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Resilient Manufacturing Through Smart Technology Strategies

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Abstract
The impact of the pandemic has led to a dearth of manufacturing systems resilience. Manufacturing industry leadership has discovered that traditional manufacturing processes are incapacitated by inefficiencies and bottlenecks in the current traditional manufacturing process. The pandemic has exposed weaknesses in traditional manufacturing processes, prompting the industry to seek ways to enhance productivity, efficiency, and sustainability. The emergence of smart technologies like IoT, AI, and robotics presents an opportunity to transform manufacturing and bolster resilience. This research paper focuses on teaching and learning within the context of manufacturing resilience. The study delves into resilient manufacturing and explores strategies for achieving it through smart technology integration. The research provides insights into how these technologies can effectively improve manufacturing operations' resilience, offering a comprehensive framework for their adoption. The goal of the research is to develop a manufacturing education framework that enables the industry to implement strategies that can assist manufacturers to better respond to disruptions, minimize downtime, and ensure sustainability. The qualitative research explores and explains the impact of smart technologies on manufacturing, contributing to the enhancement of future work in the field of manufacturing education and learning.

Keywords
Technology, Manufacturing, IoT, Robotics, AI

Introduction
Applying a practice framework used in the design for manufacturing and assembly (DFMA) as a lens, the research paper reports on the application of mechanization in productivity improvement projects. When conventional productivity improvement tools and techniques do not yield the required results but instead produce disappointing results. Production engineering must resort to measures that can alleviate the circumstance by introducing production, and mechanization through the application of production support auxiliary equipment (Smith and Johnson, 2022). It is the responsibility of production engineering to continuously develop methods and techniques that will enable the production process to achieve responsiveness to productivity improvement stimuli.

Achieving responsiveness to productivity improvement stimuli is an ever-challenging task in the production industry (Narasimah et al. 2013) and (Hinckeldeyn et al. 2015). Thus, the scope for productivity improvement always exists and henceforth, there are alternative ways and means to achieve further productivity improvement, e.g., through mechanization of the production process. The use of mechanization techniques such as auxiliary production support equipment, jigs, fixtures, and spindles to increase the responsiveness of production to productivity improvement stimuli is widely documented. Notwithstanding, the extent and depth of research in productivity improvement, there is very little literature on the design and application of other auxiliary production support tools and equipment.

Technically, a productivity dilemma occurs when conventional productivity improvement tools and techniques are applied in a production process and the result is an improvement in the production cycle time, but the process does not yield an increase in production output. Production cycle time is shorter due to the improvement attained

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by applying conventional productivity improvement techniques, but the time saved is not significant enough to increase production output. This phenomenon is a case under study in this research paper, the research occurs in a rail locomotive maintenance operation, in which locomotive components are replaced during a maintenance-service production process. When conventional productivity improvement is engaged, the cycle time is reduced but it does not result in a significant increase in output.

The reason for the lack of output increase is that the amount of production time saved does not equal the time required to service one (1) extra locomotive. Therefore, although cycle time is improved, production output is not increased and thus there is no productivity improvement (Benzaquen, 2017). Productivity improvement is not achieved, since productivity generally refers to the amount of work that is accomplished in a unit of time, using the same input factors, i.e., without increasing input factors of a production process. Productivity improvement can also be achieved when the amount of work accomplished in a unit of time stays unchanged, while the input factors are decreased (Shakeabukor et al., 2015).

Therefore, production growth or productivity increase resulting from the increase in the volume of factor inputs to a production process is limited by design as depicted in Figure 1 below. When production input volume is increased from P1 – to P2, the output growth increases from T1 –to T3. T3 is not the maximum output capacity of the production system but it is the maximum possible through the increase in input-factor volume. Growth increase resulting from productivity improvement is a better option for the production output increase, as depicted in Figure 1. Output growth is greater when it is caused by productivity improvement, for the same input-factors, i.e., volume increase of P1 –to- P2. The resultant production growth caused by productivity improvement is T2 (see fig.1 below).

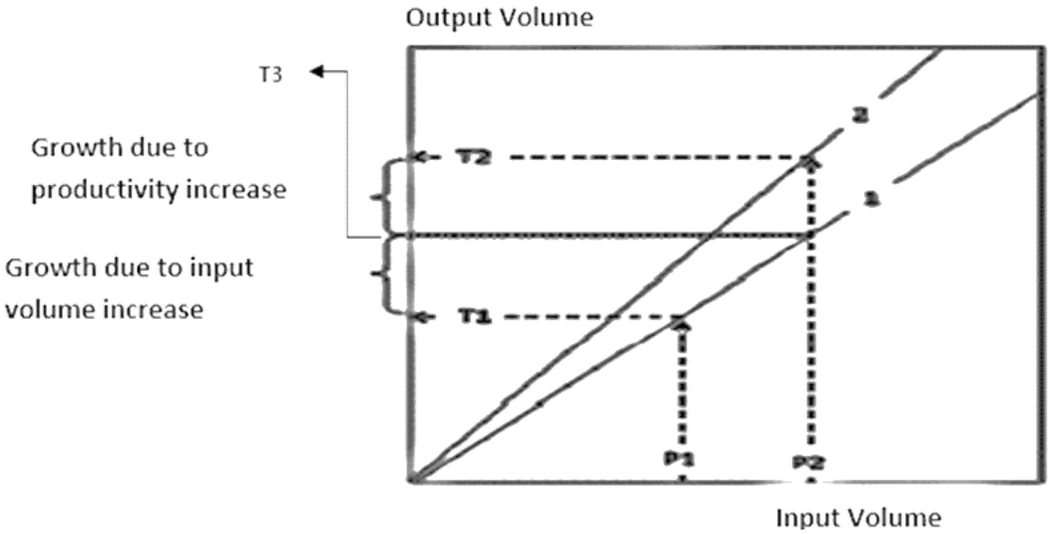

Figure 1. Component of Production Growth (Source: Saari, 2006)

The research presents a comprehensive example that illustrates the application of mechanization in productivity improvement initiatives, as a plausible panacea. Experimenting with the application of mechanization techniques such as auxiliary production support equipment, in productivity improvement culminates with a contribution to the body of knowledge for productivity improvement. This research presents an investigation outcome in which production support auxiliary equipment is applied in a productivity improvement process and the result is an increase in output; reduced turnaround time; process optimization and productivity improvement. The application of production auxiliary equipment is studied, and the results produced are used as support for the presupposition that maximum productivity improvement can be achieved with the application of mechanization in production operations.

The results of this research in which mechanization is applied in productivity improvement initiatives in a rail setting, confirm the production efficiency theory. Production efficiency theory argues that any combination of input factors of production at any point on a positively sloped isoquant is inefficient (Murillo-Zamorano 2004), i.e., combinations of input factors to production where productivity increase is a result of an increase in either of the inputs or both. An efficient combination is only found on the negatively sloped portion of a convex isoquant

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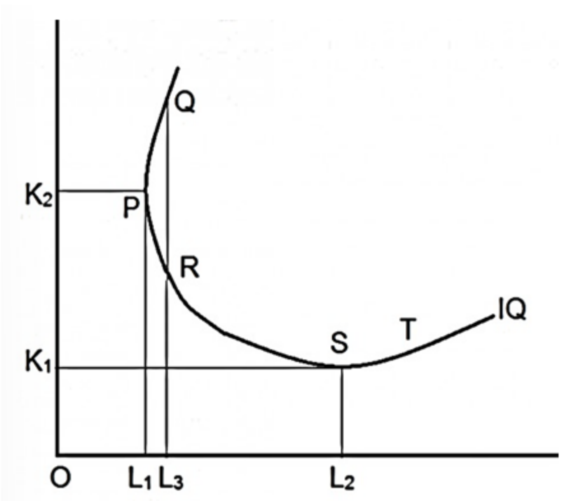
(Murillo-Zamorano 2004:34), where an increase in productivity is because of a decrease in either of the input factors to production. This efficient portion is characterized by less quantity of the input factors to production and the resultant is the same level of production output or higher.

Literature Review

Productivity improvement is typically discussed on two levels: national and organizational (Macro- and Micro-levels respectively). Nationally, productivity is seen through an economic lens, while at the organizational level, it reflects the entity's profitability. Enhancing national productivity forms the foundation for economic growth, competitiveness, and improved living standards (Kapyla et al. 2010; Nakamura et al., 2018). On the organizational side, productivity improvement involves using resources efficiently and effectively in the production process. Thus, micro-level productivity improvement becomes crucial for sustaining organizational profitability (Kapyla et al., 2010; Kapyla et al., 2014). In practical terms, productivity is often measured as the ratio of output to input, signifying the effective utilization of resources in producing goods or services. In practical terms, productivity is often measured as the ratio of output to input, signifying the effective utilization of resources in producing goods or services. Various methods are used in the production industry to measure productivity, but two common measures stand out: total factor productivity (TFP) and partial factor productivity (PFP). TFP is the ratio of total output to total input, where input includes labor, materials, equipment, energy, and capital (Thomas & Sudhakumar, 2014). Partial factor productivity is a measure of a single or a selected set of inputs in Eq.1, and it is expressed as the ratio of output to a single input or selected set of inputs. A common example of PFP is labour productivity, which is expressed as a ratio of output quantity to labour hours input. TFP is relatively difficult to compute but the measurement process is easier and controllable than when a partial factor measure is used in the computation (Thomas & Sudhakumar 2014).

In this research, PFP is measured for varying quantities of labour hours and a comparison of output for different labour inputs is done. Then the results are compared to the output of a technical change when auxiliary production equipment is applied. The law of returns to scale is a better example to use when experimenting with labour input for the calculation of PFP (Murillo-Zamorano, 2004:41) in a production and maintenance environment. The application of the law of returns to scale in the production industry where a PFP is calculated using variable amounts of labour hours and a constant capital input is depicted well using the consumer indifference curves or isoquants (Murillo-Zamorano, 2004). Isoquants are a firm's counterpart of the indifference curves (Murillo-Zamorano, 2004) see fig.2 depicted below:



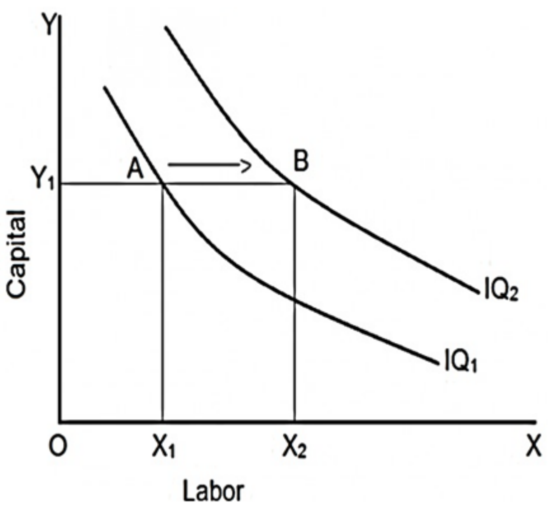


Figure 2. Production Isoquant curve and an Indifference curves map (Coelli et al. 2005)

The production isoquant curve is depicted above in the figure.2 fully illustrates the technological set of a production unit. A technological set captures all the production points with a minimum combination of inputs per output needed to produce a unit of production output. Therefore, all production input factor combinations that outline the unit isoquant PS are technically efficient (Murillo-Zamorano, 2004:34). Point P in Figure. 2 and all other points that settle above and to the right of the isoquant PS delineates a technically inefficient production input factor's combination. These points that are above and to the right of the PS curve define a technically inefficient producer since the input factors combination that is being used is more than enough to produce a unit of output (Murillo-Zamorano 2004:34).

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Mechanization of production and manufacturing equipment with the addition of auxiliary equipment improves the technological set of the production unit. To illustrate the relationship between input and output, in productivity studies, the use of a production frontier is appropriate since a production frontier represents the maximum production output attainable from each input factor level (Coelli et al. 2005). Therefore, a production frontier reflects the current state of technology in the particular industry and the technological set of a production unit. Henceforth and by implication, firms in the industry will operate on the production frontier, if they are technically efficient, or beneath the frontier if they are technically inefficient (Coelli et al. 2005). Fig.3 is an illustration of technical efficiency or inefficiency using a production frontier.

Production operations operating below the production frontier will result in lower productivity (Coelli et al., 2005) because any point on the frontier represents optimal technical scale, achievable only through efficient technical changes, which are realized through economies of scale exploitation. Thus, there's an additional source of productivity improvement known as technical change (Coelli et al., 2005), enabled by technological advancements, demonstrated by an upward and rightward shift of an efficient production frontier. This productivity enhancement in a specific production unit is illustrated by the movement from production frontier OF’0 to OF’1, as shown in Figure 3.

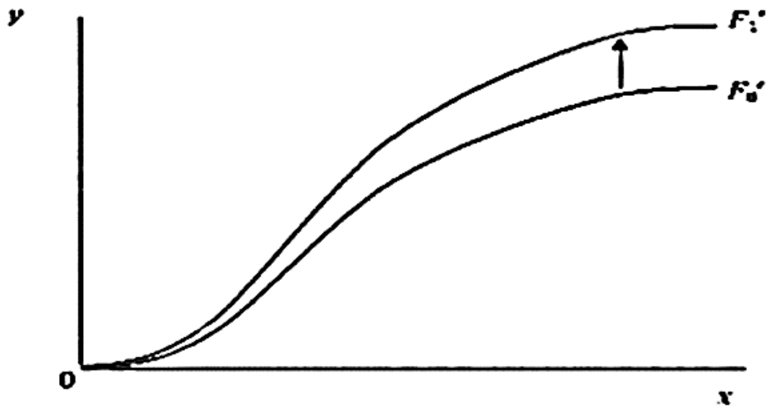

Figure 3. Economically feasible segment of a production Isoquant (Adapted from Coelli et al. 2005)

Mechanizing production with auxiliary equipment dates back to as early as 1800. One notable example is Roberts' introduction of the spinning mule in 1830, which significantly boosted productivity. Nithya and Saravanan (2015) argue that innovation plays a crucial role in maximizing the impact of new technology. Therefore, the idea that enhancing productivity is a major concern for nearly all industries, with continual opportunities for improvement, holds true. Consequently, production engineers are constantly engaged in researching ways to design and fabricate production auxiliary attachments, jigs, and fixtures (Alpert, 2003). They are consistently exploring production engineering methods to further enhance productivity, as suggested by Narasimah et al. (2013) and supported by Kamodkar et al. (2018). Therefore, the use of auxiliary production equipment such as jigs, fixtures, and other production support equipment is critical for productivity improvement. The results of this research provide evidence of the impact of auxiliary production support equipment on productivity improvement initiatives.

Research Method

To achieve the aim and objectives of the research and meet the requirements of the primary research question and the underlying assumption, a research paradigm is formulated. This paradigm serves to elucidate the nature of scientific truth, the theoretical framework, the methodology, and the data collection tools adopted in the research. Both the research question and the presupposition demand a paradigm that allows the researcher to delve into the definition of reality and address the following inquiries: what knowledge is acquired and how it is acquired. The procedure, tools, and techniques employed to acquire this knowledge, as well as the data collection process, are explained.

This research adopts a qualitative research approach because it allows researchers to gain insight into the phenomenon from the perspective of those experiencing it (Baxter & Jack, 2008; Flick, 2018). The shared purpose of qualitative research studies, as outlined by Baxter & Jack (2008), lends credibility to adopting qualitative research methodology. Following the decision to utilize a qualitative research approach for this study, various qualitative research methods are considered and analyzed (e.g., Phenomenology, Grounded Theory, Ethnography, Participatory Action Research (PAR), Hermeneutics, Case Study, Narrative, Evaluation Research (PAR),

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Observation, etc.). Therefore, this research is structured to focus on a qualitative research approach, employing action research methodology (AR) and a case study method.

Data Collection

Data collection for this study will be conducted using qualitative methods to suit the research design. A key feature of the case study method is the utilization of multiple data sources (Yin, 1994 & 2018; Patton, 2002), a strategy known to enhance data credibility (Patton, 2002; Yin, 2003). This case study will employ the following triangulation of data sources: i) document analysis and archival records analysis; ii) analysis of journal publications and field notes; iii) observation and analysis of the production process through SREDIM. By employing a combination of data sources and collection methods focused on a single phenomenon, researchers can leverage multiple sources of evidence, thus seeking convergence and corroboration to enhance credibility (Patton 2002; Yin 2003). This triangulated approach to data collection provides a comprehensive understanding of the case under study.

Results and Discussion

The maintenance demand plan requires eight (8) locomotive component replacements per day, consisting of 4 electric and 4 diesel components. However, the current capacity of the production line is only four (4) component replacements per shift, which is equivalent to a 9-hour shift. By adding three (3) hours of overtime per shift (totaling 12 hours), production output increases by one (1) component changeover, resulting in a total output of five (5) locomotive lifting activities per shift. To meet the demand and achieve an output of eight (8) locomotives per shift, productivity improvement is essential. However, improving productivity in the rail industry (and heavy industry in general) is complex due to the challenge of rapidly increasing infrastructure, equipment, and resources without incurring high costs.

Various conventional productivity improvement techniques were applied, including Lean, Six Sigma, Theory of Constraints (TOC), and Time and Method Study, to increase production output and meet the current target of eight (8) component replacements per shift. Increased output is achieved by reducing production cycle time, allowing more replacements to be completed in the same production shift. This involves a thorough study of the production process, application of production process analysis, initiation of method analysis, and the resulting improvement of production process methods. Improvements in methods lead to shorter cycle times, resulting in increased output and ultimately productivity improvement.

Numeric Results

First, a process analysis method is applied to the current component replacement production process as a selected case study unit for this research. Second, the "As Is" production process is recorded and a process flow of the current production activities is established (see Figure.1). Third, The "As Is" or current production process is examined through the application of time and method study techniques, the resultant is an identification of process waste and unnecessary motion and storage. Fourth, Method Analysis is applied to develop an easier, simpler, more efficient, and cost-effective working method (see Figure.2).
Based on the results of a method analysis, a process improvement technique is applied to improve the production operations process by reducing non-value-adding activities and removing waste (see Figure. 3). The result is a better utilization of resources, i.e., capital, personnel, and equipment. Fifth, when the improvement achieved with the application of time and method study does not yield the required target productivity and technology innovation is applied to the maintenance production process. Then an improved future-state production process is established. Sixth: The new production process is monitored and managed to maximize production output and for continuous improvement. Thus, the method improved is applied to the new maintenance production process.

The results of mechanizing the production maintenance process show a shorter process cycle time and improved efficiency in the new production process. Enhanced efficiency of the new method means fewer non-value-adding operations and less waste, resulting in increased overall operations efficiency. These outcomes indicate that the new maintenance production process (TM replacement process) is better optimized than the "as is" production process. Consequently, the new TM replacement process is more efficient than the old locomotive lifting production process. Improved process efficiency implies that the inputs of a production process are better utilized, resulting in increased output and ultimately improving productivity.

The application of Smart manufacturing techniques such as Mechanization leads to an optimization of the production maintenance process and a higher production yield is obtained.

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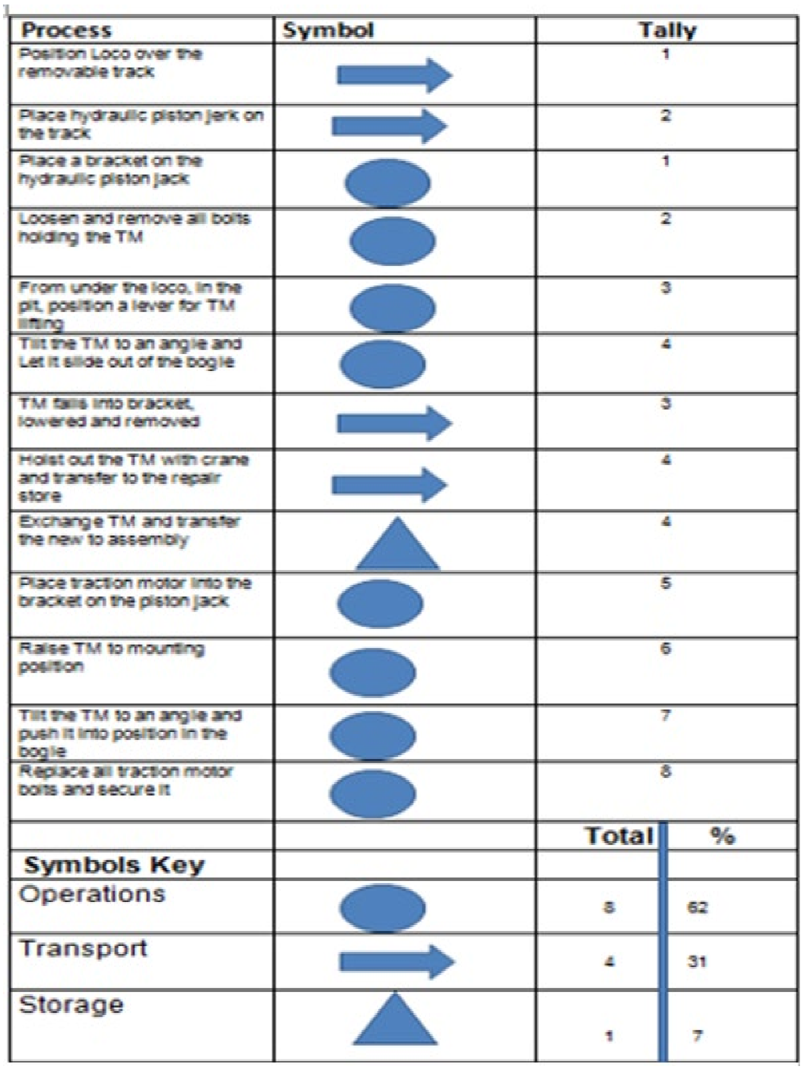

Process	Symbol	Tally	
Position Loco over the removable track		1	
Place hydraulic piston jerk on the track		2	
Place a bracket on the hydraulic piston jack		1	
Loosen and remove all bolts holding the TM		2	
From under the loco, in the pit, position a lever for TM lifting		3	
Tilt the TM to an angle and Let it slide out of the bogie		4	
TM falls into bracket, lowered and removed		3	
Hoist out the TM with crane and transfer to the repair store		4	
Exchange TM and transfer the new to assembly		4	
Place traction motor into the bracket on the piston jack		5	
Raise TM to mounting position		6	
Tilt the TM to an angle and push it into position in the bogie		7	
Replace all traction motor bolts and secure it		8	
		Total	%
Symbols Key			
Operations		8	62
Transport		4	31
Storage		1	7

Figure 4. Method Improvement of the New Production Process (Source: Author)

The results of the method analysis of the new production process demonstrate that the new process has a high percentage of value-adding process activities as compared to the improved “As Is” production process. Therefore, to assess the efficiency of the new production process (TM replacement) an application of a method improvement technique was instituted on the new TM replacement production process (see Figure.4). Results of this process improvement initiative demonstrate a 25% reduction of wasteful operations activities, 18% reduction in non-value adding movement and an elimination of storage within the production process. The new production process cycle time is 1hr to complete a TM replacement (compared to 2hrs of “AS IS” process). The method improvement exercise culminated into a reduced production cycle time and an improved efficiency of the new production process.

Graphic Results

The application of Smart technology techniques such as Mechanization on the new production process (TM replacement) results in optimum and maximum production and operation process productivity. Operations efficiency is improved by 25%, transport is reduced by 18% and storage is completely eliminated in the new production operations. The production cycle time decreases from 2hr to 1hr, achieved through improved utilization of production resources.

Analysis of production output data demonstrates the impact of the application of auxiliary equipment in productivity improvement initiatives as positively high. The impact of the application of Mechanization on production, through support auxiliary equipment in productivity improvement is vividly demonstrated in the productivity improvement data table (see Table 1).

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Table 1. Production Output Optimization Statistics Resulting from Mechanization.

Analysis Theme	'As Is' production process		Productivity Improvement		Application of Auxiliary equipment	
	HRS	Output	HRS	Output	HRS	Output
Normal Shift	9	4	9	5	9	8
Over Time	3	1	3	1	3	3
Night Shift	12	5	12	6	12	11
Total	24	10	24	12	24	22
Increase in productivity						
	%	0	%	20	%	120

In table.1, the 'As Is' production process has an output of 10 TM replacements in 24Hrs. When productivity improvement techniques are applied to the 'As Is' there is a 20% productivity improvement in output. Therefore, the total output in 24hrs is increased by two (2) component replacements, which becomes 12 in 24hrs. When auxiliary production support equipment is applied in productivity improvement, the resultant total output improvement is a 120% productivity improvement. Note that with the application of auxiliary production equipment (Mechanization) the production process output is 11 in a 12 hrs shift (22 in 24hrs). Therefore, the demand plan target is achieved. Productivity improvement experienced also alludes to an increase in efficiency, and the reduction of waste and non-value-adding activities, when Smart technology is applied (see Figure 5).

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Process	Symbol	Tally		Modification	
Position Loco over the removable track	➡	1		Set up	
Place hydraulic piston jerk on the track	➡	2		Set up	
Place a bracket on the hydraulic piston jack	●	1		Set up	
Loosen and remove all bolts holding the TM	●	2			
From under the loco, in the pit, position a lever for TM lifting	●	3			
Tilt the TM to an angle and Let it slide out of the bogie	●	4			
TM falls into bracket, lowered and removed	➡	3			
Hoist out the TM with crane and transfer to the repair store	➡	4		Set up	
Exchange TM and transfer the new to assembly	▲	4		Set up	
Place traction motor into the bracket on the piston jack	●	5			
Raise TM to mounting position	●	6			
Tilt the TM to an angle and push it into position in the bogie	●	7			
		Total	%	Improved Process	
				Total	%
	●	8	62	7	87
	➡	4	31	1	13
	▲	1	7	0	0

Figure 5. Process Optimization process results through the application of Mechanization
(Source: Author)

The graph in Figure 6 demonstrates an intrinsic examination of the interrelationships among variables within each case of the study. Consequently, comparing across cases to search for patterns and similarities reveals a fundamental understanding of the displayed phenomenon. For instance, the variable 'over time' output remains the same across the two cases, despite a productivity improvement of 20% in one specific case.

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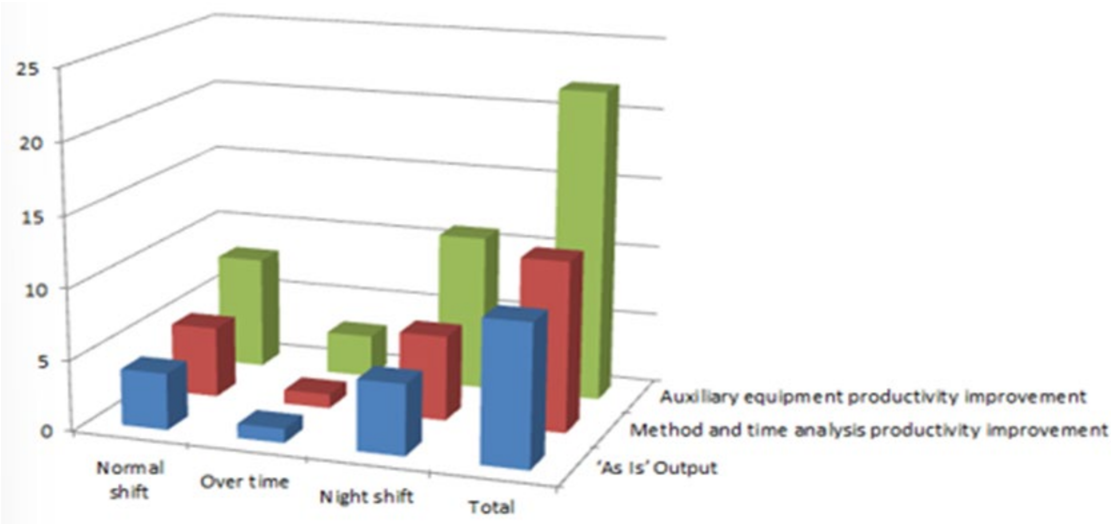

Figure 6. Production Results for different interventions in a shift (Source: Author)

Thus, it can be broadly generalized that not all process improvements will lead to an increase in output. Based on a generalized definition of productivity, which concerns the ratio of output to input, the interrelationship between the variable 'overtime' within the case 'Method and time productivity improvement' challenges a presupposition that all productivity improvements will result in increased output.

Proposed Improvement

An intrinsic examination of the interrelationships among variables within each case and engaging a comparison across cases, in search of patterns and similarities, reveals an elementary establishment that the results obtained in un-optimized productivity improvement activities are a reflection of the limitation inherent in productivity improvement tools and techniques in a particular industrial setting

The industrial setting in railway maintenance operations is rigid, therefore the output of conventional productivity improvement initiatives falls short, and the productivity achieved is less than the maximum possible output. The identified improvements are:

(i) *Identification of Limitations*: Recognize the limitations inherent in productivity improvement tools and techniques.

(ii) *Optimization of Productivity Tools*: Optimize productivity improvement activities to address the identified limitations.

(iii) *Adaptation to Industrial Setting:* Tailor productivity improvement initiatives to suit the specific industrial setting of railway maintenance operations.

(iv) *Increased Output:* Aim to achieve maximum possible output by overcoming the limitations of conventional productivity improvement initiatives.

(v) *Dynamic Approach*: Adopt a more dynamic approach to productivity improvement in a rigid industrial setting.

These proposed improvements aim to enhance productivity in railway maintenance operations by addressing the limitations identified in conventional productivity improvement methods.

Validations

Through a systematic study of the critical attributes of the limitations of conventional productivity improvement techniques and the implementation of the work-study method, it has been established that maximum and optimal improvement in productivity can be achieved. This is also true when employing auxiliary support equipment in productivity improvement initiatives. The use of auxiliary production support equipment in such projects offers significant advantages, as it can simultaneously increase total production output and substantially improve percentage growth in productivity, as demonstrated in Figure. 7 below. The utilization of auxiliary equipment in productivity improvement initiatives has a significant impact on the production cycle time.

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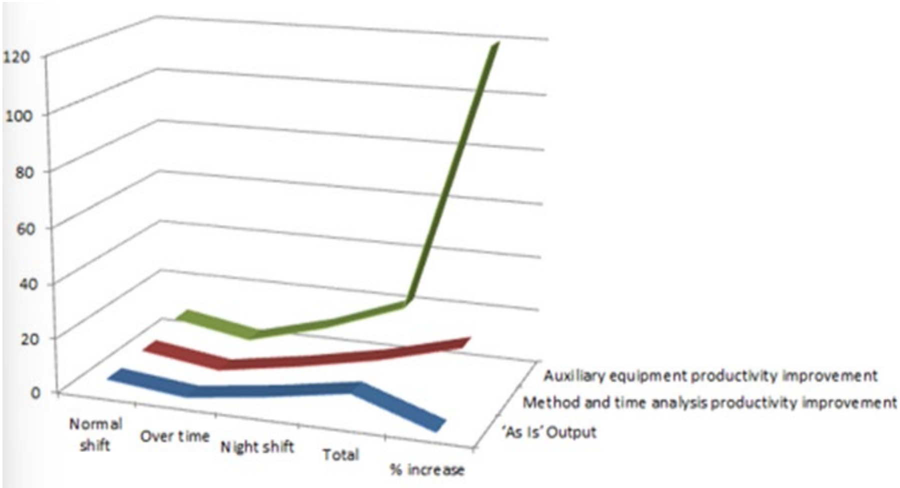

Figure 7. Validation of Productivity Results through Smart Manufacturing (Source: Author)

The magnitude of the time value-add generated in productivity improvement initiatives is directly proportional to the output yield. Productivity improvement yield is greater when auxiliary equipment is utilized in these initiatives. The total output yield is higher in cases involving auxiliary equipment, as depicted in Figure 7, and the percentage increase is the highest among all productivity interventions. The application of auxiliary production equipment in productivity improvement demonstrates its ability to simultaneously increase total production output and significantly improve percentage growth in productivity (as shown in Fig. 7).

The utilization of auxiliary equipment in productivity improvement initiatives has a substantial impact on the production cycle time, thereby influencing production output and, consequently, productivity.
Therefore, it is apparent that it is crucial to underscore the significance of incorporating the design of jigs, fixtures, and auxiliary production equipment into our manufacturing and production educational and learning endeavors.

Conclusion

In conclusion, the design and utilization of jigs, fixtures, and auxiliary production equipment are integral components of efficient manufacturing systems. These tools ensure precision, repeatability, and consistency in production, thereby enhancing overall quality and efficiency. It is imperative to incorporate this aspect into manufacturing education to equip future professionals with the skills and knowledge needed to optimize production operations. By integrating the design and use of jigs, fixtures, and auxiliary production equipment into educational curricula, we ensure that students are well-prepared to tackle real-world manufacturing challenges. This practical knowledge empowers them not only to leverage smart technologies but also to maximize their benefits by seamlessly integrating them into existing manufacturing systems.

Moreover, by focusing on these foundational aspects of manufacturing, we establish a framework that enables the industry to cultivate a workforce capable of adapting to various manufacturing scenarios, from traditional to advanced technologies. This adaptability is crucial for building resilient manufacturing systems capable of withstanding disruptions and ensuring sustainable production.

The future of manufacturing education must embrace a holistic approach that encompasses both cutting-edge technologies and enduring principles of efficient manufacturing. By emphasizing the design of jigs, fixtures, and auxiliary production equipment, we lay a solid foundation for the continued growth and innovation of the manufacturing industry, producing skilled professionals ready to meet the challenges of the future.

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