Application of Auxiliary Equipment in Productivity Improvement

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Abstract--**Production engineering is facing challenges as a result of stiff competition in today's market because manufacturers are under pressure to respond to customer demands and quality. These conditions put an insurmountable pressure on the production process and productivity improvement becomes the required leverage for an organization. When conventional productivity improvement tools and techniques do not yield the required results, engineering has to resort to measures that can alleviate the circumstance by introducing productivity support auxiliary equipment. Achieving responsiveness in productivity improvement is an ever-challenging task in the production industry. The scope for productivity improvement always exists and therefore there are alternative ways and means to achieve further productivity improvement, such as the application of auxiliary equipment in productivity improvement initiatives. Preliminary qualitative research supports the use of auxiliary production support equipment such as fixtures, jigs and spindles to increase the responsiveness of production to productivity improvement requirements. This paper presents a comprehensive example that illustrates the application of auxiliary production support equipment in productivity improvement initiatives. A comparison of results achieved with and without the application of auxiliary equipment is used as supporting evidence that auxiliary equipment has a huge impact on productivity improvement when applied in the production industry.**

I. INTRODUCTION

The application of productivity improvement tools and techniques on a production problem of limited and scarce resources, result in an increase in the utilization of current available resources and the spin-off is a significant increase in productivity. Older manufacturing methods became obsolete with the emergence of computer numeric programming machines and more production operation had to adopt more economical operations for manufacturing methods. These new economical methods were developed and implemented through better design of auxiliary production systems such as the fixturing systems that employ jigs, fixtures and other auxiliary production tools [23]. Auxiliary production equipment such as jigs and fixtures are tools and devices that are used in traditional manufacturing and in modern flexible manufacturing systems to improve productivity; machining quality; and cost of finished products. Therefore auxiliary production equipment form a systems in which production improvement tools enable a faster and more profitable production process through a quick clamp or positioning of fixtures into a correct relationship with production process tools or machines [23]. Azar et al. [2] deliberates on the evolution of machines and states that a number of add-ons have been developed to enhance performance of operations [2], these deliberation emphasise the critical role that production support auxiliary equipment occupy in productivity improvement initiatives. In the study of the design, development and implementation of automated machine guidance (AMG), the author found that these auxiliary production support equipment increased productivity by 30% for large earth moving machines and depending on the conditions of operation and the environment, a greater productivity improvement is plausible [2]. In addition to productivity increase, application of auxiliary production support equipment (in Azar's case of AMG and in this research's case of auxiliary equipment) results in more savings due to reduced production cycle time [2].Companies gain competitive advantage by improving upon productivity to build projects at lower costs, because productivity translates directly into cost saving and profitability [18].

II. LITERATURE REVIEW

Productivity is generally referred to as the ratio of output to input. It is also referred to as the effective utilization of resources in producing goods and / or services [22]. Production industry uses various and numerous measures of productivity, although there are basically two productivity measures that are commonly used. The two commonly used measures are total factor productivity (TFP) and partial factor productivity (PFP) [22]. TFP is defined as the ratio of total output to total input, with the latter comprising of labor, material, equipment, energy and capital. TFP is equation is expressed as shown in Equation 1 below.

$$TFP = \frac{Total\ Output}{\sum(Labor + Material + Equipment + Energy + Capital)} \quad \text{Eq. 1}$$

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(s) to a single and /or selected set of input(s). A common example of PFP is Labor productivity, which is expressed a ration of output quantity to labor hours input. PFP equation is expressed as shown in Equation 2 below.

$$\text{PFP} = \frac{Output\ quantity}{Labor\ hours} \quad \text{Eq. 2}$$

TFP is relatively difficult to compute but the measurement process is easier and controllable when a partial factor measure is used in the computation [22].

Productivity has been extensively studied by researchers to identify opportunities for productivity improvement. The scope for productivity improvement always exists and thus there are alternative ways and means to achieve further productivity improvement, including the application of auxiliary equipment in productivity improvement initiatives.

Mechanization of production and manufacturing equipment with the addition of auxiliary equipment dates as far as the 1800. The introduction of a spinning mule by Roberts (1830) is one famous example of improving productivity with the aid of auxiliary equipment and, since then productivity improvement with the aid of production support auxiliary equipment has been researched and applied in various production industries. Numerous postulates on the use of auxiliary equipment in productivity improvement have been published. In Girczyc and Carlson [9], Boothryd [6], Adendorff [1], Hermann and Chincholkar [11], Kahng [12], Wiyaratn and Watanapa [24], Narasimha et. al. [16], Kulkarni et al. [13], Vashist [23], Azar et al. [2], and Nithya & Saravanan [18].

Nithya and Saravanan deliberates that the one aspect that improves the impact of new technology is an innovation. Innovation that decreases the investment and maintenance costs along with a comprehensive understanding of how technology can be most effectively utilized, to improve productivity [22], for example the introduction of a spinning mule.

Vashist et al. assert that production support equipment such as fixtures have a capability to improve productivity when modified and implemented in a production process [23]. Therefore a fast and more profitable production method requires a device on which the component can quickly be positioned in a correct relationship with manufacturing tools and then productivity is improved [23].

Kulkani, Kshire and Chandratre argue that with the rapid increase in demand of production, manufacturing industries need to increase their capability in production and effectiveness to compete against their competitors. At the same time, the production process has to be ready with the ability to have abated costs with higher proficiency [13]. Hence the route to simplify the problem regarding production through the application of auxiliary equipment is of paramount importance.

Narasimha, Kumar and Moorthy highlight that the increasing productivity is an ever-challenging task and the scope for further improvement of productivity always exists, hence engineers are constantly exploring ways and means for design and fabrication of attachments or Jigs and fixtures (production support auxiliary equipment) [16].

Kahng's assertions about the design productivity gap, is also true for production productivity gap. The author is very articulate about the need to address the well- known Productivity Gap by addressing the technology productivity Gap [12]. Technology productivity is critical in productivity where complexities must be managed without sacrificing system value and turnaround time [12], hence the application of production support auxiliary equipment.

Herrmann and Chincholkar state that redesign suggestions which can increase the maximum possible output can be made in design for production (DFP), a methods that evaluates product design by comparing its manufacturing requirements to available capacity. Design for production encourages the use of auxiliary production support for productivity improvement [11].

Govil and Magrab developed and approach for determining the maximum production in a given time horizon. This approach assumes that the production cycle time at each production operation is one time period [15]. The approach uses the assembly structure to create a tree of operations and therefore the process is susceptible to the application of auxiliary equipment.

Adendorff and de Wit stipulates limitations, that are inherent in all productivity measurement theories, these are (i) It clarifies effect and not the cause; (ii) It prescribes a linear relationship, which does not always apply in practice. And productivity improvement opportunities manifest in the soft rather than the hard components of productivity improvement [1]. Therefore productivity is measured in order to collect feedback in a form of data that forms the bases for decisions aimed at changing behavior and reengineer the production process. Application of auxiliary production support equipment in productivity improvement calls for reengineering the production process.

Boothryd asserted that Japan has the most productive plants and automation and production support accounts for one-third of the total productivity in production plants. Since auxiliary production support equipment are part of automation and productivity improvement, Boothryd comments highlight the impact of auxiliary production support equipment on productivity improvement [6].

Girczyc and Carlson conclude that quality increases because of automation tools can explore greater alternatives and are less likely to make mistakes [9]. Thus the use of automation tools such as auxiliary production equipment increases quality and productivity.

Considering assertions of these scholars and their postulate theories, it is apparent that a productivity GAP exists in various forms within different types of industrial production settings. Thus Kahng's theory is plausible and material, for it states that, it takes longer to transfer leading edge publications into production flows and therefore the lag experienced forces industry to battle today's problems with yesterday's technology solutions [12].

Therefor the proclamations of Narasimha; Kumar and Moorthy, that to further improve productivity, a constant exploration of ways and means for design and fabrication of production support auxiliary equipment, were preliminary reviewed and are considered plausible. The plausibility of Narasimah's theory is influenced by the contents of the theories postulated, primarily in the literature about production auxiliary equipment and its impact on productivity. Some of parts of the body of this literature are stipulated below:

- Productivity improvement by fixture modification [23]
- Design of adjustable multi-spindle attachment [16]
- Design for production: A tool for reducing manufacturing cycle time [11]
- Design technology productivity in the DSM era [12]
- Product design for manufacture and assembly [6]
- Increasing design quality and engineering productivity through design reuse [9]

Literature review highlights the prevalence of the limitations inherent in the productivity improvement theory [1], and it also highlights the materialization of Kahng's theory that the lag in productivity technology solutions is consequential of the productivity gap [12]. Although the productivity gap theory is more confined to design productivity, it has implications on the production process productivity improvement. The role of designing production support equipment such as attachments; spindles; jigs and fixtures, and the application of auxiliary production support equipment in productivity improvement projects has been emphasized as critical and indispensable in the literature review. Therefore the notion that enhancing productivity is a key concern for almost all industries and that further productivity improvement opportunities always exist is plausible. Hence ways and means of designing and fabricating production auxiliary attachments, jigs and fixtures, are constantly explored by engineers as proposed by Narasimah et al.

III. CONCEPTUAL FRAMEWORK

Application of productivity improvement tools and techniques in production operations is a challenge because industrial settings vary in complexity and the environment is mostly fixed and rigid. This implies that a broad engineering research frame work is required, a holistic view that incorporates the traditional technical content and relevant attributes dictated by the socio-economic environment, all integrated into an production engineering research framework. It is apparent, therefore that this research requires a methodology that takes a broader perspective than a single primary research study focused in a particular direction. The goal of the research is to explore and explain how production auxiliary equipment is applied to improve productivity. This research will solicit and discover the descriptions and interpretations of constraints experienced by personnel in the production process. Therefore a qualitative research approach is suitable and appropriate for this research orientation.

Qualitative research is appropriate for this study because it enables researchers to establish an understanding of a phenomenon from the perspective of those who experienced it. The shared purposes of qualitative studies, as depicted in the Baxter & Jack, increases the plausibility of applying qualitative research methodology in this research. There are four purposes/ goals highlighted in a qualitative research and these are instrumentation; illustration; sensitization and conceptualization [5]. Instrumentation is applied in qualitative research to collect in-depth descriptive data about a particular topic; Illustration enables a research to apply one or more qualitative data collection approaches to provide a greater understanding of the phenomenon under study; Sensitization is achieved when the data obtained from participants enables the researcher to comprehensively interpret the participant's experience and subsequently develop appropriate interventions; and conceptualization of the phenomenon is illustrated in the richness of the theory afforded by the study [5].

This research is poised to focus on a specific qualitative research methodology, which is the application of case study methodology. The case study methodology is a science of the singular which aims to understand what is distinctive of a case, defined as a complex functioning system or policy or a program or process [19].

IV. METHODOLOGY

Qualitative case study methodology affords researchers opportunities to explore and explain a phenomenon within its context using a variety of data sources [5]. This approach ensures that the phenomenon under study is explored through a variety of lenses which allows an in-depth understanding and allows multi facets of the case under study to be revealed and understood [5]. The case study approach aligns with the goals of this research in that the focus of the study is to explore and explain "how" (the application of auxiliary equipment improves productivity) and it covers the contextual conditions in which the phenomenon under study occurs. Therefore this research adopts the case study methodology. The unit of analyses (case) in this study is how auxiliary equipment impacts on productivity improvement. This is a phenomenon occurring due to the impact of auxiliary equipment on productivity improvement and is bounded to current impact of technology on the production process in an industrial setting.

Attributes of this research satisfy the definition of a case as stipulated by Miles and Huberman and they are in line with Yin and Stake stipulations concerning setting boundaries for cases in a case study research approach [5]. The research also appeals to boundaries stipulated by Creswell, those of time and place [5]. In line with the boundaries of the definition and context, and the research question (i.e. How auxiliary equipment impacts on productivity improvement), the type of case study this research adopts aligns with explanatory and exploratory or descriptive case study as categorized by Yin [5].

A case study methodology is adopted to address various propositions and this case the research will lead to a development of solutions or recommendation that will address the following propositions: (i) Application of auxiliary production equipment in productivity improvement interventions will result in improved productivity, (ii)

Competing propositions. Propositions are necessary elements of a case study research in that they both lead or precede the development of a conceptual framework that guides the research [5].

V. DATA COLLECTION TOOLS

Yin and Patton stipulate that the hallmark for case study research is the use of multiple data sources, a strategy which also enhances data credibility [5]. This case study will apply the following triangulation of data sources i) Analysis archival records and; ii) Documents and field notes analysis; and iii) Process Observation.

It is rational to apply document analysis in this research since it is often used in combination with other qualitative research methods as a means of triangulation, i.e. the combination of methods in the study of the same phenomenon to enable a researcher to draw upon multiple sources of evidence, seek convergence and corroboration through the use of different data sources [7]. Rossman and Wilson, in their study of evaluating regional education service agencies, designed document reviews to identify the mission of agencies as described in documents and reports [7]. Sogunro provided an exemplary clarity concerning the use of document analysis, he reported that the use of document analysis provided information on history, goals, objectives and substantive content of the phenomenon under study [7]. Stake and Yin found that document analysis is particularly applicable in qualitative research for intensive studies producing rich descriptions of a single phenomenon [7].

The use of archival data is supported by the claim that archival data is an increasingly viable resource because of an ever greater amount of archival verbal and visual material that has become universally available with the information proliferation attributes of the internet. Archival data comprises of wide array of empirical data created by researchers for their personal use or on behalf of an organization. Contents of an archive that is applicable in this research consist of various material (e.g. letters and diaries; weblogs and discussion list posting; press releases and reports; magazine articles and rating websites; etc). Archival data will be used to develop an understanding of the research context and where applicable to inform the development of concepts and theories.

The rational to apply field notes is supported by Patton reflections that field notes are applied in qualitative research to understand the true perspective of the subject being studied and that they allow the researcher to access the subject and record what they observe in an unobtrusive and nonreactive manner. Patton stipulates that field notes are rich, detailed descriptions, including the context within which the observations were made and they consist of activities, behaviors, actions, conversations, interpersonal interactions, organizational or community processes, or any other aspect of documented human experience in the field [19]. This research requires an in-depth understanding of researcher's experiences and observations while participating in an intense and involved manner, thus field notes will be applied as data source in this research.

Observation method enables the researcher to observe theory-in-action rather than espoused theory, an observer is able to write a description of what is observed and then develop a theoretical framework to help explain the process or phenomenon observed, in the context that it is manifested [19]. It is therefore rational to apply the observation method as a data collection tool in this research, particularly the application of informal participant observation. Robson alludes to the fact that it is typical for qualitative studies to use informal participant observations where data are the interpretations of what is seen by the observer [19]. In the application of informal participant observation there are a variety of data capturing methods, these include but not limited to, audio-tapes, field notes and video tapes. A varying combination of these tools is used in observation method to enable the researcher to see and hear exactly how individuals act and interact in a given situation [19].

The culmination of a triangulated data capturing approach is a holistic picture of the phenomenon under observation and the hallmark of this approach is the establishment of a comprehensive picture of the current state of affairs which in productivity studies is decoded as the "AS IS" scenario. Once the 'as is' scenario has been developed in this particular research, then various productivity improvement tools and techniques will be applied to the production process 'as is' and the results will be captured and compared to the results of other productivity improvement tool applied to the 'as is' production process. The results of the productivity improvement method that produces the highest yield are used as bench mark to compare with the productivity improvement results obtained when the auxiliary equipment is applied in the productivity improvement intervention.

VI. DATA ANALYSES AND INTERPRETATION PROCESS

A case study analyses is argumentative by nature, and therefore there is a fair amount of competing hypotheses and evidence that is to be disconfirmed. Once the data collection phase is completed, data analyses commence and various qualitative data analyses and interpretation methods are employed.

Firstly, the data displays method is engaged in which data is organized and summarized so that information is analysed. Secondly, replication is applied as a key analytic method that is used in the analysis of multiple cases. The primary focus of replication is the overall pattern of the productivity improvement results and the extend to which observed productivity improvement pattern match the propositions stipulated in the theoretical framework. Cases of literal replication and theoretical replication will be observed as described by Yin. Based on an analytical perspective, replication is a method of triangulation in which each productivity improvement case is viewed as an independent measure [19]. Therefore it is through replication that external validity is achieved, which when achieved, it means the ability to generalize productivity improvement results to some broader theory is plausible. Validation is also achieved through triangulation and triangulation dictates that multiple methods are used in data collection and analyses so that all sources converge on the facts of a case [19].

Thirdly, the research will follow the theoretical propositions that led to the case study, the original objective, the design of the case, the research question and the literature reviews.

VII. PRODUCTIVITY LABORATORY

A. 'As Is' production process.

The 'As is' production process is the current production process applied in the replacement of a traction motor (TM) and the process is called a locomotive lifting process. In the current process the body of a locomotive is uncoupled from the bogie and lifted of the bogie. Then a TM is removed and replaced with a new one. Then the body of the locomotive is lifted, placed on the bogie and recoupled to the bogie. See the detailed process below in fig.1

The lifting process takes 2hrs to complete and therefore in a 9hrs shift, 4 lifting are done with a 1hr break. To improve the performance of the lifting process a method analysis technique was applied in search of productivity improvement opportunities. Fig.2 below is a presentation of the characteristics of the 'As is' production process.

B. Method Analysis

Application of a method improvement technique on the current production process resulted in a 10% reduction of wasteful operations activities, a 4% reduction in non-value adding movement and an elimination of storage within the production process. These results were achieved through the improvement of the production set up and performing some operations concurrently. The method improvement exercise culminated in a reduced production cycle time, see fig.3 below.

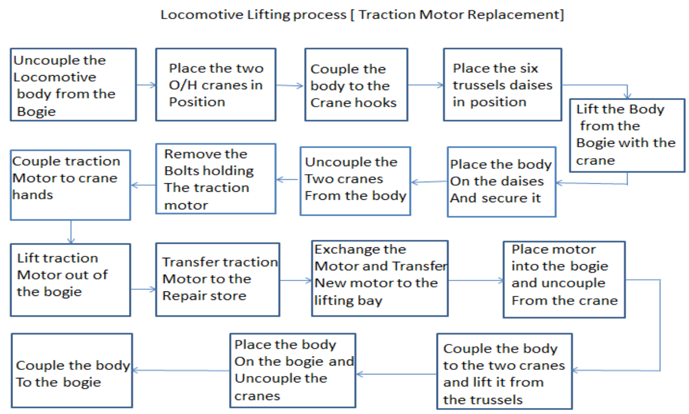

Figure.1: Locomotive lifting process

Process	Symbol	Tally	
Uncouple the Locomotive body from the Bogie	●	1	
Place the two O/H cranes in Position	➡	1	
Couple the body to the Crane hooks	●	2	
Place the six trussels daises in position	➡	2	
Lift the Body from the Bogie with the crane	➡	3	
Place the body On the daises and secure it	●	3	
Uncouple the two cranes from the body	●	4	
Remove the Bolts holding the traction motor	●	5	
Couple traction motor to crane hands	●	6	
Lift traction motor out of the bogie	➡	4	
Transfer traction motor to the repair store	➡	5	
Exchange the motor and transfer new motor to the lifting bay	▲	1	
Place motor into the bogie and uncouple from the crane	➡	6	
Couple the body to the two cranes and lift it from the trussels	●	7	
Place the body on the bogie and uncouple the cranes	➡	7	
Couple the body to the bogie	●	8	
		Total	%
Symbols key			
Operation	●	8	50
Transport	➡	7	44
Storage	▲	1	6

Fig.2: Method analysis of the Lifting Process

Process	Symbol	Tally	Modification
Uncouple the Locomotive body from the Bogie	●	1	
Place the two O/H cranes in Position	➡	1	Set up
Couple the body to the Crane hooks	●	2	
Place the six trussels daises in position	➡	2	Set up
Lift the Body from the Bogie with the crane	➡	3	
Place the body On the daises and secure it	●	3	Concurrent
Uncouple the two cranes from the body	●	4	
Remove the Bolts holding the traction motor	●	5	Concurrent
Couple traction motor to crane hands	●	6	
Lift traction motor out of the bogie	➡	4	
Transfer traction motor to the repair store	➡	5	Set up
Exchange the motor and transfer new motor to the lifting bay	▲	1	Set up
Place motor into the bogie and uncouple from the crane	➡	6	
Couple the body to the two cranes and lift it from the trussels	●	7	
Place the body on the bogie and uncouple the cranes	➡	7	
Couple the body to the bogie	●	8	

		Total	%	Improved Results	
				Total	%
	●	8	50	6	60
	➡	7	44	4	40
	▲	1	6	0	0

Fig.3: Method improvement results of the 'As Is' production process.

Key Notes explanation:

Set up = Activity will be cancelled through a new operations setup, e.g. all production material will placed next to operation before production begins and valueless movement is eliminated.

Cuncurrent = Activity Operations will run concurrently

Application of method analysis resulted in a shortened production cycle time and a reduction of waste in operations, transport and storage. This resulted in a productivity improvement of 20% in the 'As Is' production process. A 20% productivity improvement is equal to an increase in production output by 1 lifting.

Method analysis resulted in an improvement of the production cycle time and production efficiency, since waste and non-value add operations were eliminated. In an endeavour to increase productivity further, the application of auxiliary production equipment in productivity improvement initiatives became imperative.

Auxiliary production equipment required in this case is a Lever steel rod, a holder bracket, pneumatic jack and a removable rail track. The track and the jack were already available as part of the lifting bay in the maintenance pit. The lever and the bracket had to be designed and manufactured specific to the locomotive maintenance requirements.

Applying auxiliary production equipment in the production process changed the TM replacement process from a Locomotive Lifting Process to a Traction Motor tilting and replacement process. The new TM replacement process applies a lever which is used to tilt the TM at an angle so that the TM nose assembly may be removed. Then the process applies the force of gravity to drop the TM into the holder bracket and the motor is lowered with the jack and removed under the locomotive. Therefore, to replace a traction motor, there is no locomotive lifting required but the traction is removed from under the locomotive in a pit. The production cycle time is shorter because there are fewer operational activities in the new process, see fig.4 below.

C. Application of auxiliary equipment

1) Traction Motor Replacement process (with the aid of auxiliary equipment]

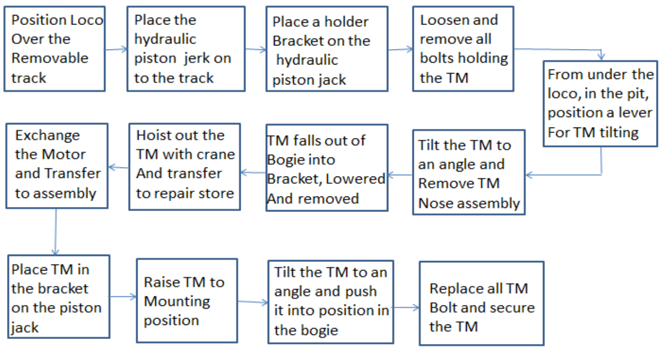

Fig.4: Application of auxiliary production equipment in Traction Motor replacement process.

A method analysis technique was also applied to the new process and results display a shorter process cycle time and better efficiency in the new TM replacement process. The new method has less non-value adding operations activities and there is still room for improvement, see Fig.5.

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

Fig.5: Method analysis of the new TM replacement production process.

2) Method Analysis: TM replacement [with the aid of auxiliary equipment]

To increase the productivity of the new TM replacement process an application of a method improvement technique was instituted on the new TM replacement production process. Results of this productivity improvement initiative displayed 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 process cycle time is 1hr to complete a TM replacement. The method improvement exercise culminated in a reduced production cycle time and improved efficiency of the new production process, see fig.6.

3) Improved TM replacement production process

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

Fig.6: Method improvement results of the new TM replacement production process.

Key Notes explanation:
Set up = Activity will be cancelled through a new operations setup, e.g. all production material will placed next to operation before production begins and valueless movement is eliminated.

D. Output Data

The impact of the application of production support auxiliary equipment in productivity improvement is vividly displayed in the productivity improvement data below see fig.7.

1) Productivity improvement data

Analysis Theme	**'As Is' production process**		**'As Is' 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

Fig.7: Productivity statistics for various production methods.

In the table above 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 output. When auxiliary production support equipment is applied for productivity improvement, the resultant output is 120% productivity improvement. Note that with the application of auxiliary production equipment the production process is reengineered. The productivity improvement experienced also alludes to an increase in efficiency, and the reduction of waste and non-value adding activities.

VIII. ANALYSIS

The analytic focus of this case study is on the overall pattern of variables within a case. In table 1, columns are cases and the rows are variables. Case oriented analysis examines the interrelationships among variables within a case, establishes a pattern and then makes a comparison across multiple cases. The aim is to establish similarities, patterns and differences that will be used to support or negate propositions established in the theoretical framework.

Table 1 below is used to classify certain events and look for patterns within and across cases. This data display is used for the same purpose as would be the (Boolean algebra based) truth table.

In this instance table 1 is quite enlightening in that it displays clearly that the elasticity of productivity improvement output is sensitive to the time value-add produced in productivity improvement of a specific case. As it can be depicted from table 1, that for the variable 'over time' there is no growth in output, even though there is 20% overall productivity improvement in this case. Therefore in this particular case productivity improvement does not yield process capacity required to increase output.

Applying the "horizontal" logic in case study analyses it becomes apparent that for the variable 'over time' not all productivity improvement cases will result in an output increase.

A. Data displays

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 of a phenomenon referred to by Yin as external validity. As Yin [25] noted external validity is the ability to generalize findings to a broader theory. Figure 8, below depicts the formation of this phenomenon in that it vividly displays that for the variable 'over time' output remains the same across the two cases, although there is a productivity improvement of 20% in one particular case. Thus it can be broadly generalized that not all productivity improvements will yield an increase in output. Therefore based on a generalized definition of productivity that it concerns with the ratio of output to an input, the interrelationship between the variable (Over time) within the case (Method and time productivity improvement) disconfirms a competing hypothesis that all productivity improvement will result in an increase in output. A very critical point depicted in the figure 1 below is that of all the three cases, auxiliary equipment productivity improvement initiative has the highest output, see figure 8 &9.

TABLE 1: OUTPUT DATA FOR MULTIPLE PRODUCTIVITY IMPROVEMENT INITIATIVES

Analysis Theme	**'As Is' Output**	**Method and time productivity improvement**	**Auxiliary equipment productivity improvement**
Normal shift	4	5	8
Over time	1	1	3
Night shift	5	6	11
Total	10	12	22
% increase	0	20	120

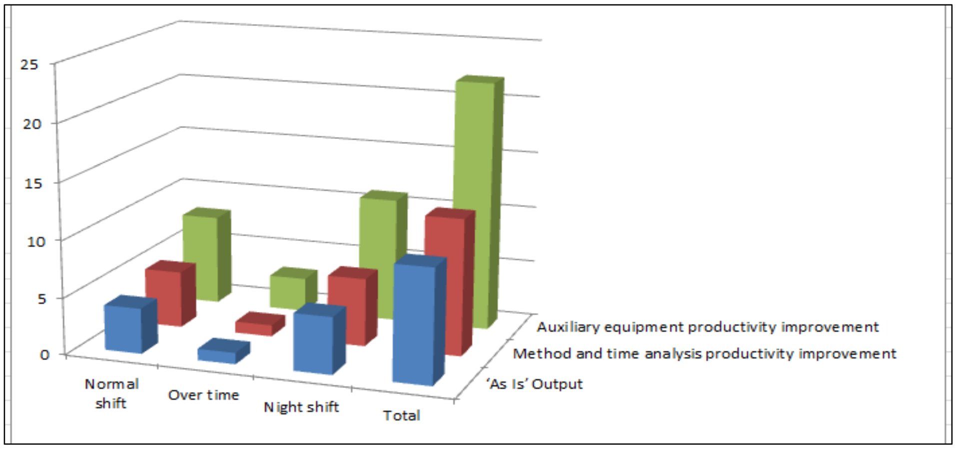

Figure 8: Productivity output for similar themes (Input = time)

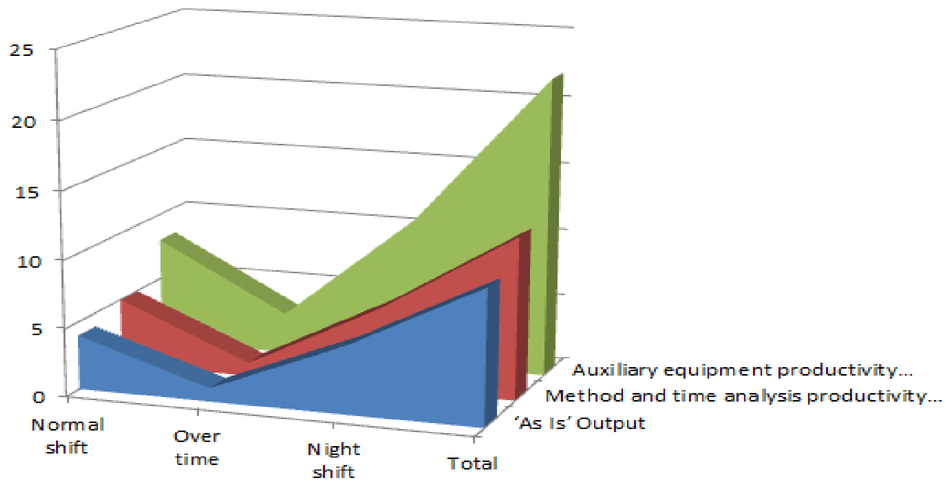

Figure 9: Productivity results patterns for various cases

Figure 9 above highlights the impact of each variable on productivity improvement and the overall (Total) impact of each case as applied on the productivity improvement initiatives. It is clearly depicted in data display 2 that the size of the time value-add produced in a productivity improvement initiatives is proportional to the output yield.

In both Figure 9 and 10, productivity improvement output yield is higher in the case where auxiliary equipment is applied in productivity improvement. The total output yield is higher for the auxiliary equipment case as depicted in Figure 9 and the percentage increase is the highest of the three cases as depicted in Figure 10.

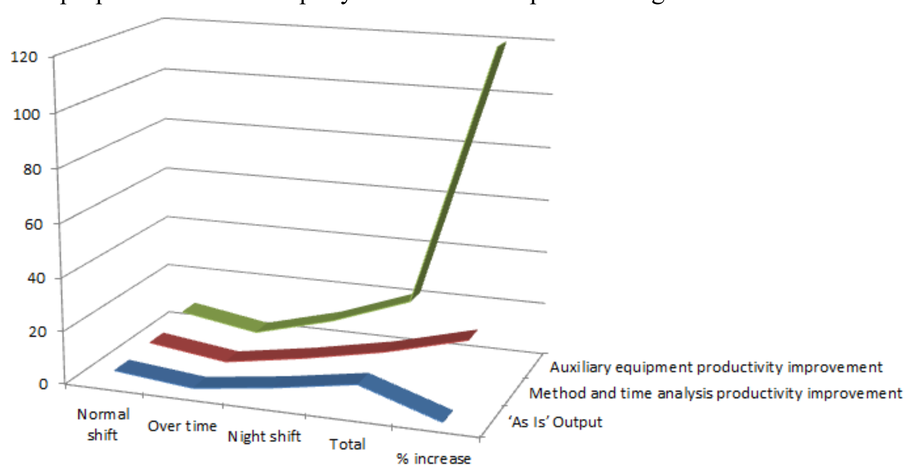

Figure 10: Productivity result data linked to propositions

Results in the Figure 8 to 10 above confirm two critical points related to the proposition that is fundamental to this research. First, this research has followed the theoretical propositions that led to the case study, the original objective, the design of the case and the research question. Secondly, data display analysis enables this research to conclude on confirming the proposition and disconfirm competing hypothesis.

B. Replication

As indicated in the methodology section this research applied the use of multiple data sources, a strategy which also enhances data credibility [5]. This case study applied a triangulation of data sources, i.e. i) Analysis of archival records and; ii) Documents and field notes analysis; and iii) Process Observation. To further improve data credibility, in each case of productivity improvement, a triangulation of time and method analysis, process improvement method and the application of auxiliary equipment, is applied.

The overall pattern of the productivity improvement results and the extent to which the productivity improvement pattern match the propositions stipulated in the theoretical framework nullifies all competing propositions and confirms the proposition that is core to this research. This process of replication validates the fact that the experiment is not dependent on the local conditions. Replication of this experiment in all three cases proves that original productivity improvement experiment is not a contingent event and it is a usable tool for productivity improvement initiatives.

In data displays all three cases of productivity improvement present a successful replication of a physical experiment and this demonstrates that the experiment can repeatedly generate the output observed in the original experiment. Therefore the knowledge and data embodied in the experiment can be utilised as a tool to advance productivity improvement. Notwithstanding the fact that this process produced a shared understanding of a set of terms and best practices that can be utilised in other productivity improvement projects, it is needless to highlight that the process aids in the verification process.

C. Confirmation or rejection of the proposition

The overall pattern of the productivity improvement results in all three cases and the extent to which the productivity improvement pattern match the research propositions stipulated in the theoretical framework confirms that the proposition is accepted. These results also validates that the experiment is a correspondence between the output from a control environment and the measures of the real world.

IX. FINDINGS

The application of auxiliary production support equipment in productivity improvement projects is highly advantageous, owing to its capability to simultaneously increase total production output and exponentially improve percentage growth in productivity. It is clear that the application of auxiliary equipment, in productivity improvement initiatives, has a huge impact on the production cycle time. The production process has to be ready with the ability to have abated costs with higher proficiency, hence the route to simplify the production process and improve productivity and output exponentially is of paramount importance.

X. CONCLUSION

This paper support the foundation laid for the use of auxiliary production equipment in productivity improvement experiments and the results observed in all three cases of productivity improvement are therefore used as supporting evidence and a basis for concluding that auxiliary production support equipment, when effectively applied to a production process, will have a huge impact in productivity improvement.

The results in this research demonstrate an overall increase in productivity when auxiliary equipment is applied in all the three cases. The rate of productivity improvement, which is the percentage growth in productivity is consistently high in all cases and does not depend on the conditions of the production process. This attribute implies that the experiment can be replicated and it will yield similar results.

Replication ensures verification and validation of the model presented, in that it aids in determining whether the model presented reflects the conceptual model and therefore forces the model developer and replicator to re-examine assumptions made in development and application processes leading to the establishment of the original model. It can therefore be generally accepted that there will be a shared understanding of the details of the productivity improvement model's design and application decisions within the respective engineering research community. These stipulations (Validation and Verification) ensure and imply the fact that the research output is not a contingent result achieved due to dependent local conditions and that the written description of the application processes satisfactorily document the knowledge gained through the application of a scientific method in the research.

In conclusion, a systematic analysis of the components of productivity improvement and an efficient application of elements of work study, together with the application of production auxiliary equipment can result in an increased productivity. This requires domain-specific knowledge of the product attributes that affect the production, process and setup times. Thus method study is applied to obtain accurate results about the production system and time studies are implemented to establish in detail of how sensitive is the production cycle time to components processing time at each workstation, to achieve overall productivity improvement.

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