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Automated Manufacturing of Variable-Sized Beams in a Single Assembly Line

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Chapter 1

Introduction

The demand for cost-effective and efficient steel fabrication is growing, particularly in small and medium-scale industries. Steel beams, including H-beams, I-beams, and T-beams, are essential components in construction and infrastructure projects, requiring precise manufacturing to meet varying design specifications. Traditional production methods rely on separate setups for different beam sizes and types, leading to higher costs, longer production times, and inefficiencies. Manual operations further introduce inconsistencies in quality and increase dependency on skilled labour.

This project aims to develop a fully automated, single-line production system capable of manufacturing multiple types of steel beams in varying sizes. By integrating robotic welding, CNC cutting, and adaptive process control, the system eliminates the need for multiple production setups, enhances productivity, and minimizes material waste. The process also includes post-processing with an anti-corrosive spray to improve product durability and resistance to environmental factors.

With a focus on automation, this approach optimizes production efficiency, reduces operational costs, and ensures consistent quality. The proposed system is designed to be a scalable and costeffective solution, making advanced steel fabrication accessible to small and medium-sized manufacturers while meeting the growing industry demand for precision and efficiency.

1.1 Background

The course Automation in Manufacturing emphasizes a comprehensive understanding of manufacturing processes, identifying opportunities for automation, assessing their necessity, and implementing effective solutions. Our project aligns with this ethos by focusing on the steel beam manufacturing sector—a critical component of modern infrastructure, including construction, transportation, energy, and heavy machinery.

Recent advancements in the steel industry highlight a significant shift towards automation and smart manufacturing. Techniques such as robotic welding, 3D printing, and advanced fabrication methods are revolutionizing steel beam production, enhancing efficiency and reducing labor intensity. These innovations not only streamline operations but also contribute to sustainable practices by minimizing waste and energy consumption.

Traditionally, steel beam manufacturing has been dominated by large-scale industries due to the substantial capital investment required for heavy machinery and infrastructure. However, the emergence of modular and scalable automation technologies presents new opportunities for small to medium-sized enterprises (SMEs) to enter the market. By leveraging these technologies, SMEs can achieve competitive production capabilities with reduced overhead costs.

In this context, our project aims to design a manufacturing assembly line tailored for custom-profile steel beams. By integrating modern automation techniques and considering the feasibility for SMEs, we seek to develop a flexible and efficient production system that addresses current industry challenges and meets the growing demand for specialized structural components.

1.2 Problem statement

This project focuses on developing a comprehensive automated assembly line for manufacturing various types of mild steel beams, including H-beams, I-beams, and T-beams, in multiple sizes. The proposed system integrates key processes such as **hot rolling, cutting, welding, inspection**, and **post-processing** into a cohesive and streamlined workflow. By leveraging intelligent automation and precision engineering, the project aims to enhance production efficiency, reduce manual intervention, and ensure consistent quality.

Designed specifically for small to medium-sized manufacturing firms, this initiative addresses the growing need for scalable and cost-effective solutions in the steel fabrication industry. Advancements in automation technologies, such as robotic welding systems and integrated beam processing machines, have made it feasible for smaller enterprises to adopt sophisticated manufacturing processes without the extensive capital investment traditionally associated with large-scale operations.

The integration of these technologies not only improves operational efficiency but also aligns with current industry trends emphasizing sustainability and adaptability. By optimizing manufacturing flexibility and maintaining cost-effectiveness, the project seeks to empower **small and medium-sized manufacturers** to compete effectively in a dynamic market landscape.

1.3 Aims, Objectives and Evaluation Factors

Aims: The primary aim of this project is to study the steel beam manufacturing process in detail and identify opportunities where automation can be effectively introduced to improve **efficiency** and **consistency.** The project further aims to design a compact, cost-effective manufacturing line tailored for small to medium-scale industries, enabling them to adopt advanced production capabilities without the need for large capital investments. A key objective is to ensure that the proposed manufacturing line remains flexible, allowing for the production of steel beams—such as I-beams, H-beams, and T-beams—in a range of variable sizes to meet diverse structural requirements.

Objectives: The objectives of this project include designing the entire layout of the shop floor for an automated steel beam manufacturing assembly line, with careful consideration of process flow and space optimization. A key part of the project is to validate the feasibility of the proposed design using simulation software such as Siemens Tecnomatix Plant Simulation, ensuring realistic modeling of production dynamics, bottlenecks, and throughput.

Evaluation Factors

- **Initial Investment Cost:** Assess the total capital expenditure required to establish the automated production line, including machinery, infrastructure, automation technologies, and installation. This cost is benchmarked against similar industry setups for cost-efficiency.
- **Production Volume (Number of Beams per Annum):** Evaluate the annual output capacity in terms of the number of steel beams produced. It indicates the system's productivity and scalability.
- **Net Profit Margin:** Calculate the percentage of revenue that remains as profit after all operating expenses (materials, labor, power, maintenance, etc.).

$$\text{Net Profit Margin} = \left(\frac{\text{Annual Profit}}{\text{Total Revenue}}\right) \times 100$$

- **Return on Investment (ROI):** Determine the investment's effectiveness by comparing annual profit to the initial investment.

$$\text{ROI} = \left(\frac{\text{Annual Profit}}{\text{Initial Investment}}\right) \times 100$$

- **Payback Period:** Estimate the time required to recover the initial investment using the profit generated.

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual Profit}}$$

- **Cost per Unit:** Analyze the cost incurred per beam, considering raw materials, energy, labor, and maintenance. It reflects per-unit production efficiency.
- **Operational Efficiency:** Assess how automation affects cycle time, resource utilization, and labor dependency. Key metrics include throughput rate and equipment utilization.
- **Scalability and Flexibility:** Evaluate the ability to scale up production or modify the system to accommodate different beam sizes and profiles with minimal reconfiguration.

Chapter 2

Literature Review

The design and implementation of the proposed automated manufacturing system are rooted in established manufacturing principles and simulation methodologies. The foundational concepts were primarily drawn from two key textbooks by Mikell P. Groover, a leading authority in automation and production systems.

2.1 Manufacturing Metrics and System Economics

Chapter 3 of "Automation, Production Systems, and Computer-Integrated Manufacturing" (Groover, 2016) outlines essential metrics such as production rate, utilization, and work-in-process (WIP), which were critical in modelling system performance and justifying automation through quantitative metrics. These principles guided our calculation of payback period, return on investment (ROI), and depreciation, forming the financial analysis in the case study.

2.2 Station-Based and Assembly Line Automation

Chapters 14 to 16 detail the characteristics of single-station and multi-station assembly systems, including automation principles, transfer mechanisms, and work-part handling. These insights informed the design of our production line in Tecnomatix, especially in determining station cycle times, buffer allocations, and robot placement. The use of robotic welding and post-processing units directly reflects these structured automation frameworks.

2.3 Production Planning and Lean Principles

Chapters 24 to 26 provide strategies for process planning, production scheduling, and lean manufacturing. We adopted the concepts of Just-in-Time (JIT) and waste reduction in our system by designing a continuous-flow line that minimizes idle time and overproduction. These principles were embedded in the logic of the simulation environment and system control strategy.

2.4 Metal Forming and Welding Fundamentals

To simulate hot rolling and welding processes, we referred to "Fundamentals of Modern Manufacturing" (Groover, 2009). Chapter 19 on bulk deformation processes supported our modelling of hot rolling operations, particularly the understanding of material flow and dimensional accuracy. Chapter 30 on welding processes underpinned the selection of robotic arc welding methods, heat input parameters, and weld quality control considerations.

2.5 Simulation Tools and Virtual Testing

To validate system performance prior to physical implementation, we utilized Siemens Tecnomatix Plant Simulation and Process Simulation (Siemens Software, 2025). These tools enabled the modelling of energy usage, throughput, bottlenecks, and material flow. Their use aligns with best practices in digital manufacturing and virtual commissioning, as supported by industry applications and recent academic literature.

Chapter 3

Methodology

The production line follows a structured, sequential workflow beginning with hot rolling and progressing through cutting, intermediate storage, welding, inspection, and finally spray painting. Each stage is designed to contribute to the overall quality of the finished steel beams, ensuring structural integrity, dimensional accuracy, and surface protection. To support this process, material handling within the facility is performed exclusively by an overhead crane system. This method is preferred over ground-based transport solutions due to its superior efficiency in lifting and moving heavy steel sheets and beams, while also offering improved space utilization and enhanced operational safety. The details of each production stage are discussed in the following subsections.

3.1 Hot Rolling

The first process in the manufacturing line is hot rolling. While steel slabs of the required beam dimensions may not be readily available in the market, steel billets are more commonly accessible and will serve as the initial raw material. The billet is subjected to reverse hot rolling, a process in which the billet is passed multiple times through rolling stands in alternating directions to achieve uniform thickness and mechanical properties. The billet is transformed into a sheet of desired thickness during this operation. Upon completion of hot rolling, the sheet is automatically transferred onto a conveyor system, positioning it for the subsequent stage in the production line.
Indian original equipment manufacturers (OEMs), such as Steewo Engineers, offer 2-High Reversing Hot Rolling Mills at an estimated cost of approximately 10 crore, making them a viable option for small to mid-scale steel beam manufacturing facilities.

3.2 Sheet Cutting

The hot-rolled sheet is conveyed to the shear cutting machine, where it undergoes precise segmentation. The sheet is cut into appropriate sizes. Each cut serves as an individual structural component contributing to the final beam assembly. This method ensures uniformity in dimensions and clean edge finishes, essential for subsequent fabrication processes. The cutting operation is carried out using a Hydrualic Guillotine Shearing machine, which is capable of maintaining tight tolerances and handling sheets of the

specified thickness and material grade.
Indian OEMs, such as Vahanvati Machine Tools and CutEdge Engineering, offer shearing machines at an estimated starting cost of 4 lakh. This relatively low investment makes them highly accessible and economically viable for small to medium-scale manufacturers.

3.3 Storage System for Sheets

The cut metal sheets are systematically stored based on their dimensions, ensuring efficient organization and accessibility. Each sheet is placed in a dedicated compartment or rack, which prevents damage due to stacking and facilitates easy identification. To further enhance storage efficiency and retrieval speed, an **Automated Storage and Retrieval System (AS/RS)** is employed. This system automates the handling of sheets, allowing for precise placement and rapid access based on production schedules. The compartmentalized AS/RS setup not only preserves the integrity of each sheet but also streamlines the process of transport and retrieval during later manufacturing stages. Such an arrangement plays a crucial role in meeting customer-specific beam configurations, allowing for quick and accurate selection of components as per project requirements.

Figure 3.1: Automated Storage and Retrieval System (AS/RS)

3.4 Welding

The welding phase of the automated beam assembly is a critical component in ensuring structural integrity and manufacturing precision. In this project, the welding process is executed using a KUKA YS10-2000 W robotic arm, programmed for precise path execution and consistent weld quality. The selected welding method is **Shielded Metal**

Arc Welding (SMAW), which is widely used in structural steel fabrication due to its versatility and effectiveness in joining thick sections. To accommodate the varying lengths of H-beams and ensure complete weld coverage, the robotic arm is mounted on a motorized cart that travels along the length of the beam. This setup allows the robot to maintain optimal positioning and reach across the entire workpiece, enabling continuous, high-quality welds while adapting to different beam sizes within the same production line.

3.4.1 Robotic Arm Configuration

The KUKA YS10-2000 W robot features a 2-meter reach and high payload capacity, making it suitable for handling large-scale components like mild steel plates used in I-beams and H-beams. The robot is integrated with a programmable controller and interfaced through ROS2 MoveIt, which enables real-time path planning, obstacle avoidance, and adaptive speed control.

Key setup parameters include:

- **Welding current:** 120–150 A
- **Electrode type:** E6013, 3.2 mm diameter
- **Travel speed:** Optimized to 3–5 mm/s for vertical and horizontal welds
- **Torch angle and dwell time:** Adjusted based on joint position and thickness

Figure 3.2: KUKA Robotic Arm for Welding

3.5 Anti-Corrosive Spraying

Prior to final inspection, the components undergo anti-corrosive spraying to protect against rust, moisture, and environmental degradation. A zinc-rich epoxy primer or polyurethane-based coating is applied using airless spray guns, which ensure a consistent and uniform layer across all surfaces. The standard coating thickness is typically between 75 to 150 microns, based on environmental exposure requirements in accordance with ISO 12944 or SSPC standards.

Before application, surfaces are prepared by abrasive blasting to SA 2.5 to ensure proper adhesion. Drying and curing times vary by material and climate conditions but generally require 30–60 minutes for surface dry and up to 8 hours for full cure. The spray coating not only protects the beams during storage and transport but also contributes significantly to their long-term performance in the field.

3.6 Inspection

The process concludes with a comprehensive final inspection, ensuring that all parts meet strict quality and safety standards. This includes:

1. Dimensional verification to ensure correct sizing.
2. Weld integrity checks using visual and non-destructive techniques (e.g., Ultrasonic Testing, Magnetic Particle Testing).
3. Surface quality inspection, especially for coating coverage and uniformity.
4. Dry Film Thickness (DFT) measurement to confirm that the anti-corrosive layer meets specified standards.

The inspection is carried out by certified quality control personnel, and detailed inspection reports are generated for record keeping and client assurance. Only components that pass all checks are approved for dispatch or final integration.

Chapter 4

Simulations and Modelling

4.1 Introduction

4.1.1 About the Software

Siemens Tecnomatix Plant Simulation is a powerful discrete event simulation software widely used for modeling, analyzing, and optimizing production systems and logistics operations. By creating digital models of real-world manufacturing processes, it enables users to evaluate system performance, identify bottlenecks, and test various scenarios without disrupting actual operations. The software supports object-oriented modeling, comprehensive data integration, and both 2D and 3D visualization, making it a versatile tool for enhancing decision-making in production planning and industrial engineering. In this project, Plant Simulation is utilized to simulate and improve the efficiency of a manufacturing layout, with the goal of increasing throughput and reducing resource waste.

4.1.2 About Modelling

The plant layout was designed with **lean manufacturing** principles in mind, ensuring minimal waste and avoiding overproduction. The model consists of five processing stations arranged to support a smooth and efficient flow of materials. Between the stations, there are three buffer storage areas to balance variability in processing times without accumulating excess inventory. A **Multi-portal Overceiling Crane** handles part transportation between stations and buffers. This setup minimizes idle time and material handling while maximizing throughput in line with lean objectives.

The functions of the stations are as follows:

- M1: Hot rolling station.
- M2: Cutting station (Using Shearing Machine)
- M3: Welding using robotic arm mounted on rail).
- M4: Spray paint and anti-corrosive material station.
- M5: Inspection Station.

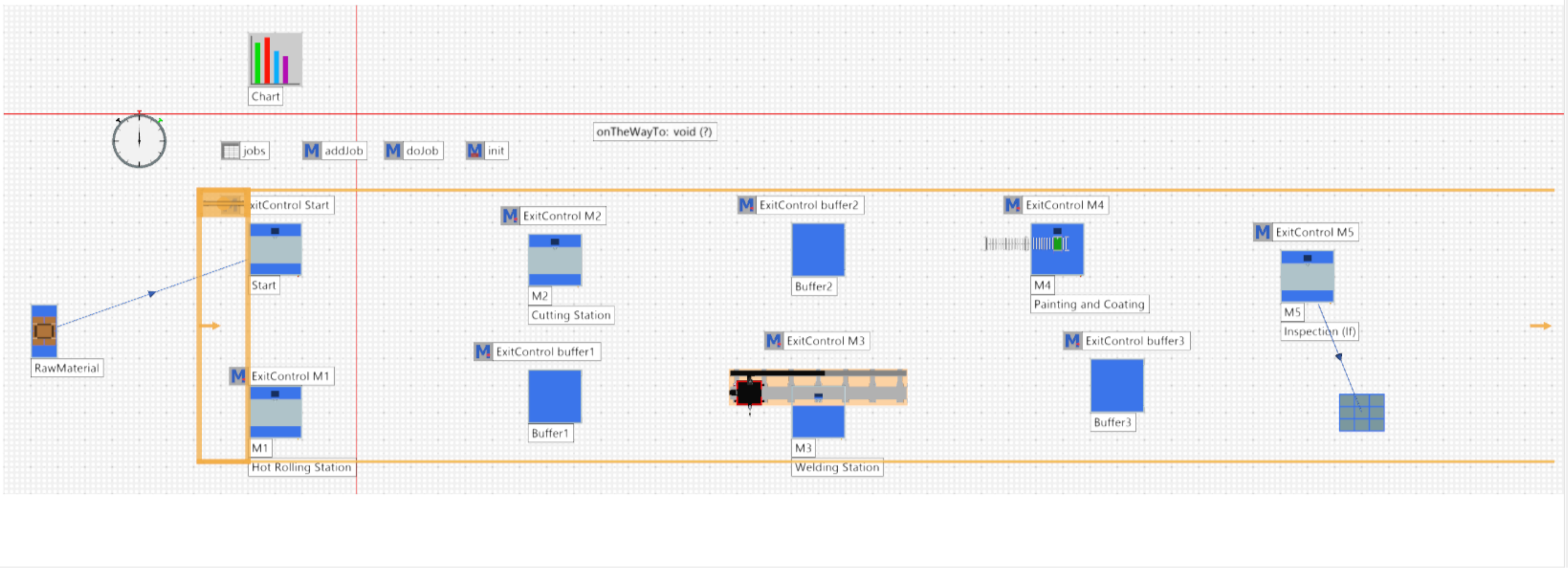

Figure 4.1: Shop-floor Plan

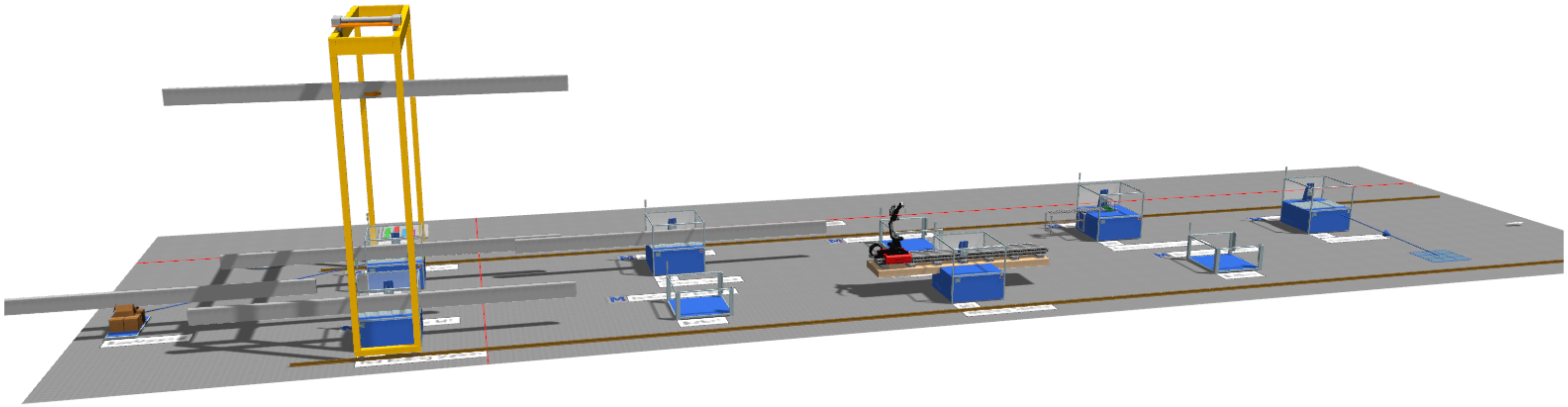

Figure 4.2: 3D View of the Model

4.1.3 Modeling parameters and Utilites

- **The *jobs* Data Table**

  The Data Table from Information Flow library is imported into the model named 'jobs' and is used as job sequence table, the jobs are added in the from and to columns and 'doJob' method is responsible for execution of the entered job. Once the job is done the job entry is deleted from the jobs table.

- **The *onTheWayTo* variable**

  The 'onTheWayTo' variable is used for maintaining the information about the movement of the crane.

- **Parameters for the modeling of each utility**

  The parameters for each of the station, crane, storage and buffer can be accessed by double clicking on it. The parameter prompt box can be seen in Figure 4.3. The parameters include the time, costs, power requirements and controls.

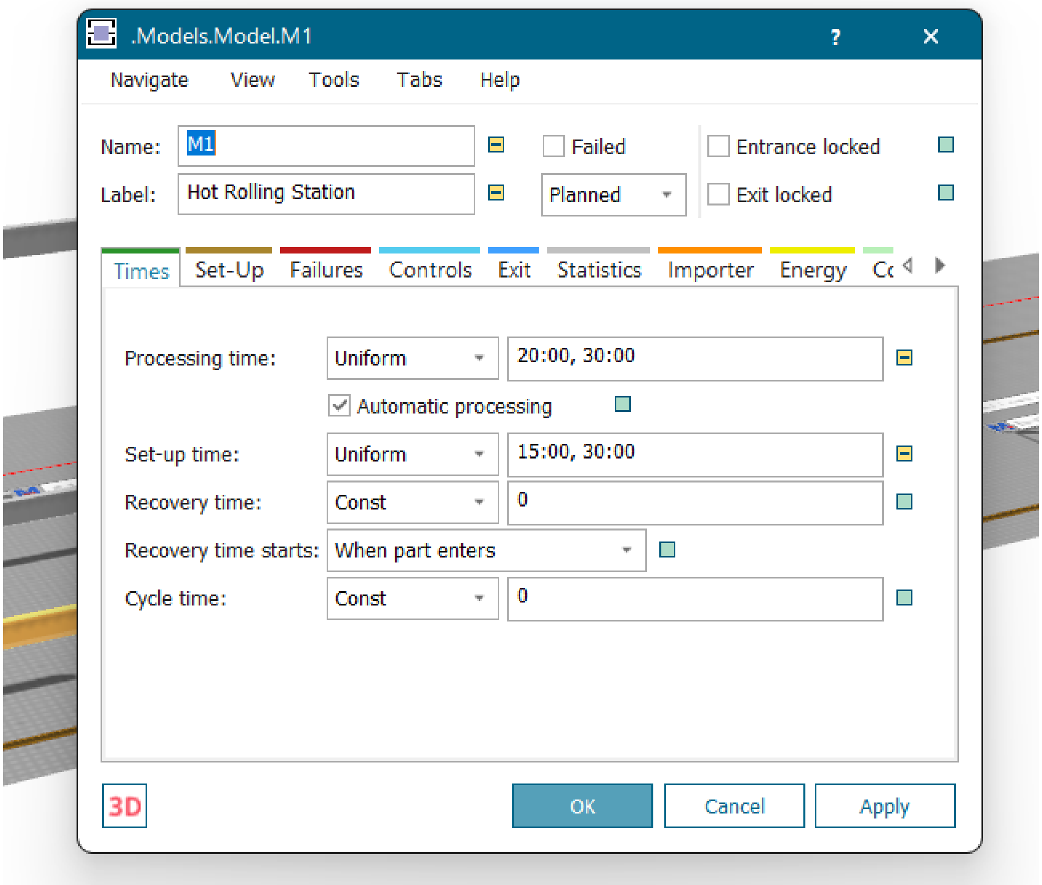

Figure 4.3: Parameters for Hot Rolling Station

4.2 Control Logic

4.2.1 Init Method

The 'Init' method is the starting point of the simulation. In this method we delete the preexisting job and crane sequence and start newly the job cycle.

```
jobs.delete;      //Clear any existing jobs in the table

//Setup crane's end sequence (ensure proper syntax)
multiPortalCrane.cont.endSequence

//Start the crane's operation by triggering first job
&doJob.executeNewCallChain;
```

Listing 4.1: Init Method

4.2.2 addJob Method

The addJob method writes the entry into the jobs data table, the work entry is further executed by crane.

```
param source:object,destination:object
jobs.writeRow(1,jobs.yDim+1,source,destination)
```

Listing 4.2: addJob Method

4.2.3 doJob Method

This method executes the chain of actions responsible for the movement of the crane for picking and placing the job at particular station or storage.

```
var start: object
var target: object
var portal: object

portal := MultiportalCrane.Portal1

waituntil jobs.yDim > 0

start := jobs[1,1]
target := jobs[2,1]
jobs.cutRow(1)


portal.moveToObject(start)
waituntil portal.state = "waiting"

portal.moveHook(9.5)
waituntil portal.state = "waiting"
```

```

    start.cont.move(portal)

    portal.moveHook(1.5)
    waituntil portal.state = "waiting"

    portal.moveToObject(target)
    waituntil portal.state = "waiting"

    portal.moveHook(9.5)
    waituntil portal.state = "waiting"

    portal.cont.move(target)

    portal.moveHook(1.5)
    waituntil portal.state = "waiting"

    self.executeNewCallChain
```

Listing 4.3: doJob Method

4.2.4 Exit Control for stations and buffers

The exit control for a block is the sequence of command actions which will be executed once the job is finished. Here all the stations have nearly same ExitControl method as can be seen below for station M2 and buffer3:

```
    onTheWayTo := buffer2;
    addJob(?, buffer2)
```

Listing 4.4: ExitControl_M2 Method

```
    waituntil M4.empty
    ontheWayTo := M4
    addJob(?,M4)
```

Listing 4.5: ExitControl_buffer3 Method

4.3 Instructions to Run the Simulation

- Download and install the student version of Siemens Tecnomatix Plant Simulation from the official Siemens website.
- Launch the software and open the project file named *sim.spp*.
- Click the green play button on the toolbar to start the simulation.
- Alternatively, double-click on the EventController (represented by the large clock icon on the shop floor layout).

- A control panel will appear, allowing you to start, pause, and adjust the simulation speed as needed.

4.4 Digital Twin Simulation

The simulation of the automated beam manufacturing system was developed using Siemens Tecnomatix Plant Simulation to model the entire production line, including material flow, processing stations, and robotic operations.

A demonstration of the simulation can be viewed in the following **video**. Performance statistics were generated based on a 24-hour simulation period. The data was obtained using the *Statistics Report* utility available under the **Home** tab in Tecnomatix. Key metrics include station utilization, throughput, and bottleneck identification.

For a detailed breakdown of simulation results and system performance, refer to the full **statistics report**.

Chapter 5

Results and Evaluation

5.1 Simulation Results and Analysis

To evaluate the performance and efficiency of the proposed automated manufacturing line, a digital twin of the system was developed and executed in Siemens Tecnomatix Plant Simulation. The simulation was run over a virtual period of 24 hours, during which key performance indicators such as **station utilization, throughput, waiting times, blocking times,** and **failures** were recorded.

Object	Working	Set-up	Waiting	Blocked
Hot Rolling	87.40%	1.58%	4.62%	6.40%
Shearing	3.47%	1.01%	83.42%	3.56%
Welding	34.70%	0.11%	55.42%	4.85%
Painting	13.84%	0.85%	81.47%	3.84%
Inspection	0.58%	0.00%	99.42%	0.00%
Buffer1	0.00%	0.00%	100.00%	0.00%
Buffer2	0.00%	0.00%	100.00%	0.00%
Buffer3	0.00%	0.00%	100.00%	0.00%
Store	0.00%	0.00%	100.00%	0.00%

Table 5.1: Operational Status of Stations and Buffers

5.2 Cost Analysis

A major part of justifying an automated system, or any new process, is the calculation of the potential economic benefits. The two main measures of how well a system will benefit a company are the **payback period** and the **return on investment (ROI)**. To evaluate the financial viability of our proposed automated steel beam manufacturing system, we conducted a detailed cost analysis. This analysis considers the **initial investment costs, annual cost savings, operational expenses, and maintenance costs**. Additionally, we incorporated depreciation calculations, allowing for a more accurate assessment of long-term financial impact. Based on these factors, we have determined key

Object	Number of Entries	Number of Exits	Min Contents	Max Contents	Relative Empty
Rolling	52	51	0	1	4.62%
Shearing	50	50	0	1	91.21%
Welding	51	50	0	1	58.29%
Painting	50	50	0	1	81.47%
Inspection	50	50	0	1	99.42%
Buffer1	51	51	0	4	85.20%
Buffer2	51	51	0	4	90.31%
Buffer3	50	50	0	1	95.52%
Store	50	0	0	50	6.79%

Table 5.2: Flow and Capacity Metrics of Stations and Buffers

Process	Total Consumption (kWh)	Working	Set-up	Operational
Rolling	7391.4558	99.47%	0.51%	0.02%
Shearing	14.92649	20.66%	2.43%	70.03%
Welding	91.288411	91.63%	0.06%	7.93%
Painting	27.093333	61.41%	0.75%	37.84%

Table 5.3: Energy Consumption and Operational States

financial indicators, including the payback period, ROI, and net savings, to demonstrate the economic feasibility and potential profitability of the system.

Table 5.4: Initial Investment Breakdown

Item	Cost (₹)
Hot-Rolling Machine	9,00,00,000
Shearing Machine	4,00,000
Welding Setup	1,85,00,000
Spray Painting Equipment	1,00,000
Total Initial Investment	**10,86,00,000**

Table 5.5: Annual Operating Costs

Cost Component	Cost per Annum (₹)
Power Consumption	2,37,25,000
Raw Material	86,61,45,000
Labour	50,00,000
Maintenance	1,00,00,000
Total Annual Operating Cost	**90,48,70,000**

Table 5.6: Revenue and Financial Metrics

Metric	**Value (₹)**
Annual Return (No. of Beams × Price/Beam)	94,90,00,000
Annual Profit (Return – Cost)	4,41,30,000
ROI = (Profit / Investment) × 100	40.63%
Payback Period = Investment / Profit	2.46 years

5.3 Conclusions

The software is capable of running a simulation and calculating various factors of the plant. We have run the simulation for a day, and the report of this data is present at the end of Chapter 4. The above tables are a part of this data. After analysing the data, we have come to the following conclusions:

- The analysis and simulation of the proposed automated steel beam manufacturing line have revealed critical insights into the system's performance and limitations. Among all the processes, hot rolling (Machine M1) emerges as the most resource-intensive operation. It accounted for the highest working time, totaling 21 hours and 22 seconds, and was active 87.40% of the total simulation time. This confirms that hot rolling not only dominates the energy consumption profile but also acts as the primary bottleneck, limiting the total number of beams that can be produced.

- In contrast, downstream processes such as cutting (M2) and welding (M3) show significantly lower working utilization—3.47% and 34.70% respectively—highlighting that these stations remain idle for long durations, waiting for the output from the hot rolling stage. This indicates underutilization of resources and suggests that optimizing or parallelizing the hot rolling operation could significantly improve overall system throughput.

- The system is currently capable of producing approximately **50 steel beams per day**, which is a noteworthy achievement given the constraints. This output was calculated based on simulations involving 12-meter beams—the largest size our facility is designed to handle. The ability to maintain medium-scale production capacity while operating within a small-scale industry budget demonstrates the efficiency and scalability of the proposed manufacturing line.

Chapter 6

Recommendations and Acknowledgements

6.1 Recommendations and Future Work

- Developing a **more efficient steel sheet preparation system** is crucial. The current **hot rolling** process is **energy-intensive**, **expensive**, and requires significant **floor space**. Alternatives like **cold rolling** or **direct casting** could reduce costs and space requirements.

- Improving **inspection techniques** is essential for quality control. Current methods may miss defects in fast-paced settings. **AI-based vision systems** can enhance accuracy, reduce **waste**, and support **lean manufacturing**.

- The lack of **industry exposure** limits parameter accuracy. Future work should involve **expert collaboration** or **internships** to validate and refine simulation models using **real-world data**.

- With more space and investment, the process can begin from **billet production using iron ore**. This allows better **material control**, **cost reduction**, and reduces **supplier dependency**.

- **IoT integration** can enhance monitoring and responsiveness. **Real-time data**, **predictive maintenance**, and **automated alerts** reduce downtime and support **Industry 4.0** practices.

6.2 Acknowledgements

1. **Ojas Wani (ME22B173)**
   I focused on analyzing the hot rolling and cutting processes through technical research and literature review. I identified key parameters for simulation, evaluated cost-effective machinery for small to mid-scale operations. I also helped structure and draft the project report.

2. **Pawar Devesh Pramod (ME22B176)**
   I specialized in Tecnomatix Plant Simulation, modeling the plant layout and importing CAD files for realism. I developed custom logic to control equipment and ran simulations using team-provided parameters, generating key performance data and gaining practical insight into digital manufacturing.

3. **Srivatsav S (ME22B202)**
   I led the cost analysis, calculating ROI and payback periods. My technical focus was on the inspection and spray painting processes, for which I identified key simulation parameters and suitable machinery. I also supported layout planning and workflow optimization.

4. **Yash Purswani (ME22B214)**
   I proposed the lean manufacturing approach to reduce costs and led research on robotic welding solutions. I simulated robotic arms in ROS2 and Gazebo and managed the overall workflow, assigning tasks and ensuring team coordination.

5. **Yuvraj Singh (ME22B214)**
   My involvement primarily focused on the economic aspects, including the analysis of raw materials, estimation of operational costs, and detailed planning of shop floor processes.

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