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# Exploring the Linkages between Lean Layout Planning and Performance Improvement

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**Abstract.** Within a competitive environment, productivity improvements represent a remarkable demand for operations strategy. In this context, lean layout planning plays a meaningful role to work environment, enabling cost savings with the elimination of unnecessary transportation and waiting avoidance, reinforcing productivity gains. This paper presents a case study of an automotive segment project of engine assembly layout improvement. The project consisted of introducing new equipment for building a straight line for crankshaft assembly, process that previously demanded that the engine was manually lifted to a second line for this crankshaft assembly task. Therefore, research design introduces a performance measurement approach to measure cycle time impacts on the workstation that was affected the most by the new work design. Results revealed cycle time enhanced an expressive performance improvement, specially on the third month after straight-line implementation. After boxplot analysis, a one-way variance analysis performed with Tukey test exposed performance average gains over the project months, except the transition between the third to the fourth month, when this improvement was no longer considered statistically significant. The main contribution is focused on reinforcing the linkage between lean manufacturing layout and performance improvements through a quantitative analysis of a real automotive case study, connecting theoretical principles to practice.

**Keywords:** Lean Manufacturing, Lean Layout, Performance Measurement, Productivity, Operations Strategy.

## 1 Introduction

In a production line, there are several approaches to improve production processes and systematically increase productivity. Layout review and the investment on digital technologies are some relevant ways to aid manual work and inspect machine work times. According to Otenšlégrová and Martinez (2018) layout planning is extremely important for the work environment, since a well-planned layout can save and reduce many costs with unnecessary transportation and waiting avoidance, enhancing significant productivity gains. The investment of emergent technologies for manual work replacement and machine cycle-time improvements have also been some highlighted strategies implied by Putri and Dona (2019) to reduce wasted time with inefficient layout.

Research relating the impact of lean manufacturing practices to cost reduction has been part of the strategic organizational management agenda. Within this field of study, Panwar *et al*. (2018) and Dave and Sohani (2019) have investigated the relationship between some lean approaches and productivity improvement, collecting performance indicators with managers such as demand leveling, visual management tools and lean layout to statistically test and emphasize how lean practices stimulate a positive impact on waste reduction.

This paper presents a case study of an automotive segment project of engine assembly layout improvement. The project consisted of introducing new equipment for building a straight line for crankshaft assembly, process that previously demanded that the engine was manually lifted to a second line for this crankshaft assembly task.

## 2 Theoretical Background

This section presents a brief theoretical background of the three most important themes considered essential theoretical topics to the development of this research: operations strategy, lean manufacturing and lean layout. Lean layout is a special issue in lean manufacturing management, since smart layout planning plays an important role on operational efficiency and brings a meaningful impact on waste avoidance. A brief overview in the old literature of operations strategy is the initial topic, since it is the great wider field of the present study.

### 2.1 Operations Strategy

The word strategy has been around for a long time and for many it is considered the highest target driver of the organizations. Mintzberg (1987) and Platts (1993) define strategy as a standard way of thinking in the future, where the perseverance of behavior is the biggest challenge in order to integrate the decision-making process with the planed procedures and expected results over time.

Platts and Gregory (1990) conceptualize strategy the direction of business objectives to be achieved through the management of appropriate structural and infrastructure resources. Slack and Lewis (2008) complement the conception of operations strategy as the conjunction of strategic definitions and actions in the most relevant areas that places an organization in its competitive environment in order to achieve long-term aspirations, ensuring its growth.

According to Slack and Lewis (2008) manufacturing strategy has two broad categories: i) decision areas that focus on the long term of manufacturing and ii) competitive criteria based on the goals of an organization or business unit. In their definition, decision areas include capacity, supply network, process technology and organizational development and these four-dimensional strategic decision areas must be established in consonance with organizational ambitions, supported by five competitive criteria: cost, speed, quality, flexibility and dependability, being cost the qualification to manage operational expenses and deliver within the budget, speed the ability to complete work quickly and in accordance with lead-time expectations, quality the capacity to deliver within quality demanded standards, flexibility the competence to easily react to changes or new requirements and, finally, dependability the ability to deliver projects and outcomes according to expectations (Slack and Lewis, 2008).

Strategy, within its five performance criteria, must be properly assessed by performance measurement systems with the purpose to continually measure the real performance of operations over target and periodically communicate employees and stakeholders the respective achievements over a certain time. Porter and Roach (1996) defend the need to apply tradeoffs in the strategic dimensions, highlighting the importance of making convenient choices regarding target positions, assuming and communicating the company's unique and specific place in the market with the definition that sets it apart from the competition. Pisano and Hayes (1994), however, challenge this strategy premise that trade-offs are really mandatory for competitiveness, considering production could possibly not be limited exclusively to low cost, high quality or fast delivery, exemplifying many Japanese factories that practiced lean manufacturing tools and consequently have reached superior performance comparing to American competition in all dimensions, achieving fast delivery, low cost, higher quality, greater flexibility and dependability, all at the same time.

The term “Lean Production” was spread by Krafcik (1988) referring to lean manufacturing, widely known as Toyota Production System and its essential concept of waste elimination. However, only after the publication of the book “The Machine that Changed the World” the term became famous worldwide (Womack *et al*., 1990). Since then, there has been given a lot of effort from academics and professionals, to replicate Toyota's success in manufacturing strategy in a variety of distinct environments.

## 2.2 Lean Manufacturing

The basis of Lean Manufacturing, developed by Toyota by Taiichi Ohno (1988), is focused on managing optimized results of production with low resource utilization. Lean production is different from artisanal production, that was characterized by specific and highly qualified labor, with handcrafted and exclusive products. Lean also differs from mass production, characterized by unskilled labor for a high rate of repetition in the same activity. Toyota Production System presents the zero-defect concept, elimination of waste and flexibility in production, which aligns the strengths of each type of previous production systems, without absorbing waste at product cost.

According to Shingo and Bodek (2005), a concept strongly highlighted by Lean is continuous improvement, commonly known as Kaizen, which is the leading focal point of success of Japanese Production System. Lean philosophy also emphasizes the importance of high-quality standards in production environment among the processes.

Hence, operational training in manufacturing is a constant demand, reinforcing employee commitment to a high level of quality.

Toyota Production System is sustained by two pillars: Just in Time and Jidoka. JIT is a disciplined approach aimed at improving productivity through waste elimination, enabling effective production in terms of cost, as well as providing only the necessary amount of components, in the proper quality, at the correct time and place, using the minimum facilities, equipment, materials and human resources. Just in Time is dependent on the balance between supplier flexibility and customer flexibility. It is achieved by applying elements that require full employee involvement and teamwork. JIT key philosophy can be traduced by simplification (Slack, Chambers and Johnston, 2009). The other pillar, Jidoka, means autonomation, and can be defined by “automation with a human touch” (Ghinato, 2000) and its role consists of guaranteeing autonomy for both the operator and the machinery in line stoppage events due to any anomaly. Although Jidoka does not aim to reduce human labor, this ends up being one of the consequent results of its application.

According to Ohno and Bodek (1988), in a lean production system, every waste is considered the symptom and not the cause of the problem. In this context, there are seven types of waste commonly found in the processes: i) Overproduction, which consists of producing more than demanded or sooner than demanded; ii) Waiting, the waste of time when no activity is processed, transported or inspected by operators or machines; iii) Unnecessary transport or movement, the waste in transporting materials is proportional to the quality of the layout of facilities, given that the physical arrangement is decisive for transport; iv) Excessive processing concerns inefficient or unnecessary activities that do not add value to the organization or product and hinder or delay production; v) Inventory in process, in the warehouse, or finished product stock; vi) Defects due to lack of quality in the production process, demanding rework and wasted materials and time; and, finally, vii) Material movement, inefficient and unnecessary movements of the employee when looking for tools, materials or instructions.

According to the consultant Tom Peters, lean is learning to see waste and almost all quality improvements come from design simplification of manufacturing layout.

### 2.3 Lean Layout

Lean layout planning implies an extensive understanding of operational processes, material flow and the arrangement of manufacturing cells. According to Otenšlégrová and Martinez (2018), effective layout design can enable better work conditions, process efficiency improvements and accident reduction in the work environment. Shingo and Bodek (2005) have also previously observed that, when new products are introduced, new tasks, materials, cells and operators are often requested, demanding greater planning and readjustments. However, it does not always suggest the need for additional space, since layout optimization brings the possibility to create smarter workflows in the processes, enhancing higher quality and dynamism in production systems.

The excess of space, on the other hand, implies higher costs and gives prominence to the unnecessary movement of resources, causing negative impacts on operational time. According to the author Taiichi Ohno (1988), unnecessary transportation of materials must be eliminated as much as possible, and the cost to transport them must be minimized with prior study and adequacy to the process, making it manageable to identify and improve certain activities. The improvement can start with training and restructuring of the physical arrangements for accessing the tools, for example, with continuous studies and the development of new variations of better work designs (Ohno, 1988; Shingo and Bodek, 2005).

Effectiveness in plant layout is also strengthened by the search for the best possible balance between demand and operations, avoiding unnecessary work-in-process when following customers' takt time, making waste easier to be identified with inventory minimization. In the context of practical studies, Putri and Dona (2019) redesigned a production layout in an Indonesian home-food industry using the lean concept and proposed new standard operational procedures after the identification of excess transport levels, which enabled waste elimination. With a similar purpose, Kovács (2020) has also investigated the application of lean tools with facility layout design approach in a real case-study, which has effectively enhanced remarkable improvements of productivity with cycle-time reduction, minimizing the number of workstations, operators, and work-in-process inventories at the assembly line.

Otenšlégrová and Martinez (2018) complementarily reinforced a combined approach with the purpose to implement 5S and lean layout methodologies simultaneously on the shop floor. According to the researchers, they are interdependent tools, following the premise that lean layout improves processes by increasing visibility of the processes' flow while 5S methodology organises the workplace to increase productivity, reducing waste indicators.

A recent study focused on lean layout was also developed by Augusto *et al*. (2021), who investigated a new assembly line layout in a welding industry using the principles of lean manufacturing as the main driver. The previous layout had a strong impact on non-productive times for operators, being related to the lean waste of waiting and unnecessary movements. The researchers analyzed a systematic layout planning implementation through Value Stream Mapping for the current scenario identification and application of the pertinent lean methods for the final redefinition of the new layout system. The new work design brought an exceptional increase in the value-adding time of the operations carried out in the sector, consistently reducing movement times between previous and final assemblies and enhancing cost savings regarding the man-hour value of the employees, operators who can possibly be transferred to other requirements in productive tasks.

Considering waste minimization literature (Ohno and Bodek, 1993; Womack *et al*., 1990), lean layout design is, therefore, a powerful tool to achieve a lean factory, reducing many forms of *Muda* (waste), *Mura* (overburden), and *Muri* (variation), placing the plant in a world class standard (Shingo and Bodek, 2005, Verrier *et al*., 2014).

## 3 Research Design

This paper presents a case study of a layout improvement project in automotive environment. The project consisted of introducing new equipment for an engine assembly line, building a straight line for crankshaft assembly, process that previously demanded that the engine was manually lifted to a second line for work execution. The previous along with the new introduced layout are presented by Figure 1.

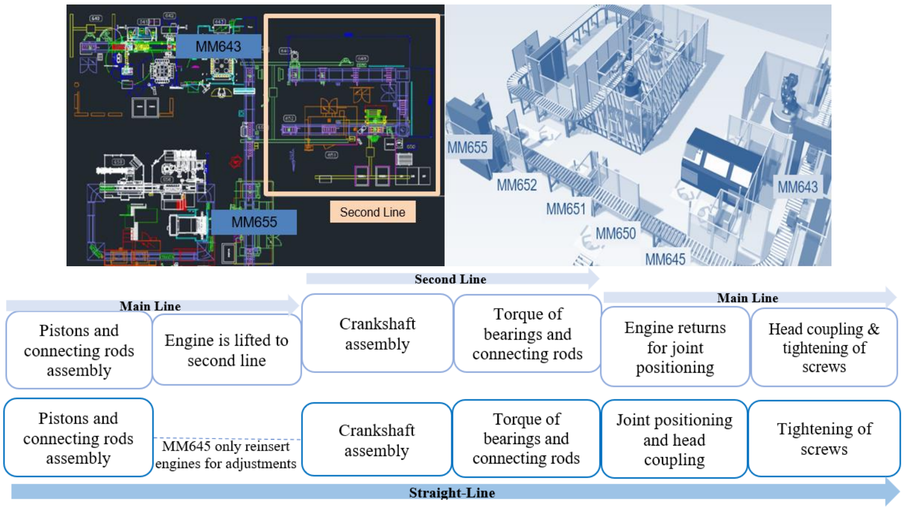
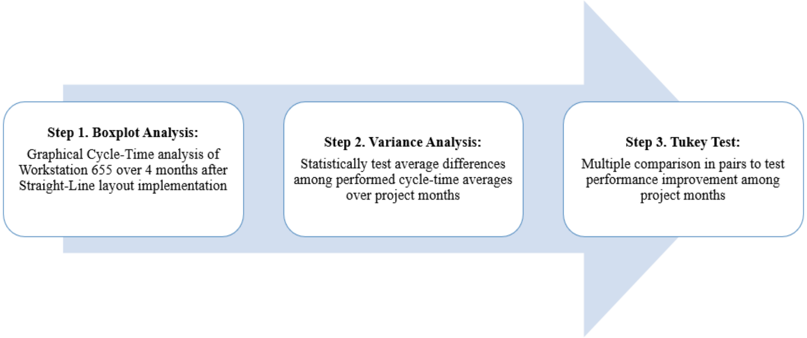


**Fig. 1.** Previous and Straight-Line Layout.

The main improvement is at the final workstation 655, where head coupling is now previously prepared with the new layout, bringing working balance between the final stations. Hence, a performance assessment for workstation 655 cycle-time is proposed for the research design, as exhibited by Figure 2.



**Step 1. Boxplot Analysis:** Graphical Cycle-Time analysis of Workstation 655 over 4 months after Straight-Line layout implementation

**Step 2. Variance Analysis:** Statistically test average differences among performed cycle-time averages over project months

**Step 3. Tukey Test:** Multiple comparison in pairs to test performance improvement among project months

**Fig. 2.** Research Design.

The main purpose is to measure cycle-time improvement brought by straight-line layout at the workstation that was affected the most by the new design.

# 4 Results

Workstations 655 exhibits wide-ranging performance evolution over the months since the implementation of straight-line work design, as presented by Figure 3.

With the purpose to analyze project learning-curve, breakdown instances were not excluded for quartile measurement, although outliers from breakdowns are not plotted for visualization in boxplot. The first month had a frequent occurrence of longer breakdowns as usual, since assembly line operators were not used to the new introduced layout and were still learning how to manage the new equipment. For this reason, it seems reasonable that the cycle-time of the first month is presented as an outlier.

It is perceptible a performance evolution from the first to the second month and a remarkable performance breakthrough from the second to the third month of the project. The fourth month of the project, however, did not exhibit an outstanding evolution comparting to the previous month, although the cycle-time average has also improved and cycle-time average is no longer an outlier as it is on the third month, which is a phenomenon explained by a lower number of interruptions and machine breakdowns.

The third and the fourth month have enhanced a noticeable stability in the process, since data is more concentrated, exhibiting persistent cycle-time performance steadiness, which may be an indicator that the third month was the learning and adaptation point with the new work design started to reach the expected performance evolution.

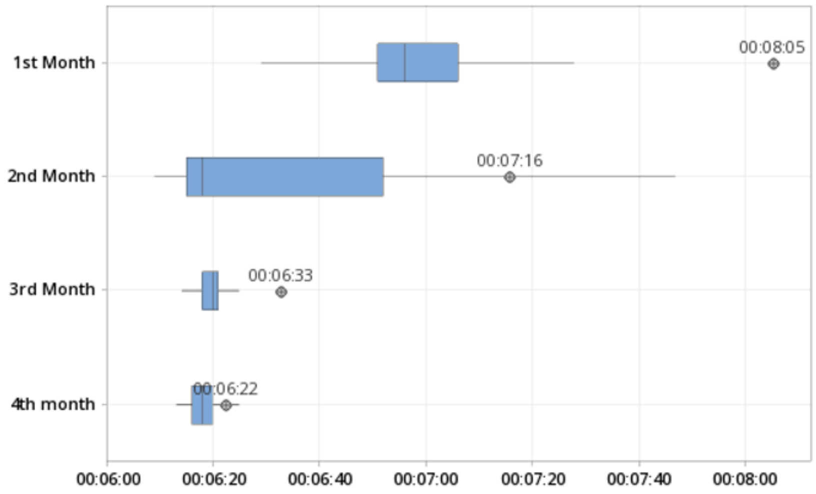


**Fig. 3.** Boxplot Analysis.

Boxplot approach provided overview graphical analysis and insights, summarizing each stage's enhancement along the introduction of the new shop-floor layout. Following this initial descriptive analysis, a single-factor variance analysis for project months was sequentially considered appropriate to test significant average differences among the project. Table 1 details the hypothesis test, performed with 95% confidence interval for this analysis.

**Table 1.** Hypothesis test.

| **Method** | |
|---|---|
| Null hypothesis | All means are equal |
| Alternativa hypothesis | Not all means are equal |
| Significance level | α = 0,05 |

Equal variances were assumed for the analysis

**Factor Information**

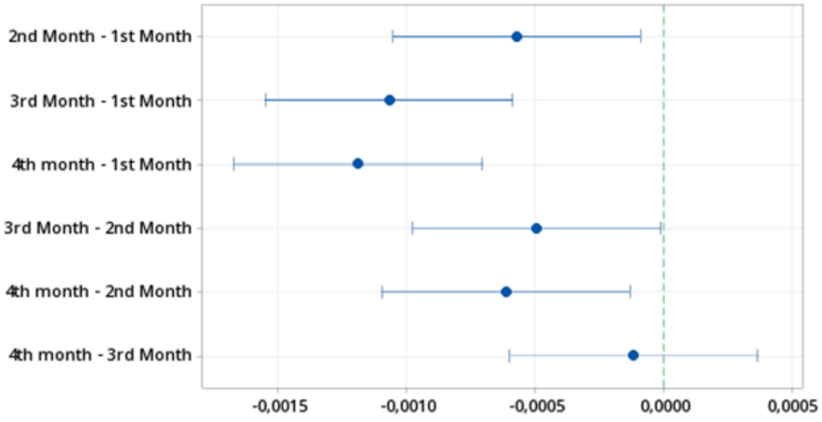
| Factor | Levels | Values |
|---|---|---|
| Factor | 4 | 1st Month; 2nd Month; 3rd Month; 4th month |

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Factor | 3 | 0,00138 | 0,00046 | 16,71 | 0 |
| Error | 6244 | 0,171836 | 0,000028 | | |
| Total | 6247 | 0,173216 | | | |

DF: Degrees of Freedom; SS: Sum of Squares; MS: Mean Square.

Before conclusions, test premises were challenged. Since residues showed a large adherence to the standard normal distribution and residual variances were approximately equal, premises were ratified. Considering a 95% confidence level, H0 was rejected, since p-value < 0.05. Therefore, statistical evidence of significant average difference for at least a couple of average cycle time over the months was found. Tukey's test was then considered conveniently useful to test average differences between phases in pairs, presented by Figure 4.



*If an interval does not contain zero, the corresponding means are significantly different.*

**Fig. 4.** Tukey Test.

By means of 95% confidence interval for differences between averages, Tukey test showed that only the transition between the third to the fourth month presented no significant difference, as suspected upon boxplots descriptive analysis. In addition, it also implied a respective improvement for all the other transitions compared in pairs since the difference is always negative, hence, it essentially diagnoses a cycle time reduction in all other month transitions.

Tukey test complementarily provided a confidence interval for cycle-time performed over the months, as exhibited by Figure 5, assuming 95% for the average internal confidence upon combined standard deviation to calculate the intervals.

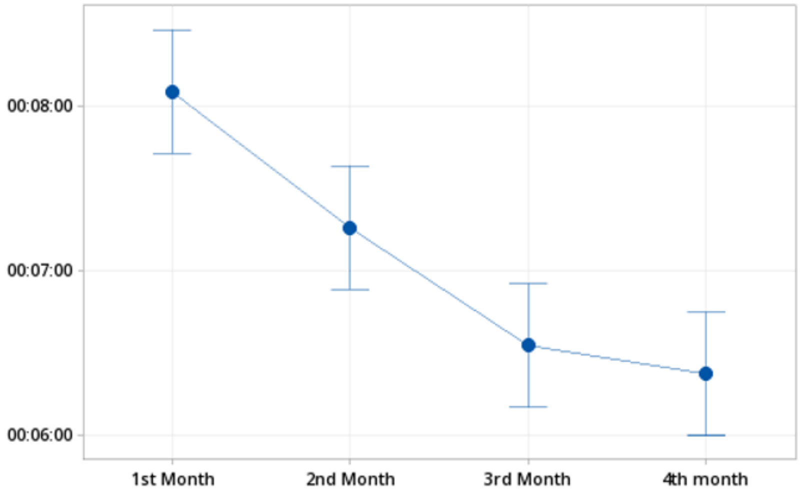


**Fig. 5.** Confidence Interval.

Performance evolution over the months is also noticeable as presented by confidence intervals. Although every month presents an improvement comparing to the previous month, only the second and the third months enhanced statistically significant achievements, as confirmed upon Tukey test.

Cycle-time average at the final two months are under seven minutes, which is a rhythm that guarantees process stability, since it is no longer closer to bottleneck performed cycle-time, which corresponds to eight minutes and ten seconds.

## 5 Discussion

Performance assessment revealed both boxplot and variance analysis approaches imply performance improvement along straight-line project. Cycle-time of the most impacted workstation has significantly reduced along the project months, enhancing greater performance stability for the whole assembly line.

The previous workstation cycle-time presented an average close to the bottleneck rhythm of eight minutes and ten seconds and straight-line made it possible for Workstation 655 not to represent a threat of disturbance to the bottleneck, which is a station apart from the change brought by the project. After the third month of straight-line layout, workstation 655 presented a much better performance under seven minutes and greater steadiness, assuring process stability. Hence, findings are in consonance to the expectation to harmonize final and basic line operational times.

A headcount per shift avoidance also provided economical gains. Moreover, considering waste minimization literature (Ohno and Bodek, 1993; Womack *et al*., 1990) the new layout went beyond a better productivity, since it has also contributed to release 180 m² of space, reducing Muda or waste of unnecessary movements of operators and materials and consequently, more efficiency with less process variations.

## 6 Conclusion

This paper strengthens the hypothesis that lean layout contributes for shop-floor performance, since quantitative analysis presented a meaningful performance evolution over straight-line project. Limitations identified on the present study are also relevant to direct following research to cover some topics left unexplored by the present case study. For this reason, a process mining approach of the whole engine assembly line is an interesting following step to extend findings of straight-line contributions. Another aspect to be measured in a further performance assessment is the avoidance of safety accidents on engine handling with a better designed process, since the new equipment imply better ergonomically standards.

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