerBC} := 5\ \mathrm{kg}$ $\quad l_{idlerBC} := 0.8\ \mathrm{m}$

Drive efficiency: $\eta_{driveBC} := 0.91$

Data goods: plastic containers filleds with different goods

$m_{good} := 0.6533\ \mathrm{kg}$ $\quad l_{goods} := 0.05\ \mathrm{m}$

SOLUTION: $g := 9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}$

Meter weights:

$$q_{good} := \frac{m_{good} \cdot g}{l_{goods}} = 128.1775\ \frac{\mathrm{N}}{\mathrm{m}} \qquad q_{idlerBC} := \frac{m_{idlerBC} \cdot g}{l_{idlerBC}} = 61.3125\ \frac{\mathrm{N}}{\mathrm{m}}$$

$$q_{belt} := m_{belt} \cdot B \cdot g = 22.07\ \frac{\mathrm{N}}{\mathrm{m}}$$

Belt conveyor:

Motion resistances in return strand:

$$F_{H1} := q_{belt} \cdot L_{BC} \cdot \cos\left(\delta_{BC}\right) \cdot \mu_g + q_{idlerBC} \cdot L_{BC} \cdot 0.02 = 13.95\ \mathrm{N}$$

$$F_{St1} := -q_{belt} \cdot L_{BC} \cdot \sin\left(\delta_{BC}\right) = 0$$

Motion resistances in conveying strand:

$$F_{H2} := \left(q_{good} + q_{belt}\right) \cdot L_{BC} \cdot \cos\left(\delta_{BC}\right) \cdot \mu_g = 80.14\ \mathrm{N}$$

$$F_{St2} := \left(q_{good} + q_{belt}\right) \cdot L_{BC} \cdot \sin\left(\delta_{BC}\right) = 0$$

$$F_{totalBC} := F_{H1} + F_{H2} + F_{St1} + F_{St2} = 94.1\ \mathrm{N}$$

$$a_{aBC} := \frac{v_{BC}}{t_{aBC}} = 0.0667\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

$$F_{AccBC} := 2 \cdot L_{BC} \cdot a_{aBC} \cdot \left(0.9 \cdot \frac{q_{idlerBC}}{g} + \frac{q_{good}}{g} + \frac{q_{belt}}{g}\right) = 4.96\ \mathrm{N}$$

$$\frac{F_{totalBC} + F_{AccBC}}{F_{totalBC}} = 1.0528$$

$$P_{MBC} := \frac{F_{totalBC} \cdot v_{BC}}{\eta_{driveBC}} = 21\ \mathrm{W}$$

9 COMPARISON OF BOTH LAYOUTS:

Table 14: Comparison of two Layouts.

Layout 1	Layout 2
Disadvantage: The availability of layout 1 is **77.31%.**	**Advantage:** The availability of layout 2 is **98.44%**
Advantage: There are lesser number of Conveying elements in the layout 1. Number of conveyors is: 7 Number of Diverters is: 61 Number of Accumulators: is 126	**Disadvantage**: The number of conveyors in layout 2 are higher than Layout 1. Number of conveyors is: 20 Number of Diverters is: 60 Number of Accumulators is: 126
Advantage: Given that the number of conveying elements is fewer than in layout 2, the power consumption for layout 1 is 2467 watts for steel and 1069 watts for aluminum.	**Disadvantage**: The power consumption for steel is 3244 watts and for aluminum is 1430 watts.
Disadvantage: With only one central conveyor in operation, there will be a high traffic of material. Consequently, proper preventive maintenance is essential to ensure smooth and uninterrupted operations.	**Advantage**: The use of separate conveyors for each quality station reduces material traffic.
Advantage: The floor space is less.	**Disadvantage:** The floor space is higher than layout 1.
Disadvantage: Layout 1 has less numbers of parallel connections.	**Advantage:** carries high number of parallel connections and lesser number of series connection.

Final Verdict:

Based on the above comparisons, we have decided to opt for layout 2. Although, it has higher power consumption due to the large number of conveying elements and requires large floor space, it has higher availability and a higher number of parallel connections.

10 COLLABORATION BETWEEN RECOM, DAMHS & EDEC GROUP:

The DAMHS (Digitization and Automation of Material Handling Systems) group collaborated with the EDEC (Establishing Digital Engineering chains) and RECOM (Requirements, Considerations, and selection of materials along engineering chains) groups, shared data regarding process times and components used in the system. The RECOM group was responsible for evaluating the detailed timing for post-processing steps and quality control steps and provided this data to the DAMHS group. The DAMHS group, in turn, gave the RECOM group information about all planned material handling systems and the total times and waiting times of the serving systems. Additionally, the RECOM group calculated the temperature of steel bars entering the post-processing station. The DAMHS group then compared the timing given by the RECOM group with the developed layout, suggested any necessary changes and improvised the layout based on the data obtained. The DAMHS group also provided the EDEC group with data on all conveyors used, to create complete documentation of the material handling system and overall manufacturing process. This information was used by the EDEC group to define the administration shell.

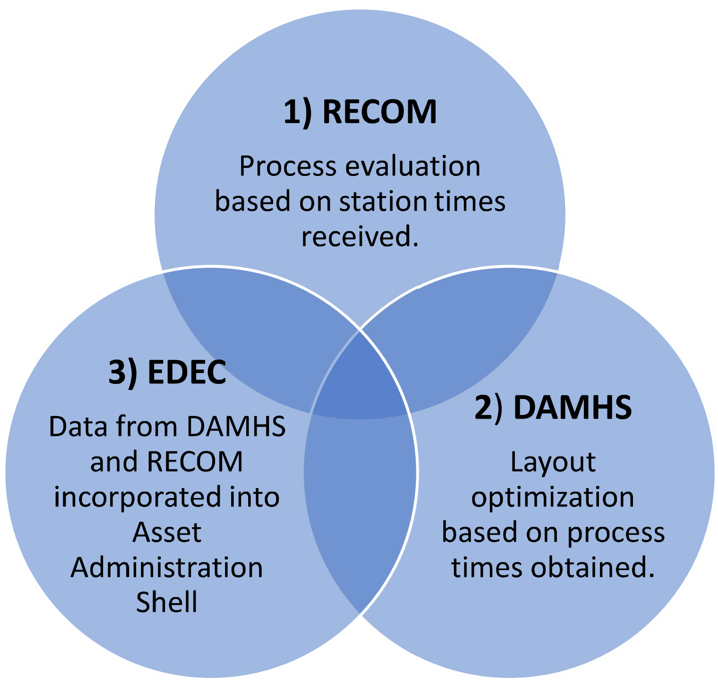


Figure 28: Collaboration between RECOM, DAMHS & EDEC groups

10.1 Collaboration with RECOM:

After discussion with RECOM group, we got to know that they have selected "2618 Aluminum Alloy" material for manufacturing of blanks which will be further used for making High Performance Race car Pistons. In order to achieve their desired microstructure, they have modified the compaction process of powdered material. RECOM group will be using sintering process. This led to change in compaction time from 90 minutes/blank to 120 minutes/blank. All other pre-processing and post-processing times were same which did not affect our calculations.

Due to this change in time, number of compaction machines were changed in order to achieve our required throughput.

Table 15: Evaluation of number of machines based on RECOM modifications

<table>
<tr><th>S. No</th><th>Process Name</th><th>Number of stations Before RECOM</th><th>Number of Stations after RECOM Changes</th></tr>
<tr><td>1</td><td>Mixing Station</td><td>4</td><td>4</td></tr>
<tr><td>2</td><td>Grinding stations</td><td>20</td><td>20</td></tr>
<tr><td>3</td><td>FAST</td><td>10</td><td rowspan="2">N/A</td></tr>
<tr><td>4</td><td>CIPSHIP</td><td>12</td></tr>
<tr><td>5</td><td>Sintering (FAST + CIPSHIP)</td><td>-</td><td>18</td></tr>
<tr><td>6</td><td>Quality Station</td><td>4</td><td>4</td></tr>
<tr><td>7</td><td>Heat Treatment Station</td><td>12</td><td>12</td></tr>
<tr><td>8</td><td>Cutting Station</td><td>4</td><td>4</td></tr>
<tr><td>9</td><td>Surface Finishing</td><td>6</td><td>6</td></tr>
<tr><td>10</td><td>Labeling Station</td><td>3</td><td>3</td></tr>
</table>

10.2 Collaboration with EDEC:

10.2.1 List of Components according to Asset Administration Shell (EDEC):

The following data was shared to the EDEC group to be documented through the asset administration shell. The data from DAMHS mainly recognizes the number of components in both layouts. This is important to maintain records and find out operating efficiency of the layouts. Similarly, accurate processing times were also shared by the RECOM group to EDEC for documentation. This data is combined when the results from the AAS are obtained.

Table 16: List of components for process

<table>
<tr><th colspan="9">Process Report</th></tr>
<tr><th>Sr. No.</th><th>Type</th><th>View Concept</th><th>Identification</th><th>Product Design</th><th>Function Design</th><th>Mechanical Engineering</th><th>Electrical Engineering</th><th>Automation Engineering</th></tr>
<tr><td>1</td><td>Process</td><td>Mixing of the Powder</td><td rowspan="3">• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td rowspan="2">• ViewID
• Cycle Time
• Estimated Time
• Measured Time
• Capacity
• Sequencing Mode
• Throughput
• Process Cost
• Man Hours</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Process</td><td>Mechanical Alloying of The Powder</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>Process</td><td>Hot Isostatic Pressing</td><td>• View ID
• Total time
• Process sequence
• Throughput Time
• Estimated Cost
• Capacity
• Cycle Time</td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>Process</td><td>Quality Control</td><td>• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td>• ViewID
• Cycle Time
• Estimated Time
• Measured Time
• Capacity
• Throughput
• Process Cost
• Man Hours</td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>Process</td><td>Heat Treatment by Quenching</td><td>• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td>• ViewID
• Cycle Time
• Estimated Time
• Capacity
• Process Cost
• Man Hours</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>Process</td><td>Abrasive Water Jet Cutting</td><td>• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td rowspan="2">• View ID
• Cycle Time
• Estimated Time
• Measured Time
• Capacity
• Sequencing Mode
• Throughput
• Process Cost
• Man Hours</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td>Process</td><td>Shot Blasting and Polishing</td><td>• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>Process</td><td>Labelling</td><td>• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td>• View ID
• Estimated Cost
• Material
• Material Grade</td><td></td><td></td><td></td><td></td></tr>
<tr><td>9</td><td>Process</td><td>Optical Check</td><td>• ProcessID
• Workstation Number
• Process Name
• Process Description</td><td>• View ID
• Cycle Time
• Estimated Time
• Measured Time
• Capacity
• Sequencing Mode
• Throughput
• Process Cost</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 17: List of components for product

Product Report								
Sr. No.	**Type**	**View Concept**	**Identification**	**Product Design**	**Function Design**	**Mechanical Engineering**	**Electrical Engineering**	**Automation Engineering**
1	Product	2618 Aluminum Alloy	• ProductID • ProductName • Product Type • Serial Number	• ViewID • Estimated Cost • Material • Material Grade				
2	Product	Alloyed Powder						
3	Product	Milled Powder	• ProductID • ProductName • Product Type	• ViewID • Material • Chemical Composition • Material Grade • Material Density				
4	Product	Bar Stock		• View ID • Material properties • Material Composition • Temperature • Formability				
5	Product	QC Passed Aluminum Bar	• ProductID • ProductName • Product Type • Serial Number	• View ID • Material Properties • Material Chemical Composition • Material Purity Level • Material Grade • Dimensions				
6	Product	Quenched Aluminum Bar	• Product ID • Product Name • Product Type	• ViewID • Estimated Cost • Material • Material Grade				
7	Product	Aluminum Bars of Required Length	• ProductID • ProductName • Product Type • Serial Number	• View ID • Estimated Cost • Material • Material Grade • Temperature of the bar • Length				
8	Product	Surface finished Aluminum Bar						
9	Product	Labelled Aluminum Bar		• View ID • Material • Material Grade • Estimated Cost				
10	Product	Final Product		• View ID • Estimated Cost • Material • Material Grade • Temperature of the bar • Length				

Table 18: List of components for resources (sensors)

Resources (Sensors)								
Sr. No.	**Type**	**View Concept**	**Identification**	**Product Design**	**Function Design**	**Mechanical Engineering**	**Electrical Engineering**	**Automation Engineering**
1	Resource	Speed Sensor	• AssetID • Manufacturer Name • Manufacturer Type Name • Manufacturer Type Description • Type Class • Serial Number • Device Revision • Hardware Revision • Software Revision		• ViewID • Purchase Cost • Repair Cost • Mean Time to Failure • Calculated Cycle Time	• ViewID • Dimensions • Weight	• ViewID • Power Supply • Voltage • Connection Wire	• ViewID • Accuracy • Resolution Range
2	Resource	Temperature Sensor	• AssetID • Manufacturer Name • Manufacturer Type Name • Manufacturer Type Description • Type Class • Serial Number • Device Revision		• ViewID • IP Rating • Purchase Cost • Mean Time to Failures • Calculated Cycle Time • Target Cycle Time Regulation • Operating Temperature • Measurement Range	• ViewID • Weight • Dimensions • Material	• ViewID • Signal Input • Power Supply • Input Wiring • Nominal Resistance	• ViewID • Maximum. • Junction • Temperature • Accuracy • Resolution • Sample Period
3	Resource	Abrasive Level Sensor			• ViewID • Type • Coverage • Class • Range • Purchase Cost • Operating Temperature	• ViewID • Dimensions	• ViewID • Supply Voltage • Power Supply	• ViewID • Accuracy • Resolution • Maximum. • Range
4	Resource	Proximity Sensor			• ViewID • IP Rating • Purchase Cost • Mean Time to Failure • Calculated Cycle Time • Target Cycle Time Regulation • Operating Temperature • Measurement Range	• ViewID • Weight • Dimensions • Material	• ViewID • Signal Input • Power Supply • Input Wiring	• ViewID • Accuracy • Resolution • Sample Period • Relative Distance
5	Resource	Light Barrier Sensors	• Asset ID • Manufacturer Name • Manufacturer Type • Manufacturer Description • Type Class • Serial Number • Device & Hardware Revision		• View ID • IP Rating • Purchase Cost • Mean Time to Failure • Calculated Cycle Time • Target Cycle Time Regulation • Operating Temperature • Measurement Range	• View ID • Length • Width • Height • Capacity • Weight	• View ID • Supply Voltage • Supply Current	• View ID • Max Range
6	Resource	Optical Sensor	• AssetID • Manufacturer Name • Manufacturer Type Name • Manufacturer Type Description • Type Class • Serial Number • Device Revision • Hardware Revision • Software Revision		• ViewID • IP Rating • Purchase Cost • Mean Time to Failure • Calculated Cycle Time • Target Cycle Time	• ViewID • Weight • Dimensions • Material	• ViewID • Signal Input • Power Supply • Input Wiring	• ViewID • Accuracy • Resolution • Relative Distance • Maximum Range
7	Resource	Imaging Sensors	• Asset ID • Manufacturer Name • Manufacturer Type • Manufacturer Description • Type Class • Serial Number • Device & Hardware Revision		• View ID • Setup Time • Mean Time Between • Failures • Mean Time to Repair • Maintenance Time • Purchase Cost • Repair Cost • Maintenance Cost • Estimated Lifetime • Energy Cost	• View ID • IP Rating • Length • Height • Width • Weight • Range • Field of View • Mounting • Mechanism • Structural • Support • Vibration Resistance	• View ID • Supply Voltage • Supply Current	• View ID • Max Range • Max Resolution • Max Accuracy

Table 19: List of components resources (machines)

<table>
<tr><th colspan="9">Resources (Machines)</th></tr>
<tr><th>Sr. No.</th><th>Type</th><th>View Concept</th><th>Identification</th><th>Product Design</th><th>Function Design</th><th>Mechanical Engineering</th><th>Electrical Engineering</th><th>Automation Engineering</th></tr>
<tr><td>1</td><td>Resource</td><td>Mixer Device</td><td>• Asset ID
• Manufacturer Name
• Manufacturer Description
• Serial number
• Device revision</td><td></td><td rowspan="2">• ViewID
• Mean Time to Repair
• Mean Time Between Failures
• Purchase cost
• Repair cost
• Maintenance cost
• Capacity</td><td>• ViewID
• Dimensions
• Material</td><td></td><td>• ViewID
• State</td></tr>
<tr><td>2</td><td>Resource</td><td>Grinding Chamber</td><td>• Asset ID
• Manufacturer Name
• Manufacturer Description
• Serial number
• Device revision</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>Resource</td><td>Hot Isostatic Pressing Machine</td><td rowspan="3">• AssetID
• Manufacturer Name
• Manufacturer Type Name
• Manufacturer Type
• Description
• Type Class
• Serial Number
• Device Revision
• Hardware Revision
• Software Revision</td><td></td><td>• ViewID
• Mean Time to Repair
• Mean Time Between Failures
• Purchase cost
• Repair cost
• Maintenance cost
• Capacity</td><td>• View ID
• Dimensions</td><td>• ViewID
Power Supply</td><td>• View ID
• Max Temperature</td></tr>
<tr><td>4</td><td>Resource</td><td>Quality Control Unit</td><td></td><td>• ViewID
• Maintenance cost
• Purchase cost
• Mean Time to repair.
• Mean Time Between Failures
• Efficiency</td><td>• View ID
• Weight
• Dimensions
• Material</td><td>• ViewID
• Power Supply
• Voltage</td><td>• ViewID
• Accuracy
• Required Quality</td></tr>
<tr><td>5</td><td>Resource</td><td>Ultrasonic Testing Machine</td><td></td><td>• ViewID
• Mean Time Between Failures
• Mean Time to Repair
• Purchase Cost
• Repair Cost
• Maintenance Cost
• Energy Cost</td><td>• ViewID
• Height
• Weight
• Length
• Material</td><td>• ViewID
• Power Supply</td><td>• View ID
• Accuracy</td></tr>
<tr><td>6</td><td>Resource</td><td>Heat Exchanger</td><td>• AssetID
• Manufacturer Name
• Manufacturer Type Name
• Manufacturer Type
• Description
• Type Class
• Serial Number
• Device Revision
• Hardware Revision
• Software Revision</td><td></td><td>• View ID
• Capacity
• Cooling rate
• Operating system
• Volumetric flow rate
• Purchase cost
• Maintenance cost
• Mean Time Between Failures
• Mean Time to Repair
• Estimated lifetime</td><td>• View ID
• Length
• Height
• Width
• Pressure
• Coolant
• Volume of the Cylinder
• Max Operating Pressure
• Material</td><td></td><td>• View ID
• Minimum Temperature
• Maximum Temperature</td></tr>
<tr><td>7</td><td>Resource</td><td>Abrasive Water Jet Cutting Machine</td><td>• AssetID
• Manufacturer Name
• Manufacturer Type Name
• Manufacturer Type
• Description
• Type Class
• Serial Number
• Device Revision
• Hardware Revision
• Software Revision</td><td></td><td>• ViewID
• Mean Time Between Failures
• Mean Time to Repair
• Purchase Cost
• Repair Cost
• Maintenance Cost Energy
• Cost
• Operating temperature
• Cutting speed</td><td>• ViewID
• Dimensions
• Material</td><td>• ViewID
• Supply Voltage
• Supply Current</td><td>• ViewID
• Maximum Temperature
• Maximum cutting speed</td></tr>
<tr><td>8</td><td>Resource</td><td>Shot Blasting and Polishing Machine</td><td>• Asset ID
• Manufacturer Name
• Manufacturer Type
• Manufacturer Description
• Type Class
• Serial Number
• Device & Hardware Revision</td><td></td><td>• View ID
• Setup time
• Target cycle time
• Calculated cycle time
• Maximum Throughput
• Mean time between Failures
• Mean time to repair
• Purchase cost
• Repair cost
• Maintenance cost
• Energy cost</td><td>• View ID
• Height
• Length
• Width
• Capacity
• Volume of
• Chamber
• Gross Weight Material</td><td>• View ID
• Supply Voltage
• Supply Current</td><td>• View ID
• Max Temperature</td></tr>
<tr><td>9</td><td>Resource</td><td>Labelling Machine</td><td>• AssetID
• Manufacturer Name
• Manufacturer Type Name
• Manufacturer Type
• Description
• Type Class
• Serial Number
• Device Revision
• Hardware Revision
• Software Revision</td><td></td><td>• View ID
• Target cycle time
• Cycle time
• Maximum Throughput
• Mean time between failures
• Mean time to repair
• Purchase cost
• Repair cost
• Maintenance cost
• Energy cost
• Movement Speed</td><td>• ViewID
• Dimensions
• Weight</td><td>• ViewID
• Supply Voltage
• Supply Current</td><td>• ViewID
• Maximum Labelling Speed</td></tr>
</table>

After working with the EDEC Group, we found that because their first assignment did not take the conveying system for the entire process into account, they were short on resources for the conveyor, divertor, accumulators, and sensors. After having an extended conversation and looking over the list of elements they had included in their Asset Administration Shell (AAS), we decided to make an additional list especially for our conveyance technology.

Table 20: Modification in list of components after collaboration

<table>
<tr><th>Sr. No.</th><th>Type</th><th>View Concept</th><th>Identification</th><th>Product Design</th><th>Function Design</th><th>Mechanical Engineering</th><th>Electrical Engineering</th><th>Automation Engineering</th></tr>
<tr><td>55</td><td>Resource</td><td>Conveyor</td><td rowspan="9">• AssetID
• Manufacturer Name
• Manufacturer Type
• Name
• Manufacturer Type
• Description
• Type Class
• Serial Number
• Device Revision
• Hardware Revision
• Software Revision</td><td></td><td>• ViewID
• Max Speed
• Max Acceleration
• Used Speed
• Used Acceleration
• Load Handling Capacity
• Maintenance Cost
• Purchase Cost
• Repair Cost</td><td>• ViewID
• Dimensions</td><td>• ViewID
Power Supply
Efficiency</td><td></td></tr>
<tr><td>56</td><td>Resource</td><td>Photoelectric Sensor</td><td></td><td>• ViewID
• Purchase Cost
• Repair Cost
• Mean Time to Failure
• Calculated Cycle Time</td><td>ViewID
Dimensions
Weight</td><td>• ViewID
Power Supply
Voltage
Connection
Wire</td><td>• ViewID
Accuracy
Resolution
Range</td></tr>
<tr><td>57</td><td>Resource</td><td>Divertor</td><td></td><td rowspan="2">• ViewID
• Max Speed
• Max Acceleration
• Used Speed
• Used Acceleration
• Load Handling Capacity
• Maintenance Cost
• Purchase Cost
• Repair Cost</td><td>• ViewID
Dimensions</td><td>• ViewID
Power Supply
Efficiency</td><td></td></tr>
<tr><td>58</td><td>Resource</td><td>Accumulator</td><td></td><td>• ViewID
Dimensions</td><td>• ViewID
Power Supply
Efficiency</td><td></td></tr>
<tr><td>66</td><td>Resource</td><td>Visual Recognition sensor</td><td></td><td rowspan="5">• ViewID
• Purchase Cost
• Repair Cost
• Mean Time to Failure
• Calculated Cycle Time</td><td>• ViewID
Dimensions
Weight</td><td>• ViewID
Power Supply
Voltage
Connection
Wire</td><td>• ViewID
Accuracy
Resolution
Range</td></tr>
<tr><td>67</td><td>Resource</td><td>Color Sensor</td><td></td><td>• ViewID
Dimensions
Weight</td><td>• ViewID
Power Supply
Voltage
Connection
Wire</td><td>• ViewID
Accuracy
Resolution
Range</td></tr>
<tr><td>87</td><td>Resource</td><td>Ultrasonic Length Sensor</td><td></td><td>• ViewID
Dimensions
Weight</td><td>• ViewID
Power Supply
Voltage
Connection
Wire</td><td>• ViewID
Accuracy
Resolution
Range</td></tr>
<tr><td>106</td><td>Resource</td><td>Eddy Current Sensor</td><td></td><td>• ViewID
Dimensions
Weight</td><td>• ViewID
Power Supply
Voltage
Connection
Wire</td><td>• ViewID
Accuracy
Resolution
Range</td></tr>
<tr><td>107</td><td>Resource</td><td>Laser Profilometric Sensor</td><td></td><td>• ViewID
Dimensions
Weight</td><td>• ViewID
Power Supply
Voltage
Connection
Wire</td><td>• ViewID
Accuracy
Resolution
Range</td></tr>
</table>

11 CONCLUSION:

In conclusion, the collaborative efforts of the DAMHS, RECOM, and EDEC groups have resulted in a well-optimized powder-metallurgical processing route with automated material handling systems. The chosen identification method, conveyor design, and integration of various sensors ensure efficient tracking and processing of steel bars. The selection of Layout 2, despite higher power consumption, was based on its superior availability and parallel connections. The documentation through the asset administration shell enhances record-keeping and operational evaluation. Overall, the comprehensive approach ensures efficiency, traceability, and adaptability in the production of metal stock products.

12 REFERENCES

3D Laser Profilometer. (n.d.). Retrieved from KEYENCE: https://www.keyence.de/ss/products/microscope/pr_vr-6000_02/

Fabric Belts. (n.d.). Retrieved from HABASIT: https://habasit.com/en/Products/Fabric-Belts

II, B. B. (n.d.). *The Material Handling Blog*. Retrieved from Bastian Solutions: https://www.bastiansolutions.com/blog/the-beauty-of-zero-pressure-accumulation-conveyor/

Inductive Sensors (EDDY CURRENT),. (n.d.). Retrieved from MICRO-EPSILON: https://www.micro-epsilon.com/distance-sensors/inductive-sensors-eddy-current/

In-Sight 2000 Vision Sensor. (2024). Retrieved from COGNEX: https://www.cognex.com/en-gb/products/machine-vision/vision-sensors/in-sight-2000-vision-sensors

Ltd., P. E. (n.d.). *Cleated Belt Conveyor*. Retrieved from Perfect Engineering Components (P) Ltd.: https://m.perfectcomponents.com/cleated-belt-conveyor-5940699.html

Photoelectric Sensor. (2023). Retrieved from AKUSENSE: https://www.akusense.com/Photoelectric-Sensor

VHT Engine Enamel High Heat Coating. (n.d.). Retrieved from VHT: https://www.vhtpaint.com/high-heat/vht-engine-enamel