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# Improving Takt Time in a Railway Manufacturing Line in South Africa

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## Abstract

Takt time optimisation is critical for improving production efficiency in railway manufacturing, particularly within car body shell production lines. Unlike automotive production, railway manufacturing involves larger and more specialised components, extended assembly cycles, and lower production volumes, making takt time management more complex and susceptible to bottlenecks. This study adopts a quantitative case study approach to investigate bottlenecks and capacity management strategies in a South African railway manufacturing facility. Data were collected through time–motion studies, production logs, and structured questionnaires administered to graduate trainees, quality engineers, production managers, process engineers, and operators. The analysis identified welding delays, material handling inefficiencies, and unbalanced workstation loads as key bottlenecks that disrupt operational flow and extend takt time beyond optimal thresholds. Further statistical examination revealed that workforce skill variability, equipment downtime, and supply chain inconsistencies also contribute significantly to inefficiencies in takt time. To mitigate these challenges, the study evaluated capacity management interventions including line balancing, predictive maintenance scheduling, and lean workflow redesign. The findings indicate that the adoption of these strategies can reduce takt time, thereby enhancing throughput and resource utilisation. The study provides practical insights for optimising production processes and supports evidence-based decision-making in railway manufacturing operations.

## Keywords
Capacity Management, Bottleneck, Takt Time and Railway Manufacturing Industry.

# 1. Introduction

Effective capacity management is fundamental to sustaining productivity, cost efficiency, and timely delivery in manufacturing environments, particularly in the railway sector, where operations are extensive and resource-intensive (Gadde & Wynstra, 2017). Although takt time serves as a critical metric for aligning production output with customer demand, many railway manufacturing operations continue to experience prolonged lead times, bottlenecks, and underutilised equipment, largely as a result of inadequate process coordination (Ekene, 2018). A notable gap exists in the limited research addressing the optimisation of takt time within South African railway production lines. This paper seeks to address this gap by examining the specific challenges encountered in South African railway manufacturing and by proposing capacity management strategies aimed at improving takt time. In doing so, the study not only enhances the adaptability and innovation of railway production systems but also contributes to the broader literature on takt time within an emerging industrial context.

## 1.1 Problem Statement

The railway manufacturing sector faces persistent challenges arising from ineffective capacity management, which manifest in variable takt times and recurrent production delays. Inefficiencies such as bottlenecks, unbalanced workflow allocation, and underutilised resources not only diminish overall productivity but also extend lead times across critical processes. These operational constraints undermine the sector's ability to meet customer demand reliably and punctually, thereby affecting competitiveness in a market where efficiency and responsiveness are vital. Furthermore, the scale, complexity, and resource-intensive nature of railway production exacerbate the difficulty of achieving stable takt times compared with other manufacturing industries, such as automotive production. Addressing these challenges requires a systematic evaluation and refinement of takt time as a core performance metric. By optimising capacity utilisation and streamlining workflow processes, railway manufacturers can enhance operational efficiency, reduce variability, and ultimately improve industrial performance in line with customer expectations and sustainability imperatives.

## 1.2 Aim of the study

This study aims to evaluate the challenges of capacity management within a railway production line and to identify the key factors influencing takt time. It further seeks to develop solutions that enhance takt time performance and achieve a more balanced production flow, thereby reducing manufacturing delays and improving resource utilisation. Ultimately, the study aspires to strengthen overall manufacturing effectiveness while increasing the system's adaptability to customer requirements.

## 1.3 Objectives

The objectives of this study are threefold. First, it seeks to examine the bottlenecks encountered in the car body shell production process that adversely affect takt time. Second, it aims to analyse the key factors influencing manufacturing takt time within this production line, with particular attention to workforce, equipment, and process-related variables. Third, the study intends to investigate capacity management solutions capable of enhancing takt time efficiency, thereby contributing to improved productivity and operational performance in railway manufacturing.

## 1.4 Scope and limitations of the study

This study is confined to the railway manufacturing sector, focusing specifically on optimising capacity management by improving takt time within a single South African production facility. The investigation is limited to internal operations, scheduling, manpower allocation, equipment utilisation, and process standardisation, while excluding broader functions such as product design, marketing, or after-sales services.

The study's findings are subject to certain limitations. As a single case analysis, the results may not be fully generalisable to other facilities or industries. External influences such as supply chain disruptions, regulatory pressures, and macroeconomic conditions are also beyond the scope of this research. Despite these constraints, the study offers valuable insights into improving takt time and capacity management within the context of railway manufacturing.

## 1.5 Value of the study

The study provides empirical evidence and practical insights into takt time optimisation in railway production, an area that has received limited scholarly attention in the South African context. The findings contribute to the existing body of knowledge on capacity management and takt time, while offering actionable recommendations for industry practitioners seeking to enhance operational efficiency, reduce delays, and improve responsiveness to customer demand.

# 2. Literature Review

## 2.1 Bottlenecks Experienced in the Manufacturing industry

According to Bilinovics-Sipos and Reicher (2023), bottlenecks can manifest within a system in various forms, including management, workforce, materials, equipment, processes, policies, and environmental factors. A bottleneck is commonly defined as an activity that negatively affects system performance and reduces the overall efficiency of a process (Ibidunmoye et al., 2015). In manufacturing, for example, multiple production lines are often interconnected, whereby the output of one stage becomes the input for the next. Although the specific form of a bottleneck may vary depending on the nature of the business, the techniques used to identify such constraints are largely consistent. Bottlenecks restrict the throughput and capacity of a production system, which in turn leads to localised stock accumulation, production stagnation, and, most critically, a decline in overall system productivity.

According to Ongbali et al. (2021), the primary cause of production delays in manufacturing units is the presence of bottlenecks. Such constraints must be identified, analysed, and systematically addressed using evidence-based approaches. Accurate and effective identification of a bottleneck can significantly reduce manufacturing costs while simultaneously improving the overall efficiency of the system. Within production environments, constraints may be either short-term or long-term in nature. Bottlenecks within a process or system can be detected by applying various methods. The fishbone diagram is one of them, it is a method for finding possible explanations for an issue in a systematic and pictorial approach, employing categories to focus and structure the thoughts in order to move toward determining fundamental causes also known as the Ishika diagram and cause-effect diagram (named after Dr. Kaoru Ishikawa, a Japanese quality control statistician who invented it) (Kamauf 2019). To notice the consequence, there must be a cause, according to this method. As a result of this strategy, various data pertaining to the problem are gathered. These data are meticulously evaluated to determine the main cause of the problem (Mauch 2018).

## 2.2 Takt Time

According to Soliman (2020), takt time refers to the maximum allowable duration for producing a single unit of a product to meet customer demand precisely. It is determined by dividing the total available production time by the number of units required by customers within the same period. Takt time functions as the rhythmic pulse of lean manufacturing systems, aligning the pace of production with market demand to minimise waste and improve operational flow. The concept is central to bottleneck analysis, as it incorporates not only production duration but also the availability of critical resources such as materials, labour, and equipment. Moreover, establishing an optimal takt time provides a valuable benchmark for evaluating system performance, thereby supporting the identification of capacity constraints and workforce utilisation inefficiencies. Mathematically, takt time is expressed as:

$$Takt\ time\ (units\ per\ time) = \frac{Customer\ Demand\ (Units)}{Available\ Production\ Time\ (time)} \tag{1}$$

Although commonly associated with the Toyota Production System (TPS), the concept of takt time originated in the German aviation industry during the 1930s. As Frandson (2019) observes, its earliest application sought to accelerate the assembly of aircraft fuselages. The concept was later adopted by Mitsubishi and subsequently integrated into Toyota's manufacturing practices in the 1950s, where it became a central feature of lean production. Effective utilisation of takt time requires alignment with the operational capacities of individual workstations along a production line to ensure a balanced and continuous workflow. Misalignment between established takt times and workstation capacities often gives rise to inefficiencies. As Mönch et al. (2022) explain, significant discrepancies typically manifest in two ways: either a workstation becomes starved of input, remaining idle because preceding processes are unable to supply materials on time, or inventory accumulates between stations when downstream operations are unable to process incoming outputs at the required rate. These challenges underscore the inherent complexity of balancing production systems, a difficulty further compounded by variability in production outputs and fluctuations in customer demand.

## 2.3 Improving Takt time

According to Sunday et al. (2021), production planning refers to the systematic organisation and allocation of resources, including labour, equipment, and raw materials, to ensure the timely completion and delivery of finished products. Production Planning and Control (PPC) constitutes a comprehensive framework designed to enhance productivity by managing manufacturing resources, workforce deployment, and equipment utilisation in an optimal manner. To sustain competitiveness, manufacturing organisations must consistently provide high-quality products at competitive prices, whilst maintaining sufficient flexibility to adapt rapidly to changing market demands. Sharma (2019) highlights that PPC functions as a critical operational mechanism, enabling firms to achieve greater visibility and control over production processes. Moreover, PPC promotes collaboration, improves productivity, and supports the effective use of data within the production environment.

Nevertheless, even with robust planning, deviations from production schedules frequently occur due to a range of factors. These include shortages or unavailability of raw materials, fluctuations in market demand alongside urgent orders, employee absenteeism, machinery breakdowns or malfunctions, and inadequate coordination or ineffective communication across organisational functions. As a result, discrepancies between planned and actual production outputs are common. In such cases, production control becomes essential. According to Kiran (2019), production management employs control mechanisms that introduce corrective actions to realign actual production with planned targets. Through systematic evaluation of ongoing activities, production control ensures timely adjustments and adherence to predefined production schedules.

### 2.4 Capacity Management Strategies

Nangulu (2018) defines capacity management as the ability of an organisation to meet customer requirements through the effective utilisation of available resources such as labour, facilities, machinery, and raw materials. Effective capacity management is therefore essential for coordinating organisational processes, including product development and marketing initiatives, while addressing constraints that arise from the interaction of multiple resources. Robust capacity management frameworks are crucial, as limitations in processes or resources can create significant operational challenges and hinder overall efficiency. Kamau (2018) observes that capacity management entails aligning an organisation's available resources with its actual production output to ensure optimal utilisation, thereby reducing inefficiencies and enhancing productivity. Similarly, Rao (2023) underscores its role in harmonising supply and demand by establishing, measuring, monitoring, and adjusting capacity levels across different planning and execution phases of manufacturing operations. Such decisions are inherently strategic, requiring the balancing of demand with the organisation's capacity to deliver products or services effectively. Rajani et al. (2022) further argue that an organisation's ability to manage capacity in response to fluctuating demand directly influences its capability to sustain service quality and optimise asset utilisation. Accordingly, capacity management emerges as a central operational strategy, integral to achieving both sustained competitive advantage and operational excellence.

## 3. Methodology

### 3.1 Research Design

The study employed a quantitative research methodology, selected for its suitability in facilitating statistical analysis and its capacity to generate reliable and generalisable findings. This approach enables the identification of relationships and patterns among variables, thereby broadening the scope of investigation. Quantitative methods provide a systematic and rigorous framework for data collection and analysis, enhancing objectivity while minimising potential bias in the research process. By utilising numerical data, this approach supports precise measurement and evaluation of variables, leading to accurate and replicable outcomes. Accordingly, the adoption of a quantitative methodology ensured the production of robust insights into the research problem, thereby reinforcing the validity and credibility of the findings.

### 3.2 Population and Sample

The study targeted a sample of 150 respondents randomly drawn from a total workforce of approximately 400 employees within the South African railway industry. The respondent group comprised graduate trainees, quality engineers, production managers, process engineers, and operators, representing the primary workforce directly engaged in manufacturing operations. Although 150 participants were initially sought, responses were ultimately secured from 139 individuals, providing a substantial and representative sample for the purposes of this research.

### 3.3 Data Collection

The study adopted a quantitative approach to data collection, focusing on measurable aspects of the railway manufacturing process. Structured data were obtained through time studies, production logs, and performance indicators such as takt time, machine utilisation, and output rates. Time studies involved direct observation of operators, with task durations recorded using stopwatches. The data were averaged over multiple cycles to establish standard times and identify areas requiring improvement. Questionnaire items were developed based on existing research on capacity management and takt time to ensure alignment with the study's objectives and were refined with input from experts to better reflect the actual challenges and opportunities within the railway production line. Quantitative data were collected over a defined period to capture production cycles, detect delays, and measure bottlenecks. This approach enabled the examination of trends, calculation of takt time variations, and assessment of the impact of diverse operational factors on overall capacity performance, thereby providing a robust, data-driven foundation for improvement initiatives.

### 3.4 Data analysis

The study employed descriptive statistical analysis to summarise and interpret the dataset. Measures of central tendency, including the mean, standard deviation, and frequency distributions, were calculated to provide insights into the demographic characteristics of respondents as well as patterns within the production data. Descriptive statistics were particularly valuable in establishing an overview of workforce composition and identifying initial trends in operational performance. To further explore relationships between variables, correlation analysis was undertaken as part of the inferential statistical procedures. This enabled the examination of associations between factors influencing takt time, such as workforce skills, equipment utilisation, and process efficiency. The Statistical Package for the Social Sciences (SPSS), version 29, was employed for data analysis, offering a reliable and systematic platform for conducting both descriptive and inferential tests. The combined use of descriptive and correlation analyses ensured not only an understanding of general data trends but also a rigorous evaluation of the interdependencies shaping capacity management within the railway production line.

### 3.5 Reliability

The reliability of the questionnaire employed in this study was assessed using Cronbach's alpha coefficient. Cronbach's alpha is a widely used statistical measure for evaluating the internal consistency of survey instruments, indicating the extent to which items within a scale are interrelated. Higher coefficient values denote stronger consistency among items, suggesting that they reliably measure the same underlying construct. In this context, the analysis was undertaken to determine the degree to which the questionnaire items collectively assessed the intended concepts related to capacity management and takt time. A coefficient value approaching 1 reflects high reliability, signifying that the items are strongly correlated and consistently capture the targeted construct.

## 4. Results and Discussion

### 4.1 Demographics

### a. Respondents Qualifications

Figure 1 shows that most respondents hold post-secondary qualifications, with 50% possessing a diploma and 30% an undergraduate degree, while 12% hold a master's or higher. Only a small proportion reported secondary-level education or below (8%). This indicates that the railway manufacturing workforce is predominantly semi-professional and professional, equipped with technical and managerial skills necessary for production operations.

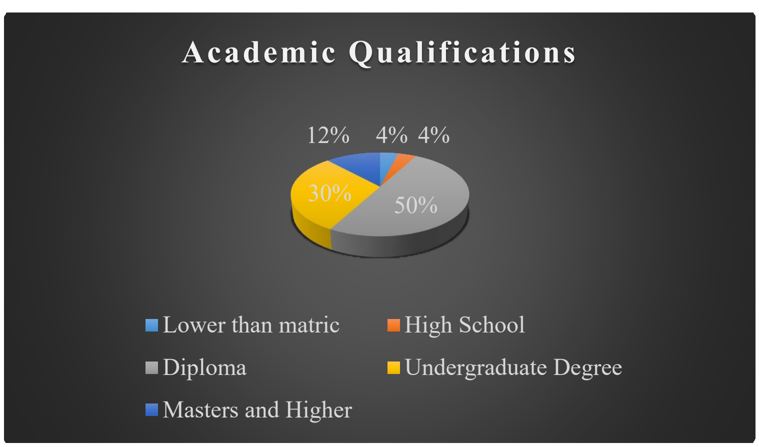


Figure 1. Respondents' qualifications.

In relation to the study, this qualification profile is important as workforce skills directly influence takt time performance. A technically skilled workforce supports capacity management initiatives, yet variability in education and training levels may also contribute to inconsistencies in workflow and resource utilisation.

**b. Respondents position**

Figure 2 shows that the majority of respondents (58%) are operators, while engineers (quality and process) account for 27% combined. Smaller groups include production managers (8%) and schedulers/controllers (7%). This distribution highlights strong representation from the operational workforce, ensuring direct insights into takt time challenges, while also incorporating managerial and engineering perspectives essential for capacity management solutions.

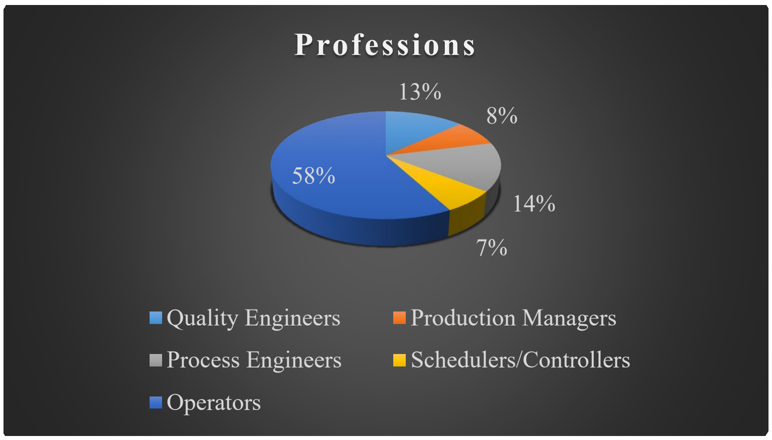


Figure 2. Respondents' professions in the company.

**c. Respondents years of experience**

The data in Figure 3 indicate that 43% of respondents have between 6 and 10 years of experience, while 28% fall within the 11 to 15 year range. A smaller proportion reported 1 to 5 years (18%) and 16 to 20 years (11%) of experience. This distribution suggests that much of the workforce possesses mid-level to substantial industry experience, which strengthens the reliability of the study findings. This is significant as experienced employees are more likely to provide informed perspectives on bottlenecks, capacity utilisation, and takt time variability within railway manufacturing. At the same time, the inclusion of less experienced respondents ensures representation of newer workforce challenges, such as skill variability, which was identified as one of the factors affecting takt time efficiency.

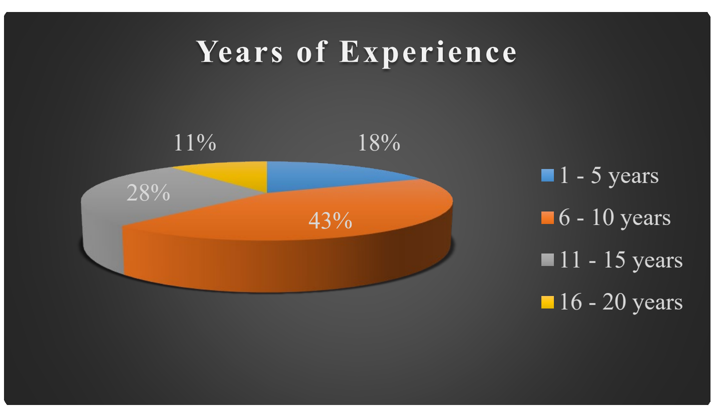


Figure 3. Respondents' years of experience in the company.

## 4.2 Descriptive analysis

### a. Capacity Management Practices

The descriptive statistics on capacity management practices indicate that the most influential approaches are planning for peak periods, maintenance scheduling, and equipment investment decisions, which achieved the highest mean score of 3.94 with a standard deviation of 0.957. Practices related to efficient resource utilisation and employee engagement in improvement initiatives followed closely, each with a mean of 3.90, underscoring their perceived importance in enhancing operational efficiency and reducing cycle times. Adaptability during demand fluctuations and improving asset availability were also rated moderately highly, highlighting recognition of their role in sustaining consistent performance. In contrast, strategies centred on aligning production pace with capacity (mean = 3.63) and relieving bottlenecks through process or resource adjustments (mean = 3.62) received the lowest ratings, although still within a positive range, suggesting moderate agreement among respondents. Overall, the findings suggest that proactive planning and workforce involvement are considered central to effective capacity management in the railway manufacturing context (Table 1).

Table 1. Capacity Management Practices in the Railway Manufacturing Line

| Rank | Practices | Mean | Std. Deviation |
|---|---|---|---|
| 1 | Helps in planning for peak periods, maintenance scheduling or equipment investment decisions | 3.94 | .957 |
| 2 | Ensures efficient resource utilization and minimizes overproduction or underutilization | 3.90 | .958 |
| 3 | Engages employees in suggesting improvements that enhance efficiency and reduce cycle times | 3.90 | .958 |
| 4 | Enhances adaptability during demand fluctuations or machine downtimes | 3.86 | 1.004 |
| 5 | Improves asset availability and extends useful life of critical machines or infrastructure | 3.85 | 1.083 |
| 6 | Reduces idle time, increases efficiency and maximizes use of available capacity | 3.82 | .957 |
| 7 | Ensures production pace aligns with available capacity and delivery schedules in railcar or train component manufacturing. | 3.63 | .894 |
| 8 | Strategies such as process redesign, equipment upgrades, or workforce reallocation are used to relieve bottlenecks | 3.62 | .951 |

### b. Bottleneck Reduction Practices

The descriptive statistics for bottleneck reduction practices reveal strong consensus regarding the effectiveness of both technological upgrades and workforce flexibility in mitigating production constraints. The highest-ranked practices replacing outdated machinery with automated alternatives and training employees for multi-functionality, each achieved a mean score of 4.05, with relatively low standard deviations (0.895 and 0.919, respectively), indicating broad agreement on their value in alleviating process slowdowns (Table 2).

Table 2. Bottleneck Reduction Practices in the Railway Manufacturing Line

| Ranking | Practices | Mean | Std. Deviation |
|---|---|---|---|
| 1 | Replaces outdated or slow machinery with faster, automated alternatives at critical points | 4.05 | .895 |
| 2 | Trains workers to perform multiple roles or tasks, enabling flexible staffing | 4.05 | .919 |
| 3 | Redistributes tasks across workstations to ensure no single station becomes overloaded. | 4.01 | .868 |
| 4 | Adjusts work schedules and shifts to allocate more resources during peak load times at bottleneck stations. | 4.00 | .860 |
| 5 | Introduces buffer zones (inventory or staging areas) before bottleneck areas to prevent upstream delays. | 4.00 | .885 |
| 6 | Implements real-time monitoring (using KPIs like cycle time, throughput rate and downtime) to detect emerging bottlenecks early. | 3.98 | .944 |
| 7 | Identifies the underlying causes of recurring delays in bottleneck areas. | 3.96 | .955 |
| 8 | Visualizes each step in the production or maintenance process to identify where delays or congestion occur | 3.95 | .837 |

Task redistribution across workstations (mean = 4.01) and adjusting work schedules during peak periods (mean = 4.00) further underscore the importance of workload balancing and resource reallocation in addressing capacity limitations. Similarly, the adoption of buffer zones (mean = 4.00) and the implementation of real-time monitoring systems (mean = 3.98) reflect proactive approaches to managing workflow variability and detecting constraints promptly. Identifying the root causes of recurring delays (mean = 3.96) and visualising each production step (mean = 3.95) also highlight the significance of data-driven analysis and process-mapping techniques in driving continuous improvement. Collectively, these findings suggest that an integrated strategy, combining automation, workforce flexibility, real-time analytics, and visual management is regarded as most effective for reducing bottlenecks in manufacturing operations.

### c. Improved Takt Time Practices

The descriptive statistics for improvement strategies related to takt time management indicate mean scores ranging from 3.55 to 3.90 (Table 3). The highest-rated practice was the involvement of frontline employees in identifying inefficiencies and proposing improvements (mean = 3.90), reflecting the strong perceived importance of employee engagement in driving process enhancement. In contrast, redistributing tasks evenly across workstations received the lowest mean score (3.55), though still suggesting a moderate level of emphasis. Standard deviations for these strategies ranged from 0.942 to 1.066, pointing to a moderate degree of variability in responses. This variability implies some divergence in participants' views regarding the importance or effectiveness of takt time improvement strategies, although consensus remains moderate. Taken together, these findings highlight the recognised value of a holistic approach to takt time optimisation integrating employee involvement, process standardisation, equipment reliability, and workflow adjustments to strengthen efficiency and reduce delays.

Table 3. Improved Takt Time Practices in the Railway Manufacturing Line

| Ranking | Practices | Mean | Std. Deviation |
|---|---|---|---|
| 1 | Involve frontline employees in identifying inefficiencies and suggesting improvements. | 3.90 | .995 |
| 2 | Introduce multiple stations for tasks that exceed takt time | 3.86 | .942 |
| 3 | Ensure that all materials and tools are available at the workstation before production starts. | 3.84 | 1.051 |
| 4 | Apply the 5S methodology (Sort, Set in order, Shine, Standardize, Sustain) to create a clean, efficient workspace | 3.78 | 1.057 |
| 5 | Multi-skilled operators can also switch roles, maintaining flow during absences or peak demand. | 3.78 | 1.000 |
| 6 | Invest in faster, more reliable machines and ensure regular preventive maintenance | 3.74 | 1.066 |
| 7 | Establish standardized procedures and work instructions for each task. | 3.73 | 1.004 |
| 8 | Redistribute tasks evenly across workstations to ensure each station completes its work within the takt time | 3.55 | 1.002 |

## d. Improved Efficiency Practices

The data reflects the ranking of improved efficiency practices based on their perceived effectiveness, as indicated by the mean scores and standard deviations (Table 4). The highest-rated practice is providing continuous training on new technologies, safety and lean practices (Mean = 3.96), suggesting a strong emphasis on workforce development for operational improvement. This is closely followed by leveraging technologies like IoT, AI and robotics (Mean = 3.89) and adopting proactive maintenance strategies (Mean = 3.85), highlighting the growing importance of digitalization and predictive maintenance. Facility design for workflow optimization (Mean = 3.83) and the standardization of tasks (Mean = 3.81) also contribute significantly to efficiency. Real-time tracking of key performance indicators (Mean = 3.81) and elimination of wasteful activities (Mean = 3.77) indicate a lean management focus. Although slightly lower, enhancing interdepartmental communication (Mean = 3.57) remains an important yet less prioritized practice. In summary, the practices reflect a balanced approach between technological adoption, process optimization and human capital development.

Table 4. Improved Efficiency Practices in the Railway Manufacturing Line

| Ranking | Improved Efficiency Practices | Mean | Standard Deviation |
|---|---|---|---|
| 1 | Provides continuous training for workers on new technologies, safety protocols and lean practices. | 3.96 | 1.116 |
| 2 | Uses technologies such as IoT, AI and robotics to automate repetitive tasks and monitor systems in real time | 3.89 | 1.040 |
| 3 | Shifts from reactive to proactive maintenance using condition-monitoring tools | 3.85 | 1.063 |
| 4 | Designs production or maintenance facilities for smoother workflow and minimal movement | 3.83 | 1.070 |
| 5 | Establishes clear, repeatable processes for production and maintenance tasks | 3.81 | 1.101 |
| 6 | Tracks KPIs like throughput, cycle time and downtime in real time. | 3.81 | 1.011 |
| 7 | Eliminates non-value-adding activities such as overproduction, waiting time and excess movement. | 3.77 | 1.002 |
| 8 | Enhances communication and coordination between departments (e.g., engineering, operations, procurement). | 3.57 | 1.084 |

## e. Reliability

According to Polit (2015), reliability refers to the extent to which a measurement instrument consistently produces stable and dependable results across time and under varying conditions. In this study, reliability was assessed using Cronbach's alpha. The analysis demonstrated high internal consistency for both constructs under investigation. Capacity Planning Practice recorded a Cronbach's alpha coefficient of 0.936 across eight items, indicating excellent reliability. Similarly, Improved Takt Time Practice achieved an alpha coefficient of 0.932 across eight items, likewise reflecting excellent internal consistency (Table 5).

Table 5. Cronbach's alpha

| Variables | Conbach's alpha value | Items |
|---|---|---|
| Capacity planning Practice | 0.936 | 8 |
| Bottleneck Reduction Practices | 0.932 | 8 |
| Improved Takt time Practice | 0.932 | 8 |
| Improved Efficiency Practices | 0.837 | 8 |

### 4.3 Proposed Improvements

To optimise capacity management and improve takt time in railway production, several targeted measures are recommended. The application of lean manufacturing principles is fundamental to eliminating non-value-adding activities and streamlining production processes. Techniques such as value stream mapping, 5S, and standardised work practices can significantly reduce process variability while promoting workflow consistency. In addition, the integration of real-time monitoring systems and digital dashboards enables continuous tracking of production indicators, early detection of bottlenecks, and the implementation of timely corrective measures. Investment in operator training and the development of cross-functional skills are equally critical to fostering workforce adaptability and enhancing task performance.

Improved synchronisation between material supply and production schedules, facilitated by just-in-time (JIT) practices, helps align input availability with takt requirements, thereby minimising idle time. Optimising workstation layouts can further reduce unnecessary movement and improve operational efficiency. Similarly, predictive maintenance of critical machinery can mitigate the risk of unexpected failures that negatively impact takt time. Finally, collaborative planning involving engineers, supervisors, and production staff encourages continuous improvement initiatives focused on cycle time reduction and process standardisation. Collectively, these strategies, when effectively implemented, have the potential to strengthen line performance, ensure consistent adherence to takt time, and enhance overall capacity utilisation in railway manufacturing operations.

## 5. Conclusion

Improving takt time in railway manufacturing, particularly within car body shell production, is vital for enhancing operational efficiency. This study identified key bottlenecks, welding delays, material handling inefficiencies, and workstation imbalances alongside contributing factors such as skill variability, equipment downtime, and supply chain disruptions. Through quantitative case study analysis, interventions including line balancing, predictive maintenance, and lean workflow redesign were shown to reduce delays, improve throughput, and optimise resource utilisation. The findings reinforce takt time as a critical performance metric in complex manufacturing systems and underline the need for data-driven, adaptive capacity management. The study provides practical insights for managers in the railway industry, offering strategies to support sustained productivity improvements and operational resilience.

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## Biographies

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