Productivity and process performance in a manual trimming cell exploiting Lean Six Sigma (LSS) DMAIC – a case study in laminated panel production

Daniel Lee Hardy, Saikat Kundu and Muhammad Latif
Dept. of Engineering, Manchester Metropolitan University, Manchester, UK

Abstract

Purpose - This case study investigates inefficiency and downtime factors within a panel lamination process cell at a timber component manufacturing company. Areas of concern related predominantly to the manual trimming or finishing of a range of laminated timber panels for the Caravan and leisure industry. The intermittent feeding of inputs and material outputs was also investigated during this case study.

Design/Methodology/Approach - The case study was conducted over a six-month period using the Six Sigma Define Measure Analyse Improve Control (DMAIC) construct. But was equally supported through a combination of tools both applied in lean manufacturing and the statistical properties commonly assigned to Six Sigma projects.

Findings - This paper provides insights about the identification of the root causes for poor productivity and OEE issues experienced by manual trimming/finishing operations in a laminated timber panel production cell. It also identifies solutions to overcome these issues and benefits (such as improved OEE, reduced downtime and savings in staffing costs) that were obtained due to the application of these solutions. This study contributes to understanding the interconnections of Fork Lift Truck movements with staff working within manual finishing areas connected to a panel lamination cell.

Originality – This paper contributes new knowledge into the root causes of poor productivity and process performance within manual finishing operations in a laminated timber panel production cell at a Small Medium Enterprise. By applying elements of Six Sigma' quality focused analytical methods within the DMAIC structure, and simultaneously applying the waste reduction method of lean manufacturing this paper provides useful perspective on why both these quality improvement based ideologies are applied to overcome process issues in manufacturing.

Key words- DMAIC, Six Sigma, Lean Manufacturing, Productivity and Processes
Paper Type – Case study

1.Introduction

Increased competition means that Lean paradigms are increasingly employed to reduce waste and improve productivity: to reduce non-value added activities and create value for the customer (Kommula et al., 2016). One method to analyse process issues and variance is Six Sigma and was developed in the 1980s by Motorola (De Mast and Lokkerbol, 2012) and is analogous to previous improvement techniques, such as, Total Quality Management (TQM), whereby objectified improvements become the business requirement (Hakimi et al., 2018). However, over time Six Sigma diverged into a strategic pattern of Defining, Measuring, Analysing, Improving and Controlling (DMAIC) of problem areas. Similar to its forerunners, such as Plan Do Check Act (PDCA) (De Mast and Lokkerbol, 2012) the DMAIC structure is a means to analyse manufacturing deficiency (Vendrame Takao et al.,2017).

By and large Six Sigma is credited for delivering results, particularly in large organisations. According to research carried out by Vendrame Takao et al., 2017, organisations, notably Motorola and General Electric (GE), reaped multi-billion dollar savings because resources were available transpiring to well trained dedicated teams were able to focus on their objectives, enabling continuous investigations right through the core of business. Whilst this method may be invaluable to a large organisation; the requirement of skills and resources for Six Sigma programs may not be so accessible to smaller business (Hudson et al., 2001).

Nonetheless, as Coronado, R. &. A. J., 2002, noted in their study that it is imperative that any business links any Six Sigma project to provide key advantages against competitors and ensure that the project seeks to improve on its critical quality measures, such as, the yield or a process cycle time, despite a business' resources. With that said, and with limited resources smaller business has found a way of synthesising ideas using quality management tools, such as, Six Sigma. For example, a case study of an SME biscuit company carried out by Kaid et al., 2016, applying Six Sigma resulted in reducing the deviation rate of flour material from 27.55% to 10.45%. Their paper outlined that the key to progression in a Six Sigma DMAIC project is comprehending business requirements in the define phase, through the voice of the customer (VOC), the voice of the process (VOP) and the voice of the business (VOB) in order to define the Critical to Quality (CTQ) plan.

Subsequently, the essence of Six Sigma encapsulates a focused mindset whereby statistics denoted in process control charts are analysed to reduce costs, product variation and increase overall process quality (Gohel J, et al., 2018). This further links to the type of analysis a business seeks: using either complex statistics for quality control or applying a controlled DMAIC methodology. To support this theme, Antony and Banuelas's 2002, study reflects on introducing key ingredients to Six Sigma programs by explicitly stating that training and communicating with staff is key to a changing culture. Yet, Kwak and Anbari's 2006, paper noted that this must arguably be supported by an agenda with achievable objectives, tied into the management strategy. This argument is reinforced in, Elshaer, I. a. Augustyn, M., 2016, paper whereby their analysis highlighted leadership and strategy to be a key driver to any succesfull quality management program.

Therefore, the aim of this study is to implement a management strategy that utilises Lean and Six Sigma tools to both understand and assist in breaking down inefficiencies, poor productivity and to recognise the importance of optimising 'Overall Equipment Effectiveness' (OEE) in a panel lamination production cell to appease stake holder interests, defined by the: Critical To Quality (CTQ) plan.

This research is divided into eight sections. Section 2 provides the background. Section 3 introduces the DMAIC methodology and the case study structure. Section 4 highlights the summary results obtained from the five steps of the DMAIC, whilst also providing key commentary on the phased study findings. The key findings from the implementation of Lean and Six Sigma tools to address operational inefficiencies and productivity issues associated to the movement and motion of staff, and materials and operational activity in order to improve OEE are then discussed and concluded in section 5 and 6. The studies Implications (section 7) to the business and the case study limitations (section 8) of the study complete the paper.

2. Background to Case Study

This case study investigates the finishing processes on a high-volume panel lamination line. The line was introduced to add value to one sided timber panels, such as, ply wood, poplar and Medium Density Fibreboard (MDF) of varying sizes with a Polyvinyl acetate (PVA) glue for the caravan and leisure industry. The laminate is designed with a range of different wood or wall paper type finishes. However, with this wide range of materials and different customer options the process suffers a litany of process issues. As a consequence, and due to inadequate process controls, this has resulted in poor synchronisation at the beginning and ending of processes. One of the main aspects of the process is the manual trimming of the laminated panels (finishing), and is a value adding contribution (see figure 1 flow chart of process).
Driving this manual trimming process are the staff, who for the most part are long serving with an average age of greater than 55 years old and thought to contribute to some of the productivity issues. Although, some academics have acknowledged that experienced elder staff can benefit the production floor, as Bryson et al., 2018, argued for compromise with age and experience, muting some limitations of the physicality of older staff. Nevertheless, the work is physically demanding, and staff are tasked to handle panels varying in sizes, from 1220mm*1937mm up to 1220mm*2440mm and vary in depth, from 2mm up to 3.6mm. By observation the process is simplistic yet is beset with a multitude of problems. Therefore this study is designed to breakdown the paradox between productivity, improve OEE and reduce production costs.

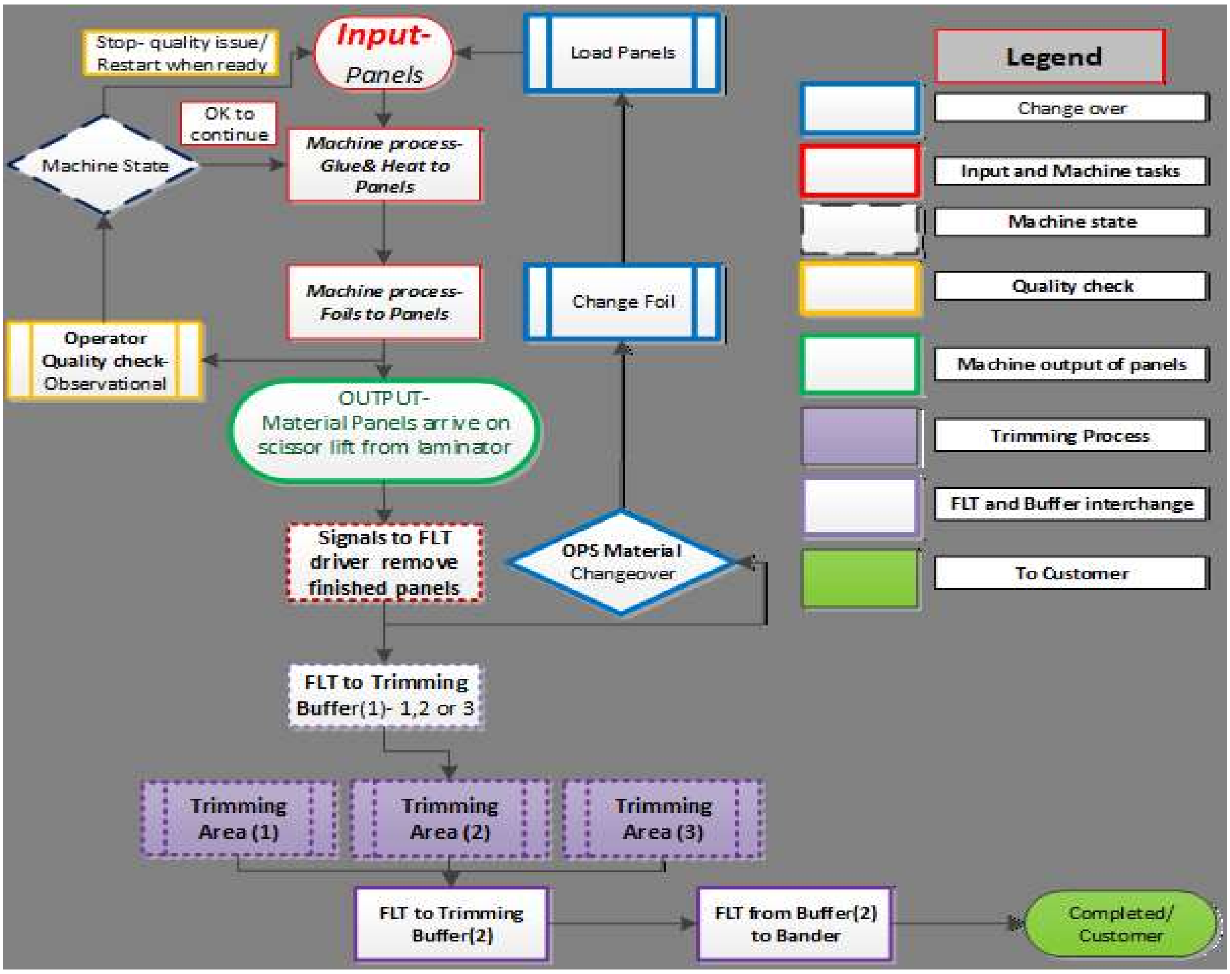


Figure 1 Flow Chart of Lamination Machine and finishing Process [Fork-Lift Truck, (FLT)]

The flow chart in figure 1 presents the process overview. At the beginning of the process the unfinished panels are manually loaded onto the machine by one person. The glue and foil is added as a continuous process and is controlled by machine sensors. As the semi-finished panels arrive at the machine output station the panels are visually checked for quality. Should the quality fail, the panel is rejected to a reject pile and the process continues. When a batch is complete the operator signals to the Fork Lift Truck (FLT) driver to send the finished batch (up to 250 in quantity) of panels to the finishing section(s) 1, 2 or 3. Simultaneously operators change over foils and load panels for the next job in the process to reduce downtime. The panels are then manually trimmed with sharp knives and double checked for quality issues by three teams of two, before concluding at the banding process and out to the dispatch zone for loading.

The next sub chapter outlines the DMAIC methodology and its systematic approach to work based analysis and proves why it is formative in constructively applying solutions for project and work teams.

3. Methodology of Case Study

The five step DMAIC methodology, common to six sigma and lean studies is applied in this study (Girmanova et al., 2017). To prove its topical use in problem solving, Marti 2005 and Dora, M. Gellyck. X., 2015, approach their case studies using the tried and tested DMAIC structure in completely different operational areas, proving its versatility to many types of problems. The outcome of each study was dissimilar in terms of the results output. However, because the DMAIC structure is designed with a simple analytical matrix: that provides a logical breakdown of problems; it is therefore capable of devolving systematic process breakdowns to unit areas of research, and thus offers an uncomplicated mechanism to analyse event lags and general apathy within workforce doctrines, despite its application. Within this, each step of the DMAIC processes uniquely forces the next step to generate platforms of information, key to establishing the main and summary points open for review, change and discussion. In essence the DMAIC methodology pulls together different elements of project work, such as, people, systems and ideas to bring about a change to improve business and manufacturing functions. The steps are presented in the next sub-headings.

Define (Process Problems)- A project charter outlined eight-key team roles, see below for details

- Project Sponsor – Manufacturing Director
- Project Manager – Manufacturing Engineering Manager
- Production manager, supervisor and three members of the production staff
- Quality Manager

Critical to driving the team forward was to undertake Gemba walks and observational studies, which outlined problem scope; assisting in the development of the Critical To Quality (CTQ) plan. Aiding this the Voice of Employee (VOE) presented internal staff mindset, with the Voice of Business (VOB) presenting Indicative financial data. The current process mechanics data was introduced with the Voice of Process (VOP).

Measure (Understand the Process)- Three-months of data was entered onto a Value Stream Map (VSM). Although, limited production access meant sample data was restricted to about 10% to 15% of batch quantities and later extrapolated over an average batch quantity of 250 to mitigate production means. Probabilistic outcomes common to processes were applied to downtime factors for better representation of process instances, such as, poor communication because of non-binary production outcomes (Williams, 2015). The Statistical Process Control Chart (SPCC) indicatively demonstrated current and intended process metrics over a 3σ range.

Analyse (Measurements from Measure Phase) - The Ishikawa diagram highlighted the breadth of problems within the research and was supported with the lean 5 whys analysis tool, which helped address the complex nature of the process failures. The range of problems meant other methods, such as, statistical Correlation analysis presenting trend data for panel trimming events, general downtime and Fork-Lift Truck (FLT) wait times, offered opportunities for further investigation. Relationships below +/- 0.6 were not considered in this study.

Improve (Implement Improvement Strategies Based on Analysis)- The improvement phase was broken down into five numbered strategies using Lean tools, such as, Plan Do Check Act (PDCA) to break down the problem, Single Minute Exchange of Dies (SMED) techniques to sub-divide task elements to reduce waste and motion and Andon principles were introduced to reduce poor communication protocols and a general lack of control.

Control (Control the Implemented Improvement Strategies)- The control phase summarises the study with a Failure Modes Effects Analysis (FMEA) table, which presents the risk to the process through a lack of discipline in the trimming area and also shows the effects of changes to current – following the improvement phase – and for the future review period. This in turn is supported with control charts in Statistical Process Control and probability plots that demonstrate additional changes in output post improvement phase. The graphs are used to demonstrate the effectiveness of the changes made.

The results for the case study are presented in the next section.

4. Case Study Results

The primary focus of the study was aimed at the manual panel trimming processes which followed the lamination process and the offload of panels from the machine end scissor lift.

4.1 *Define phase: Defining the Process*

Voice of Employee (Staff in the work area) - In the VOE 80% of the twenty staff, involved in the process surveyed, identified process speed as the greatest problem, with 70% identifying manpower requirements for manual trimming as adequate. These results defied the logic of protectionism and in turn fed the argument to improve or automate processes. Moreover, the layout, which seemed to be a harbinger of poor productivity, scored only 40%, somewhat generalising the results and made the interpretation of the results one of caution.

Voice of the Business (VOB) - Economic data from the process presented Multi Factor Productivity (MFP) and profit decreased in 2019, with further investigation highlighting a rise in material and labour costs at +23% on the previous year; part Government (due to minimum wage increase) and part raw material cost increases. This resulted in an MFP of 0.12 panels/£ for 2019, down by 8.3% on 2018. This suggested issues with cost base and reinforced the argument for improvements focused on increasing individual and process productivity.

Voice of Process (VOP) - The pre-project cycle covered three-months monitoring of eight-hour morning shifts. The machine TAKT time target would require 4.05 panels per minute or one every 14.8 seconds, increasing output by 57%: beyond the realms of this study. However, an increase of around 33% in output was more practical; meaning a finished panel leaving a trim station every 20 seconds at 3.1 panels per minute and increasing OEE to 70%.

CTQ plan – The key components of the define phase**,** the VOE, VOB and VOP all contributed to the development and underpinning of the CTQ plan, which is the academic and business essence of the research. The conclusion of which presented one primary need: to increase productivity. This in turn fed the quality drivers, for example, reducing down time and waste between process phases with people and the machinery loading and unloading. Due to the amount of resources available at any one time the CTQ plan represents short, during the case study and longer-term objectives, post study to work to. The measure phase investigates these process issues in the next sub-section Refer to figure 2 for research CTQ plan.

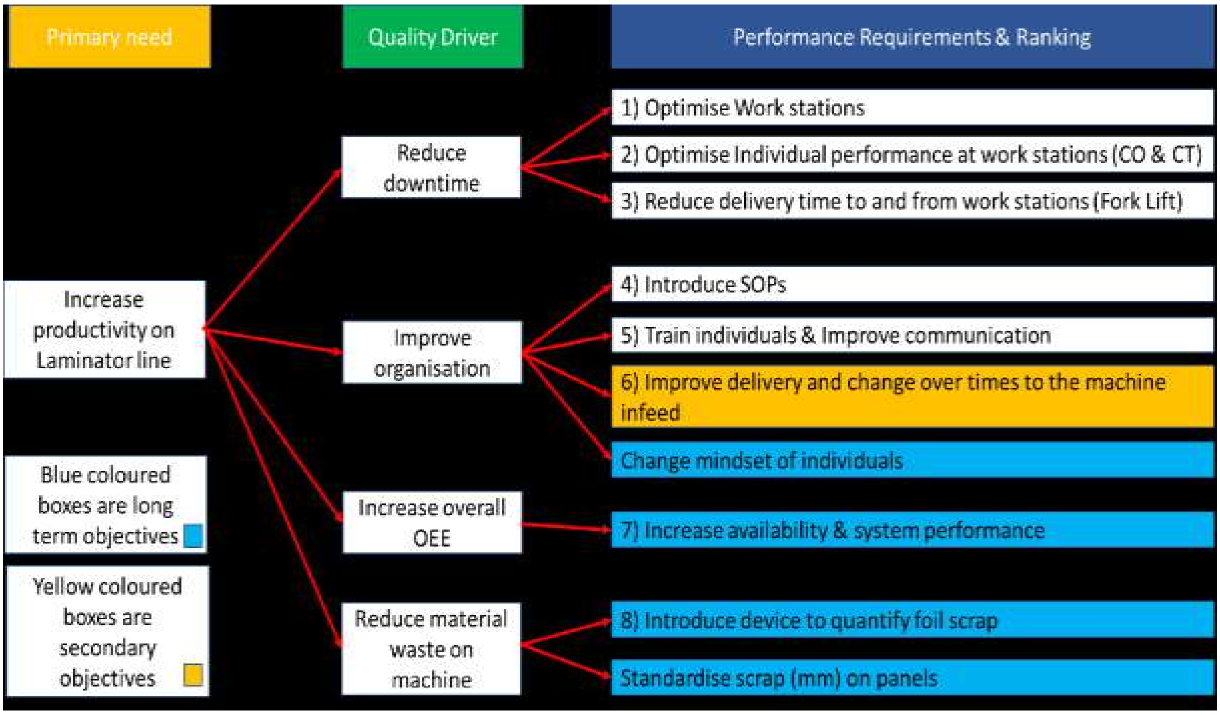


Figure 2 CTQ Plan for Case Study Problem

The CTQ plan is the fabric and shape of the research and study intent. With this structure to work to there was always a reference point at which those working in the team could direct their focus. The main and primary need for this case study is to increase productivity within finishing cells. The quality drivers subdivide reference points into manageable elements, with each of these, again, broken down into ranked performance requirements. With objectives ranked, the process to control the feed of information to the team was simplified and provided a method to reduce confusion during the measure phase with short and longer-term objectives singled out, as denoted in the diagram.

4.2 Measure Phase: Measuring the Process

Value Stream Mapping (VSM)

Information captured within the VSM over the three-month period is presented in Table i, summarises the initial data capture for the study. Further VSM information is available in the pictorial reference in figure 3.

Table i Measure Phase: Salient VSM Data for lamination process

	Station description	***VA/ NVA***	***C/t (s)***	***C/O (t)(s)***	***OEE (%)***	***A (%)***	***P (%)***	***TAKT (t) (s)***	***Mean panel output (per day)***
1	infeed to the machine	NVA	5	303	29	78	36	14.79	1825

2	adding foil and changing over new panel batch	VA	1.2	300	55	61	91	14.79	1825
3	Unloading scissor lift & travelling to the trimming buffer	NVA	36	22.5	41	55	75	14.79	1825
4	Wait time for processed panels	NVA	46	44.5	38	63.68	61	14.79	1825
5	Panel trimming	VA	30.7	46	38	58	66	14.79	1825
6	Counting panels	NVA	338.4	46	15	38	40	14.79	1825
7	Banding panels	VA	77.6	99.8	62	73.5	85	14.79	1825

Table i Key: P= Performance, A= Availability, VA= Value Added, NVA = Non-Value Added, C/T = Cycle time C/O= Change over, OEE = overall equipment effectiveness. [1]

These initial results show that manual panel counting returned a mean of 338 seconds with OEE at 15% and waiting time for panels recorded at 46 seconds with OEE at 38%. Panel in-feeding OEE was recorded at 29% and a mean of 190 seconds of downtime. The poor results were characteristic of large piles of inventory and an array of communication confusion witnessed during Gemba walks with the team within the define phase.

[1] OEE = Quality*Availability*Performance [At the time of measurement quality =1]

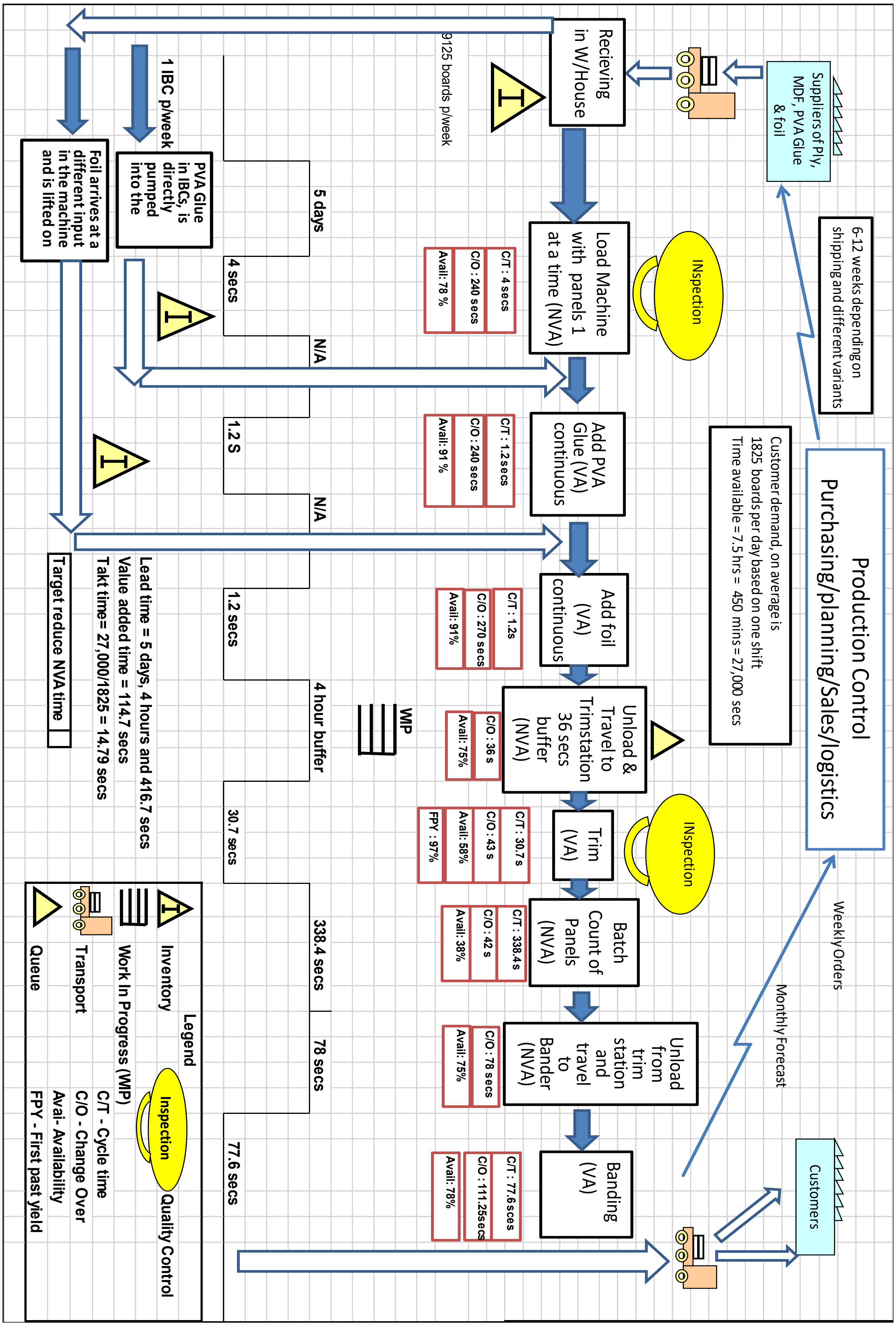


Figure 3 The Case Study VSM for the Lamination and Panel finishing Process

The VSM is a pictorial reference for the data presented in table i, which further acted as the starting point to breakdown individual tasks, as seen in the process map in figure 4. This simplified data collection and supported investigations of people, motion and workplace functions. The advantage of using this lean tool was to provide a more compounded view of the workplace under investigation, which was adopted and presented to staff and management of the process. Particularly important was the knowledge gained in understanding 'what are the wait times?' at different junctions in the process which were previously unknown to the floor team. Thus, allowing the generation of improvement strategies to improve productivity in staff and machinery as designed by the CTQ plan.

Process map of trimming area

To further strengthen the theme of process breakdown figure 4 presents the micro world of the panel finishing area.

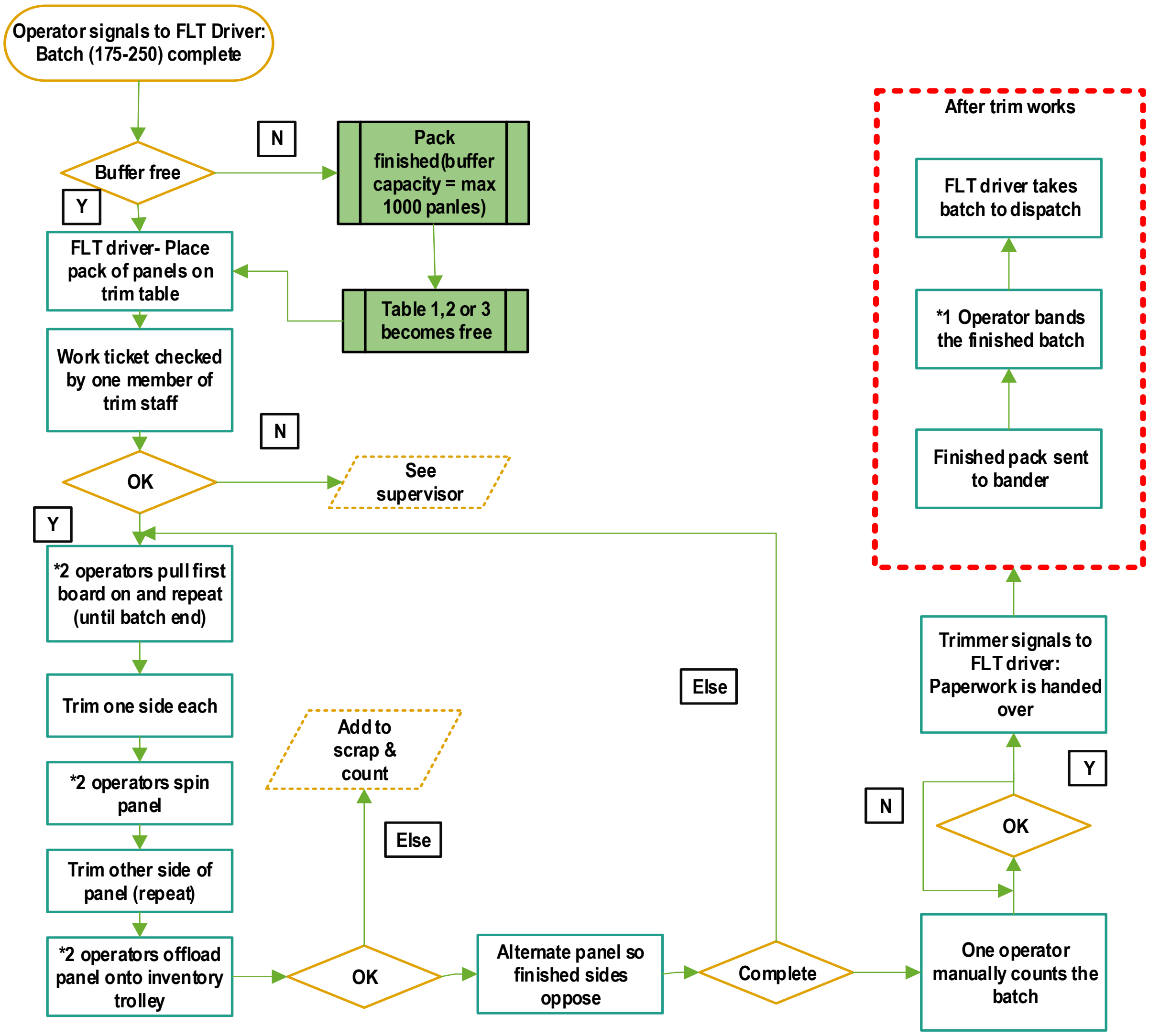
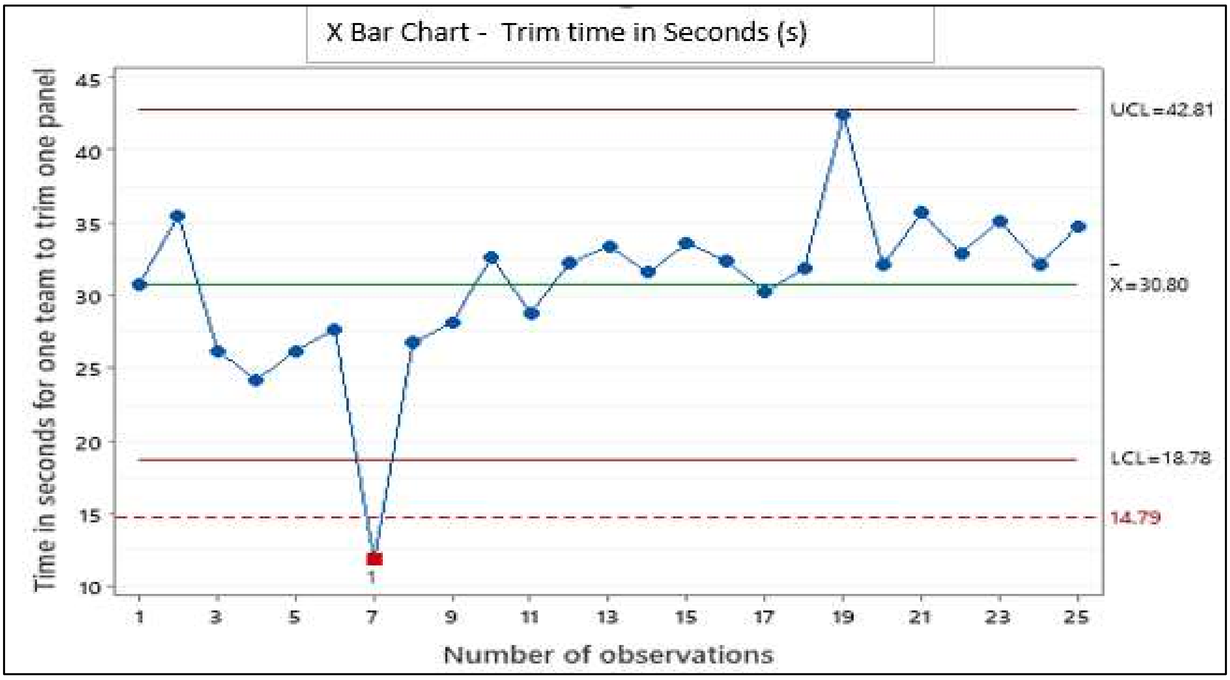


Figure 4 Process Map of trimming stations showing in/out event transitions

Each point on the flow chart designates a change in the transfer of products. The logical if statements are used to denote points of change when panels do or do not make it through because of, for example, poor quality. This chart does not use time as a reference. However, what the chart does is to demonstrate the number of changeovers/transfers required for a single panel to transfer through to completion. The recorded number of trim only actions amounts to 12, which is extremely high and evidently required improvement. One method considered for the breaking down the amount of handling functions was to introduce Deming's Plan Do Check Act cycle to systematically reduce the problem to its smallest parts.

Control Charts in Statistical Process Control (SPC) for Trim time activity of machine process

Presented in figure 5 are the results from the SPC using 3σ as the upper and lower control limits. The chart highlights the variation around the mean time taken to for one team to trim one panel over 25 separate investigations. The TAKT time is included to demonstrate panel output from the machine.



F*igure 5 Control Chart Initial process measurement v target TAKT time and further performance targets*

The graph illustrates TAKT time (calculated using the mean panel demand of 9125 panels per week, divided by the available time in seconds per week, i.e. 135,000) of 14.79 seconds is significantly less than a single trimmed panel; in most investigations it is 50% less. The spike outside the Lower Control Limit (LCL) (11.88 secs) was conducted during a training test. The graph also displays a target mean of 21 seconds trim time per panel, per team of two. The evidence in the chart demonstrated a need to investigate the poor performances recorded.

Probability of Instance for Trim station downtime

One of the main issues during the measure phase was breaking down the problems into unit areas and because of the random nature of occurrences the task could only be estimated by applying contributory probabilities to the outcomes for the 25 separate investigations for downtime factors, such as, batch Changeover (C/O), C/O to the bander and FLT wait times; refer to table ii for the summary findings for respective downtimes. The table also presents a target figure following the improvement phase.

Table ii Measure Phase: Summary Mean values from applied probability of 60% for layout issues

Criteria	**batch C/O (s)**	**C/O to bander (s)**	**FLT wait (s)**	**Total trim time D/T (s)**
Mean values	46.0	99.8	44.6	190.4
Criteria	**Target D/T for C/O (s)**	**D/T minus target D/T (s)**	**Total D/T in mins**	**Minus 60% D/T (s) relating to layout**
Mean Values	100.0	90.4	4.9	54.3

Table Key-D/T (Downtime), C/O (Changeover), s (seconds), mins (minutes), FLT (Fork Lift Truck)

The summary outcomes presented a 60% probability (or chance) that the layout and the layout with different combinations created obstacles to progression and good working practises: layout issues at 8%; combined lack of standard operating procedures and communication (signage) 8%; lack of training 8%. For additional contributory factors refer to table iii, which presents further empirical downtime relationships.

Table iii Layout and combinations calculating the probability of occurrence

(X) Values	Frequency	Relative Frequency %
Layout and combination all downtime occurrences	5	20%
Layout only issues	2	8%
Lack of training only	2	8%
Layout and comms issues	2	8%
Layout and lack of training	3	12%
Layout, communications and no standard operating procedures	1	4%
Comms and standard operating procedures issues	2	8%
Comms and training issues	1	4%
Comms, no standard operating procedures and lack of training	3	12%
No standard operating procedures and no training	2	8%
Layout, no standard operating procedures and lack of training	1	4%
Layout and no standard operating procedures	1	4%

Table iii demonstrates that the process layout, along with other factors, inhibited not only effective communication, but a web of production inefficiencies. But it is also comparable to state that all instances are not unordinary for a process environment; whereby it is common to have procedures in place to prevent communication lapses and also to provide training for staff optimisation. Further to this, a lack of standard operating procedures , poor communication and a lack of training or combinations of these contributed the remaining 40% of downtime, equivalent to a mean of about 20 seconds per batch. Therefore, by introducing improvement strategies it is estimated that around 90 seconds per batch would be saved. The analyse phase investigates where the process was breaking down.

4.3 Analyse Phase: Analysing the Process

Cause and Effect Diagram Adding Cards (CEDAC) and 5 Whys Analysis

Key representative information taken from the measure phase and a work-based questionnaire supported the creation of the CEDAC diagram in figure 6. This effective tool supported the rationalisation of potential problems causing productivity issues. Each cause is fundamentally linked to each other and difficult to challenge due to the scale of problems presented.

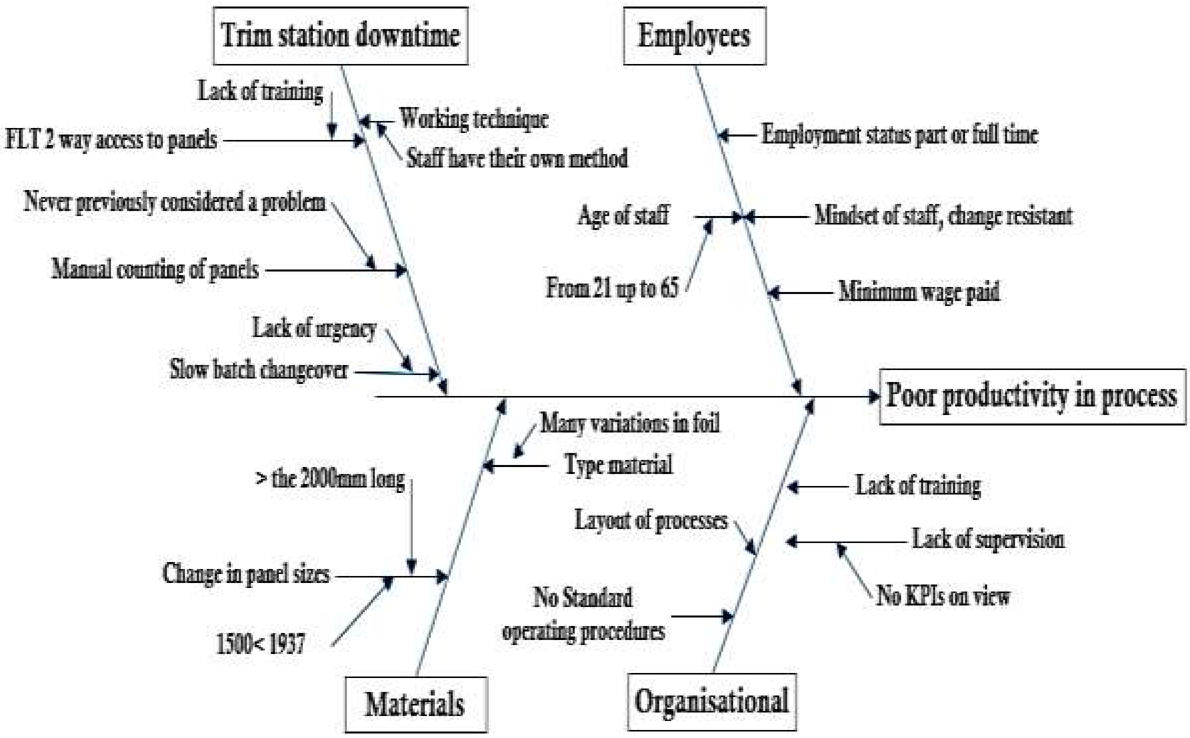


Figure 6 CEDAC Diagram for Poor Productivity within the process

The Cause and Effect diagram presented a raft of causes attributed to poor productivity and clearly demonstrates a blend of tangible and intangible causes impeding the process. The information relating to the specifics within the diagram were drawn together with the members of the project team. To further address the complexity of issues the lean manufacturing tool 5 whys analysis was implemented. Table iv on the following page presents the results (in no particular order) of this phase of the research. The information tabled together was drawn from group meetings with the project team, which acted as a filter for workable and non-workable solutions to problems. The very essence of this study was to bring simple and cost-effective solutions in order to take the pressure off the process in line with the CTQ plan.

Table iv Summary of 5 Whys Analysis

Issue No.	Issue Description and/or it's Cause(s)	Remedial Action(s)
1	Floor plan is poor	Alter layout to suit process
2	Inadequate training	Provide additional training
3	Lack of supervision	Increase supervision in process areas
4	Poor communication in process areas	Introduce Standard Operating Procedures
5	Line balancing out of sync	work to practical TAKT time
6	NO KPIs on view	Introduce process metrics chart
7	No process signage on view	Introduce Andon principles
8	Manual counting increases downtime	Introduce manual counting device
9	Trim technique is poorly actioned and asynchronous	Use SMED to improve techniques and reduce handling of panels
10	Staff age causing slow working	Mix the age of the teams up

Using the 5 whys analysis method and the experience of the project team staff, the causes presented in the cause and effect analysis were drawn in with possible actions, as is shown above, for the improvement phase and therefore allowing the team to begin focusing on the path ahead. The correlation analysis (next) further helped to delineate instances of why downtime places great strain on the productivity of the process.

Correlation analysis of Trim time downtime over 25 Investigations

Only the strongest correlations were considered, such as, FLT wait times/manual count times returned a coefficient of -0.60; manual count time/changeover to the bander returned -0.70. Although, the manual count time/trim down time returned 0.52 it was expected to be much higher than 0.8 as the manual counting time alone presented a mean time of 339 seconds and was the most significant downtime. Therefore, the interpretation of the results was carefully considered, particularly as no major linear relationships were apparent.

Summary Analysis of Employment Type and Staff age

Earlier research of age and or experience in the manufacturing sector demonstrated a mixed view on added value and the process considered for this research was no different. In this case the inexperience of agency or mixed teams achieved higher mean outputs per panel, at around 29 seconds. Conversely, full time staff achieved an output of one panel every 32 seconds. Although the margins are small, this data does support the inclusion of the inexperienced agency staff on the production floor but, also presented age (although individual health was not assessed) as a harbinger to improving trim times. For example, trim times of around 29 seconds were recorded with a mean age of 37, compared around 32 seconds with a mean age of 61, adding 12 days to the process. The improvement phase, next, uses a range of lean and six sigma strategies to bridge the poor results so far demonstrated. During observations of the process it was noted that the process was physically demanding and tough going on the older operatives. Yet, due to this observation the opportunity for future automated solutions looked more probable.

4.4 Improve Phase: Improving Processes with Lean and Six Sigma Strategies

Strategy 1- Layout change of panel trimming area (finishing area)

The research within the previous phases provided compounding evidence linking system downtime with poor communication and process layout. Furthermore, the previous layout suited individuals and friendship groups. Therefore, the new layout both maintained a tactical bridge of healthy work relationships, and ensured communication between the panel unloading from the lamination machine output - with the Fork Lift Truck - to the beginning of panel finishing and then on to panel banding was coordinated to reduce communication breakdowns. It was also evident that inventory piling added further downtime.

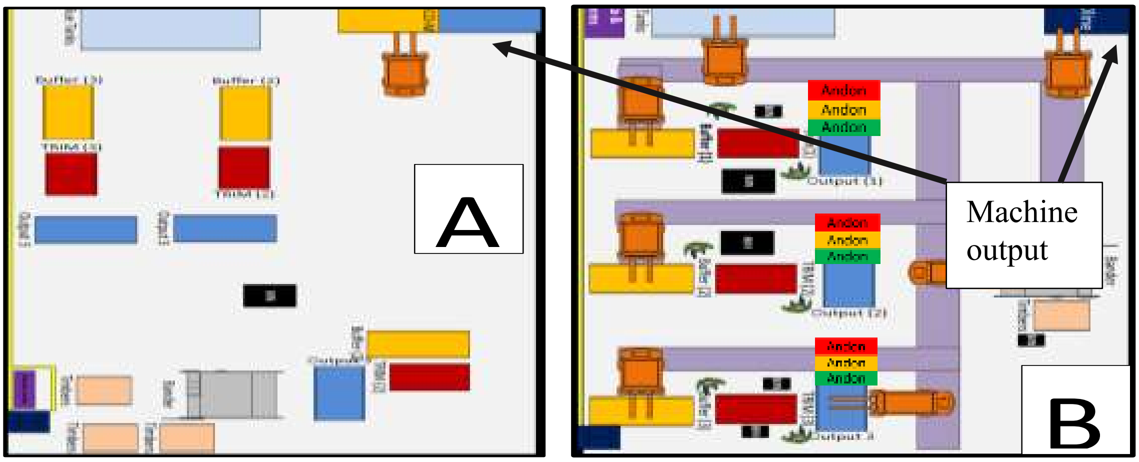


Figure 7 Illustrating layout A (old) and B new layout with Andon displayed at each output area

By altering the layout a good and consistent flow of people and material traffic was introduced and was aided with the application of the lean manufacturing tool of Andon principles, as cross communication was simplified due to unimpeded lines of sight. As a result of this the downtime improvements resulting from the layout alterations were recorded as part of Strategy 5 - Andon Communication using RED, Amber and Green Markers.

Strategy 2 – Plan Do Check Act (PDCA) for mechanical Counting device Introduction

The research in the previous phases clearly demonstrated a link with downtime and manual panel counting. To remedy this Demmings PDCA technique was applied to introduce a simplistic method to reduce waste. For this a simple mechanical counting device was introduced and would be stroked each time a panel was completed and sent to the awaiting output trolleys. Figure 8 presents the results of the device inclusion.

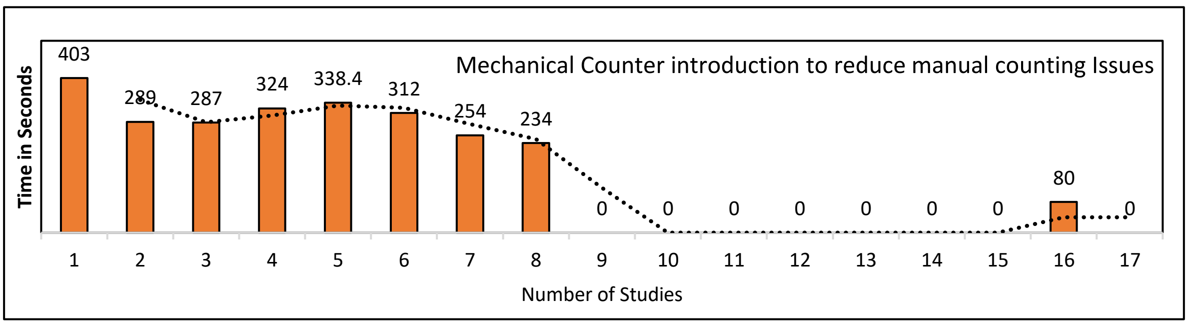


Figure 8 Graph of Count times for pilot tests following the introduction of a mechanical counting device

The first 8 studies show evident downtime, in spite of the mechanical counter insertion as shown between experiments 1 and 5. This was attributed to poor communication by the team. To remedy this a standard operating procedure was introduced to convey the changes. The result of this reduced the mean count time of 384 seconds at experiment 5 to almost zero at experiment 9, gaining a mean 6.4 minutes gain per batch and approximately 45 minutes per day. Study no. 16, was recorded on a slow Friday afternoon, which presented a new set of challenges for overall production tempo. Although, not considered for this research study.

Strategy 3 - Communication Techniques, introduction of a 'Manufacturing board'

The initial research phases conveyed issues of poor communication, resulting in material transition lapses and delays. To improve this a manufacturing board conveying team targets, with Key Performance Indicators (KPIs) initially set to 150 panels per team per hour or 1 panel every 24 seconds was introduced. This was gradually phased in to maximise staff output but also to avoid over working staff. This was particularly relevant to staff of +55 years, who were more experienced, yet, proved detrimental to overall process speed as the research has discussed. To address this teams of two were mixed up: age; skill set; with part and full members. Over time panel output increased to 175 panels per hour. The following sub-section presents a histogram of the mean output of a team of two.

Strategy 4 – Introducing Single Minute Exchange of Dies (SMED)

Alongside the previous improvement strategies SMED techniques were employed to reduce the number of handling transitions of a panel. By applying this lean manufacturing technique panel handling functions reduced from 12 to 6 per team of two. This notable change built on the previous improvement work undertaken, helped to reduce downtime from 429 seconds per batch to 70 seconds, an overall of improvement of 513%. The histogram in figure 9 presents the target +/- that of 175 boards per hour, per team of two as the previous sub-section denoted.

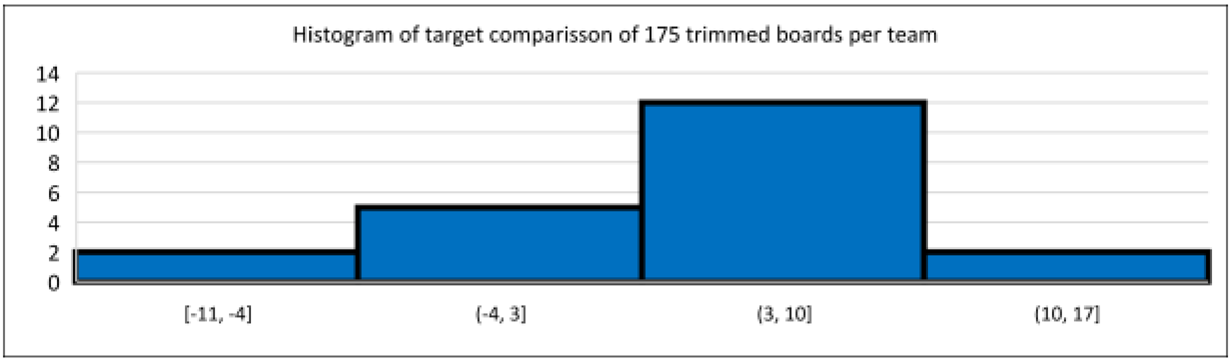


Figure 9 Improvement Phase: Histogram showing standard deviation of trim output

The histogram presents the process performance was within a range of +17 and -11 panels of the 175 panels per hour target. This net gain in output is around 30% greater when compared with the data recorded in the measure phase, whereby one panel was trimmed approximately every 31 seconds, or 120 panels per hour and galvanises the strategies applied during this improvement stage.

Strategy 5 – Applying Andon Communication methods using Red , Amber and Green Markers

The Andon method provided a strategy to inform of process conditions in order to reduce waste. In principle its inclusion was to provide an alarm for the fork lift truck driver(s) by using a red indicator when new batches of panels were required at trimming stations; secondly, to notify a supervisor of an issue with for example, paperwork using an amber marker and thirdly displaying a green marker to affirm that the process conditions were satisfactory.

This yielded a reduction in Fork-Lift Truck wait times, batch arrivals and bander change overs to around 21, 26 and 34 seconds respectively. Due to this intervention the mean total downtime reduced to 162 seconds, and over time further reduced to 70 seconds per completed batch. In addition to this, OEE increased from its previous low of 38% to 57%, a 19% upward change. But still leaving work to do, which was to form part of the structure during and following the control phase, as improvements would be constantly under review. Refer to next sections for results.

4.5 Control Phase: Controlling the Process

To present the changes post research period a Failure Modes Effects Analysis (FMEA) was incorporated to record the risk to the quality performance. Table v presents a summary of the results following the improvement phase. Ideally the Risk Prevention Number (RPN) was designed to be less than 10. The score of the RPN was drawn from team experience. Table v is supported by figures 10 to 12 which presents the ongoing performance of the process.

Table v Control Phase: Summary results of FMEA table

[redacted]

Table v summarises the risk to the process failing and identified, actioned and reassessed for conditions of change following the improvement stage. It is clear that all causes of failure have improved. Although further improvements are required in order to satisfy an RPN of 10 or less in the first five causes. However, with the introduction of the final column the quantitative and qualitative gains made during the research are significant, with at the very least a 33% increase in all elements. This demonstrates once again the depth of the historical issues blighting the process and the progress made during this research project.

Figure 10 below presents representative data within an SPC recorded from the trimming stations following the improve phase. The sample range was averaged over the range of 25 samples twice to provide a closer approximation of the mean value. The TAKT time of 14.79 seconds (the dotted line) is shown for reference of the machine output.

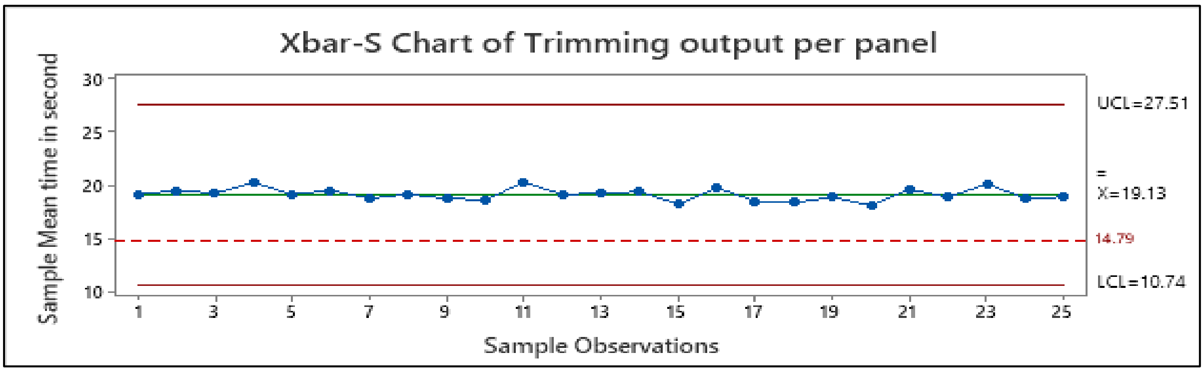


Figure 10 Control Phase: Control chart showing the retuned data from the trimming stations

Stabilisation is evident in figure 10, due to the methods applied in this research project. The process mean (process mean doubled) is now consistently around 19 seconds, as opposed to around 30 seconds as presented in the probability plot pre-improvement stage in figure 11. The tightening of the process parameters can be further compared in figure 11.

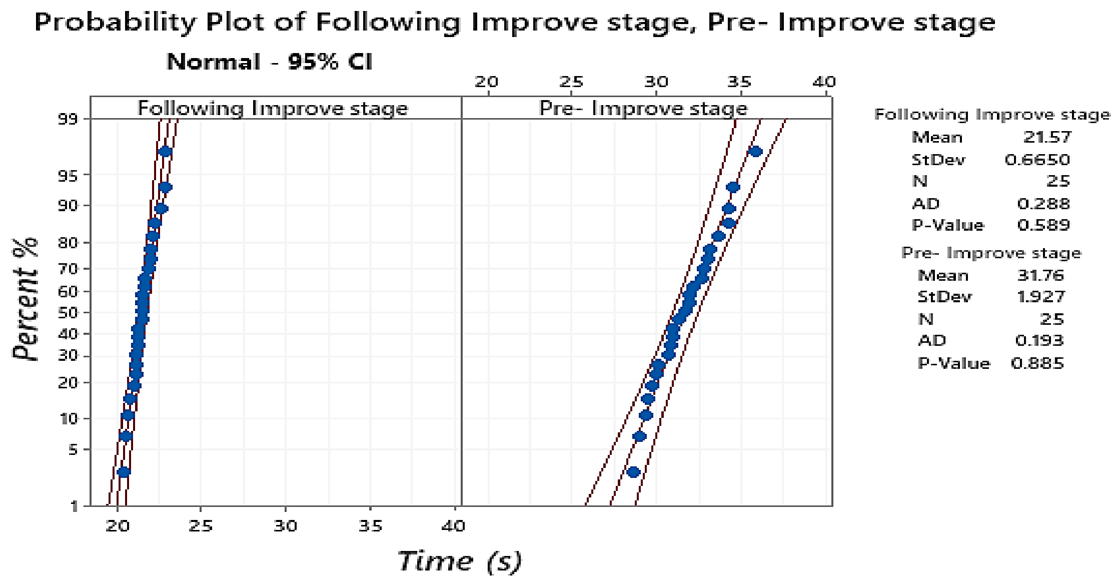


Figure 11 Control Phase: Probability plot showing the retuned data from the trimming stations pre-improvement and post improvement phase.

Plot 1 (following improvement stage) demonstrates a closer relationship to the goodness of fit line when compared to plot 2, which shows a wider time band distributed over the sample range of 25. Although both graphs illustrate P-values greater than 0.005 which means that both demonstrate a 95% confidence of following a normal distribution. That said it is clear from the results tab on the right-hand side of the graph that there is an approximate 10 second gain per trimmed panel. Further evidence of the improvement in the process is demonstrated in figure 12, which presents the results from process conditions that were considered problematic to the timing of events within the panel finishing area.

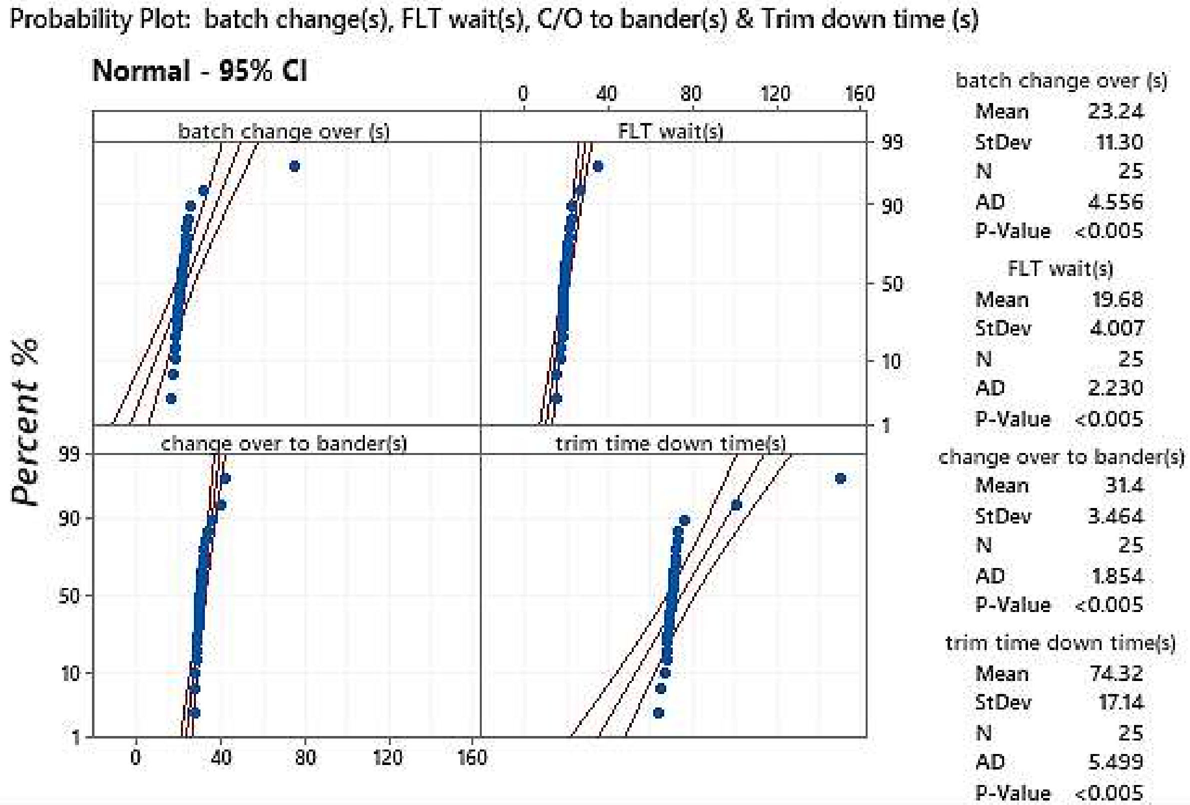


Figure 12 Control Phase: Probability plots showing retuned data from the batch change over, the Fork -Lift Truck (FLT) wait time, change over to the bander and the actual downtime experienced in seconds (s) post improvement phase.

It is evident that the quality of the process has improved, because in each case deviation from the goodness of fit lines were restricted to a minority of incidents recorded at the beginning of the sample. Although, the analysis demonstrates less than a 95% probability of following a normal distribution. That said, each graph presents better cohesion and is more conducive to a settled process with significant gains compared with data from the earlier part of the research: See table vi for comparison. All measurements are in seconds (s) for pre and post-improvement means. The % scale is provided to demonstrate the change events.

Table vi Pre and Post-Improvement mean data compared

Event Measured	Pre-improvement mean	Post-Improvement mean	Gain in %
Batch change over (s)	46	23	100%
FLT wait time (s)	44	20	120%
Change over to Bander (s)	100	31	223%
trim area overall down time (s)	455	74	515%

Table vi is confirmation of continued discipline within this panel trimming area, whereby all significant events measured during this study improved by more than 100%. The ascension of this data contributed to more strategic matters, whereby the redistribution of two members (or 33%) of staff from the panel trimming were utilised in other areas of the business, and thus reducing the cost of the process and further supports the applied methodologies in this study.

5. Discussion

The gradual introduction of Lean and Six Sigma tools progressively broke down the early doubters to progress. For example, one root cause of downtime was the manual counting of panels which added significant downtime of a mean of 384 seconds per batch. However, by introducing a simple mechanical counting device, downtime reduced to virtually zero and returned 6.4 minutes to the process and strengthened the business case for the research.

Furthermore, with a mix of full and part (agency) time staff with a wide range of ages and different skillsets and attitudes, complicated production anomalies. However, by distributing age and skill sets to counter production issues, the analysis showed that mixed teams (agency and full time) and reducing the mean age to approximately 37 helped to achieve panel trimming transitions to one every 21 seconds as opposed to one every 31 seconds per panel. This action was further strengthened by introducing a localised KPI chart to communicate production targets, as accorded by the 5 whys analysis and further crystallised targeted output improvements.

Problems were also evident with panel trimming techniques as individuals applied an individualistic approach, largely resulting from poor training. To remedy this Demmings PDCA cycle and SMED was actioned. The result of applying these techniques reduced personnel movements by 50% and by combining other improvements, downtime reduced to around 70 seconds per batch. This was equivalent to a 513% gain in available time and a 30 second gain on the 100 seconds target. Furthermore, out of 25 samples investigated, 66% were above the 175 panels per hour target compared to pre-project data whereby one panel was trimmed approximately every 31 seconds, netting a minimum gain in output of 32%.

Poor communication placed a strain on the resources within the area as denoted in the 5 whys analysis. To remedy this Andon Principles were introduced and the trimming area was redesigned to suit the CTQ plan. These actions helped to prevent FLT driver and operator miscommunication and galvanised cross sectional relationships between the FLT drivers and the trimming operators, further reducing downtime and supporting the increase in OEE at trim stations to around 57%; a 19% improvement.

The measure of OEE within this study demonstrated a means to connect component quantities with the reality of relatable workflow that all staff could relate to. With that said, as the general rise in OEE within the finishing areas was incontestable it was also possible to demonstrate the strain each interconnection placed when parts were distributed without recourse and the overall effects this had on system productivity.

The control phase demonstrated the improvements as the process settled down and tangible gains were evident, with trim station downtime down by 515%. Strategically this resulted in requiring only four staff as the quantities leaving the finishing area were 14% above the mean of 1825 panels per day and thus resulted in a saving of 33% on salaries in this area. This was because transitions were more efficient and proved that the applied methods within the improvement phase were successful through a combination of applying a range of tools and ideas generated by a dedicated team of individuals as opposed to applying a standalone method with one individual generating the ideas.

6. Conclusion

The net gains attributed during this research study were subject to a data driven mindset, whereby staff and resources were gradually and exploratively developed to alter a significant aspect of business output within its panel lamination finishing area; it just required a moment where the past could be compared with a new and different alternative. The alternative being that a cohesive and measured structure could, with the help of the Six Sigma DMAIC dogma, break down the old processes and its associated problems to bring about essential change.

It is also fair to comment on the issues raised during the case study that they were not uncommon to the process industry, only the environment and workplace in which the measurement took place differ, such as, the unique manual environment investigated during this research. Thus, meaning that despite the fact Six Sigma and lean programs are common to large businesses, then it is also possible for an SME to utilise Six Sigma and lean tools to mobilise small improvement strategies without applying great resources, as this research study has shown. The proof being the results and the tremendous impact during this study.

In essence the application is made more achievable when individuals are partisan and ringside for each phase of the process, from the define stage right through to the control phase. The respect gained through idea sharing reduced waste through travel and motion, and with improved communication techniques contributed to significant reductions in the downtime previously experienced and created a more efficient and productive value adding process to the business.

7. Managerial Implications

The study brings new and exciting opportunities for the business to continue to develop in this data driven environment. The new environment that encompasses everybody who can feel a sense of belonging to the improvements and sustainability of doing so. One of the lessons learned from the passage of the study was that the inclusion of people at all levels proved to be successful and is now beginning to be adopted throughout the business. This in turn drives more focused individuals; subtly becoming more productive without adding additional strain to their daily routines, which is ethically and economically inviting for all stakeholder interests.

8. Limitations

The freedom to conduct a simultaneous investigation over the whole process was not practical or possible, because of the nature of the business environment: this reduced the amount of data available and led to drawing conclusions through extrapolating information, using mean values instead of absolutes. Also, probability calculations applied, such as, 60% to layout issues only applied to the observable investigations. This chance of event would counter different probabilistic outcomes over time but would require a more in-depth study to provide a more precise range of probabilistic outcomes and hence a need to apply random number generators.

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