

Original Article

A Lean-Based Integrated Production Model Combining Layout Optimization and Visual Control for Metalworking SMEs

Rodrigo Santiago Baca-Vial¹, Alessandra Sánchez-Sánchez², Wilson David Calderón-Gonzales³

¹Carrera de Ingeniería Industrial, Universidad de Lima, Perú.

*Corresponding Author : wcalder@ulima.edu.pe

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Abstract - Metalworking SMEs in developing economies had suffered inefficiencies for a long time, even after Lean and layout adjacent studies that reported only partial gains. This initiative addressed urgent issues of variability, huge amounts of internal transport, weak standardization of work processes, and unreliable production information. An integrated production model based on Lean Manufacturing, Systematic Layout Planning, and Kanban-type visual control was proposed and tested out in a Peruvian metalworking SME. New work methods were designed, plant layout was optimized, and information flow was improved with simple means of visual records. Results indicated that production efficiency improved from 80.20% to 90.80%, that systemic time per product was reduced by 9.44%, total travel time also by 8.13%, while information recording errors were reduced by 60.34%. Results indicated that some degree of operational stability was attained with measurable improvements in productivity, all without expending large amounts of capital. Theoretically, the initiative added more empirical information about synchronizing methods, spaces, and information in SMEs. From a social point of view, it is hoped that the additional competitiveness thus gained will contribute to reliable delivery ability extending downstream. Further studies are desired to extend the model.

Keywords - Lean Manufacturing Integration, Systematic Layout Planning (SLP), Kanban Visual Control, Operational Efficiency, Process Standardization.

1. Introduction

Metalworking SMEs are an integral component of industrial growth, supplying fabricated steel products and structural systems used in construction, energy development, and the industrial sector. Globally, Metalworking SMEs provide an element of flexibility and responsiveness to engineer-to-order supply chain systems where product customization and delivery reliability are critical to maintaining a competitive advantage over the long term. Empirical studies of Lean systems demonstrate a structured methodology for improving operational performance for Metalworking SME's by reducing waste, increasing process stability, and building a culture of execution discipline [1].

Metalworking SMEs in developing regions such as Latin America play a key role in urban expansion and infrastructure improvements, yet typically they operate with limited capital, informal production management systems, and limited access to advanced planning technologies. A specific example of this can be found in Peru, where Metalworking SME's focusing on designing, fabricating, and assembling metal structures often combine workshop-based manufacturing

with on-site assembly activities under tight delivery timelines [2].

From an operational standpoint, Metalworking SME's regularly experience chronic production problems associated with long and variable lead times. These issues often correlate with inefficient flow of materials within the production process, excess internal transportation, and fragmented production management. The research examining Lean implementation at Metalworking SMEs emphasizes the fact that without a comprehensive framework, the improvement efforts typically turn out to be very limited and unsustainable in the long term [3]. Often, Plant Layouts at Metalworking SMEs are developed incrementally and reactively to short-term needs without regard to optimizing workflow, creating inefficient proximity between operations, requiring the retracing of materials through multiple processes, and resulting in bottlenecks around shared resources. Production layout design studies focused on small production runs and multi-product environments have demonstrated that Non-Value-Adding Time (NVAT) is



increased significantly with such types of layouts and ultimately decreases productivity [4].

In addition to NVAT, layout-related inefficiencies become more apparent in metalworking facilities since the steel components are relatively heavy and large; therefore, steel materials require multiple handling steps (i.e., cutting, machining, fitting, welding, and finishing). Furthermore, the empirical application of Systematic Layout Planning (SLP) has shown that layout redesigning can significantly reduce the distance travelled and the time spent handling products by using both logical and relationship-based layouts to improve the continuity of work-in-progress and the efficient use of manufacturing space [5]. However, layout redesign by itself does not establish a sustained gain in productivity for the metalworking facility unless the established work practices are operated consistently and predictably across the various locations where the work is performed by the worker population. Productivity improvement studies reveal that when combining the optimal arrangement of the plant layout with the basic principles associated with Lean activities, the combination maximizes the effects of redesigning a plant by reinforcing a system of operational discipline [6].

In addition to layout-related inefficiencies, another major source of inefficiencies for metals SMEs is the absence of standardized manufacturing processes and the duration of set-up time. The production systems employed in the manufacturing of steel often consist of many changes in set-up (or set-up sequence) for product variety and project-based demand. Using the SMED (Single-Minute Exchange of Die) concept to standardize setup times for the metalworking and machining industries has demonstrated evidence of the significant impacts of the elimination of wasted time associated with set-up processes and enables the preparation of components for production in a shorter period of time, ensures smoother sequencing of production and results in the decrease in total cycle times [7]. While these studies have provided evidence of the value derived from improvements implemented at the method level, they also provide evidence demonstrating that method-level improvements can result in stabilized production; however, the results of both studies reveal that the effectiveness of method-level improvements to improve production stabilization may be limited without the accompanying physical layout to facilitate the intended production flow. Metalworking SMFs will enhance their competitive position and will also sustain their development by meeting the challenges associated with high cycle times and sub-optimal facility layouts. Increased cycle times and sub-optimal layouts impose high operating costs for SMFs and prevent SMFs from performing multiple jobs concurrently, which is common within steel structure manufacture. To alleviate these issues, a Lean Manufacturing approach has gained considerable traction with SMFs by focusing on waste elimination, improved process transparency, and continuous improvement. Many case

studies across steel-related sectors show that the application of Lean tools (value stream mapping) provides significant reductions in non-value-adding activities and greater operational visibility [8]. The studies have also shown, however, that over time Lean initiatives may lose their effectiveness if not addressed by spatial constraints and sub-optimal facility layout-driven wastes.

In response to the spatial constraint challenge, an additional method called Systematic Layout Planning (SLP) provides the ability to align the physical configuration of a manufacturing plant to its manufacturing process and facilitates the coordination of these two elements. In reference to studies associated with the relocation and redesign of layouts using SLP and flow analysis, there are reports of meaningful improvements in the material handling efficiencies and production flow of small and medium manufacturing businesses [9]. The literature continues to identify that Lean Manufacturing and SLP are typically treated as two separate initiatives. In most cases, Lean studies employ process mapping and standardization as the primary methodologies to create their value propositions, whereas SLP applications emphasize material handling processes with a focus on distance but do not incorporate Lean execution logic [10]. The separation of these methodologies limits the ability to maximize the reported improvements, particularly within the family of SMEs that operate under high variability.

The research gap becomes evident when considering metalworking SMEs involved in the fabrication and assembly of steel structures, as these SMEs often have inefficiencies due to non-standardized processes, layout-driven transportation losses, and limited production control.

Existing studies examining Lean Manufacturing as it relates to steel-related manufacturing have demonstrated reductions in the number of late deliveries and operational delays; however, most studies have not included a systematic redesign of the manufacturing layout within their Lean Manufacturing improvement architecture [10]. Consequently, few empirical studies exist that have developed production improvement models that integrate Lean Manufacturing, specifically process standardization and SMED logic, with SLP via an empirical approach developed to meet the constraints of SMEs.

Considering this knowledge gap, this research endeavors to build an integrated production model that develops an integrated operational improvement methodology that incorporates essentially Lean Manufacturing and Systematic Layout Planning to create an operationally efficient Metalworking SME that designs, fabricates, and assembles metallic structures. What is unique about this work is that it should be treated as a comprehensive approach to the interdependence of method stabilization, setup reduction, and layout optimization. Empirical support for this model will be

provided through an industrial case study to provide an example of how synchronizing process and layout interventions can collectively reduce non-value-adding time and increase operational efficiencies for metalworking SMEs.

2. Literature Review

2.1. Systematic Layout Planning for the optimization of production plant layouts

Systematic Layout Planning (SLP) is one of the prevalent methodologies for designing and redesigning industrial layouts today. This is due to the systematic assessment of relationships between activities, material movements, and spatial limitations and constraints through the systematic approach provided by SLP. The literature strongly indicates that the great strength of SLP is the ability to change from empirical to systematic layout decision-making. A layout decision-making process is established using relationship diagrams, flow analysis, and the ability to compare layout alternatives. Recent studies have indicated that SLP leads to substantial reductions in internal travel distance, material handling time, and transportation costs in production environments with high levels of interaction between processes and activity [11] and [12].

Several studies reported in the IEOM proceedings indicate that SLP can be extremely effective when combined with multi-criteria decision technique methods such as TOPSIS, allowing the selection of the optimal layout in terms of distance, safety, flexibility, and space utilization [13]. In addition, applied research indicates that layout redesign, based on SLP, improves operational measurements such as internal lead time and flow productivity, using real route movement frequency data [14]. SLP has continued to be an applicable methodology for traditional manufacturing when dealing with issues associated with spatial disorganization, unplanned growth, and bottlenecks created by functional layout designs not aligned with the production sequence [15].

2.2. Work study For Process Standardization

The work study method, study, and work measurement provide a technical base for process standardization. The reviewers assert that workers may consider standardization as simply paperwork describing the process. In fact, standardization should be viewed as the best-known way to do the work, clearly defined because of careful study of motions, times, and working conditions. The application of work study is reported to reduce uncontrolled variation in the workplace, making processes more repeatable and providing a good foundation for continuous improvement work [16]. Work in both industrial and service settings shows that standard work promotes discipline and stability in the workplace, enabling visual control and the early detection of abnormalities [17]. Research shows that standardization based on objective time studies helps to expose the waste associated with unnecessary motions, waiting times, and

rework, resulting in increased system efficiency and productivity [18].

2.3. Kanban Cards to Reduce Information Recording Errors

Kanban cards have been used as a means of controlling material and information flow, particularly in pull-based production. It was reported that one of the weaker areas of Kanban lies in its ability to minimize errors in registering information as necessary data about replenishment, such as quantity, place, source, and destination [17]. Case studies demonstrated that the use of physical Kanban systems limited misunderstandings and incomplete records in internal supplies processes [18]. With the advent of digital technologies, Kanban further developed the concept of e-Kanban systems, an alternative to eliminate human errors generated by the handling of physical cards. E-Kanban systems can improve traceability, reduce information losses, and allow for online monitoring of a logistics performance indicator [19]. Additional evidence describes that Kanban cards (physical or electronic) improve information reliability and coordination between the production and warehouse areas, given that clearly defined operating rules and periodic audits are applied to the system [20].

2.4. Efficiency Problems in Metalworking Plants

Metalworking plants face specific efficiency challenges derived from high product mix variability, job shop-type processes, high frequency of setup changes, and functional layouts that generate excessive internal transportation. The literature claims that low equipment availability, idle time, rework, and poor synchronization between processes and information flows are the main sources of inefficiency. Applied studies in the sector showed that lack of standardization and inadequate layout design markedly increase cycle times and operational costs [18] [22].

Recent studies conducted in metalworking SMEs found that the integrated use of Lean tools—works standardization, layout redesign, flow control—significantly improves productivity and system-wide efficiency [21]. In this subject, the literature generally argues that metalworking plant efficiency problems are not of a technological nature, but rather result from accumulated losses due to the design and organization of operations and of the system itself.

3. Contribution

3.1. Proposed Model

The proposed production model in Figure 1 was derived from both the Lean Manufacturing philosophy and the systematic layout planning process (SLP), which together structured the approach to improving operational efficiency as an integrated approach to creating a more effective production model. The production model was designed for a Small-to-Medium-sized Enterprise (SME) in the metalworking industry that designs, fabricates, and

assembles metallic structures, and therefore, it considered the typical limitations that these businesses typically face, such as limited resource availability, demand variability, and the physical layout of operations. Lean's core premise is that standardised processes provide a baseline of consistency that enables improved management of operational variability, an essential component of the Lean approach. The question remains as to how to create the standardisation required to support Lean thoughts and make it easier to use Kanban cards to create visibility between operations (production). The

analysis and rearrangement of a facility's layout can help facilitate a more logical sequence to areas of production, as well as facilitate a more streamlined and efficient flow of materials and information between each production stage, which can then be further supported by Lean principles. Ultimately, the Lean-mentioned models, along with the SLP process, provide the metalworking industry with an integrated method for optimising production's management capabilities to create greater levels of continuous improvement.

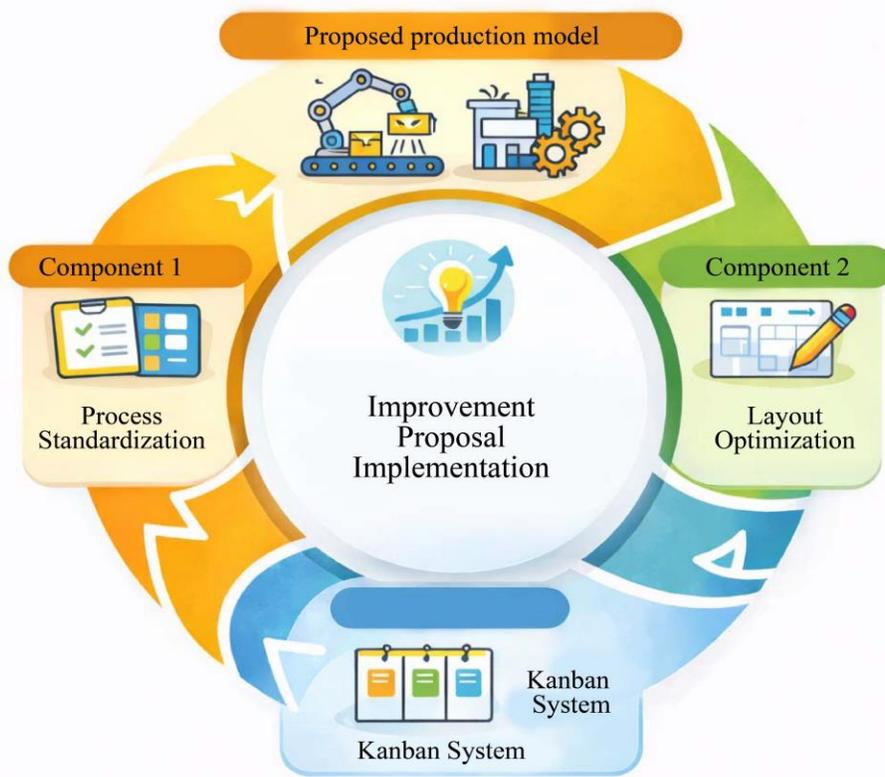


Fig. 1 Proposed Model

3.2. Model Components

The relevance and contribution of the model presented here has to do with the practical application (Figure 1) of a method created to respond to the ongoing challenges faced by metalworking SME's (small and medium-sized enterprises) due to a lack of stability in the production flow caused by the following conditions: available technical skills, physical limitations on production facilities, and unstable demand patterns.

In general, metalworking organizations that design, produce, and assemble metal structures will not always increase production capacity simply by increasing execution speed. Rather, as discussed previously, they can improve productivity by identifying and eliminating daily frictions, items that do not add value to the customer but instead consume time and resources.

The model presented in Figure 1 is based on the premise that the application of Lean Manufacturing principles in conjunction with the combined methodology of SLP (Systematic Layout Planning) will assist organizations in creating more predictable, traceable, and manageable production operations by providing tools to support those methodologies with the appropriate considerations.

The basis for the successful application of this model is to effectively tie together the tools of the referenced methodologies. The three primary tools of Lean Manufacturing are process standardization, layout redesign, and the management of visual information.

Thus, Figure 1 represents not a decorative sequence but a structured framework that organizes decisions, establishes

priorities, and guides the implementation of improvement practices in an integrated manner.

3.2.1. Component 1: Intelligent Work Standardization through Methods Study

The first component of the model is the work standardisation component that identifies work processes not merely as a documentary process, but as a mechanism to achieve operational stability for production processes and activities that provide for continuously improvable, repeatable, and auditable production processes. In a metalworking SME, for instance, production activities include marking, cutting, drilling, assembly, welding, grinding/finishing, painting, and pre-assembly. From what would appear to be inconsequential issues, such as sequencing of tasks, preparing their tools and their materials, the criteria for inspection and the recording of progress, variability results in an increase of the set-up times on new jobs, an increase in the need to do rework, an increase in complexity in the coordination of teams, and an excessive dependency of employee resulting in their work. The standardisation of a model acts as a "common baseline"; it provides flexibility in the production of steel/sheet metal structures, but also prevents each job from being treated as a completely new job.

In terms of Methods Study, Methods Study has been defined as the primary tool for observing and documenting work in the actual conditions in which it is done on the production floor, addressing many of the operational details that many would consider irrelevant for general description. In the model, this component is organised based on a systematic approach to the selection of critical processes based on a priority scheme. As a general guideline, critical processes are selected based upon those that have high frequency, are labour-intensive, and are most likely to result in delays or cause non-conforming problems. In practice, these are processes where variability has cascading effects; for example, pre-assembly and tack welding have cascading effects on final welding, and the cutting and preparation of the materials for manufacturing have cascading effects on multiple stages of fabrication. Selection of an objective had to be made in order to maximize the effect of the standardisation process as contrasted with the stabilisation of the most frequently occurring actions that had the greatest influence on overall workflow; hence, in their Work Method Study (WMS) method, after determining the objective, they described their work based upon systematically direct observation, documenting the work flows, movements, preparation times and work execution conditions.

In metal manufacturing facilities, there are many micro actions that contribute to the overall productivity. While the performance of the operator can be described as only the performance of his or her main task, it is actually a combination of all the micro actions, such as searching for

measuring instruments, positioning parts for machining, moving supports, waiting for lifting equipment, replacing cutting discs, or repairing welds due to poor access conditions. As a result, a method study takes the method used by the operator and decomposes that method or action into discrete steps, separating out the value-adding activities from those actions that are the result of disorganization or an absence of a common method. In addition, the method study assists in identifying the locations of delays attributable to both coordination and resource availability problems; therefore, the objective of this type of study is not to assign fault, but instead to establish a baseline against which to agree on the best-known method of performing a given task based upon the true limitations of the organisation.

The standard method is defined based on the development of the collected information as the technical-operational agreement between the method of performing the task, including the sequence of the task, the minimum requirement of conditions under which the task must be performed, the tools required to perform the task, and the measurable verification criteria to validate that the method was followed. The standard method is developed using language that is clear and easy to use and avoids using complex and often-useful documentation; therefore, the standard method model is designed to be visible and used by operators without interrupting their work. In the context of metalworking, where operations typically include both power tools and heavy materials, standardization is completed by combining the method of how to do the job with conditions for their safety, rather than having these guidelines separated from the method itself. This ensures that the standards of the method do not only include a description of how to complete the task but also provide a way to complete it while guaranteeing less improvisation and, therefore, less variability in the outcome.

One aspect of this component is how it relates to pre-execution preparation, or the ability to begin an operation with no loss of time or productivity due to not having all necessary inputs (information and/or tools) at hand. As part of the metallic structure fabrication process, schematics, material lists, work orders, and specifications are created and distributed to operators. In some cases, the information provided to operators may be incomplete or inaccurate with respect to the actual shop floor situations. By using pre-execution verification methods prior to the start of the execution of standard methods, this component allows for a quick method for the operator to verify the availability of all required materials, verify that critical measurements match those on the schematics, verify that the condition of all required tools matches the manufacturer's expectations, and establish the work area is free of disorganization and distractions that could cause time losses or delays. In other words, this component is designed to get operators to be more efficient by shifting the time for "doing it and correcting it"

to “preparing to do it well” to put more stability into the process.

Another important factor associated with the creation of standards is the involvement of operations personnel in the development and creation of standards, not simply as a requirement, but as a requirement in order for the standard to be realistic and for operators to buy in. As part of an SME, it is common for operators to develop practical solutions to the challenges they face in their operating environments; this component captures these types of solutions while applying consistency criteria so as to preserve what adds value to an operator’s performance and eliminate those practices that add risk and disorder. Therefore, by utilising an approach of co-constructing the standard, it will lead to the greater acceptance of, and allow for standardisation to be seen as providing a greater degree of support for operators to do better work, rather than as an outside controlling force. As stated within the context of Lean thinking, Standards represent the point of departure; therefore, Standards are not meant to be rigidly enforced, but rather serve to foster the improvement process.

Lastly, as with any standard, this component will lead to the establishment of continuous improvement within standards by embedding lightweight monitoring and continuous improvement routines into the daily workplace. Therefore, rather than relying upon infrequent audits for quality, this model relies upon brief checks, immediate feedback, and real-time adjustments to materials, tools, and configurations as they change. The inherent variability associated with many projects within the metalworking industry requires that the standard must continue to evolve and remain adaptable whilst providing discipline as the “current best practice”. This combination will provide flexibility and create a strong basis for the second component of this model, as optimised layouts will provide value over a sustained period only if the method used for performing work is constant and clearly defined.

3.2.2. Component 2: Layout Optimization through SLP to Enable a More Continuous Flow

The second component focuses on optimising layouts through Systems Layout Planning (SLP), with the goal of reducing unnecessary movement of humans and materials, which are the result of inefficient flow of humans and materials through the production process. Many of the layouts in the metalworking SME space are the result of a combination of unplanned actions over time, e.g., where machines are located where there was previously an empty space, a temporary area has become a permanent area, or a spontaneous storage area created to help deal with daily urgency. In many instances, while these processes are not seen as structural problems at the time, the negative implications that these processes create, such as disruptions to flow, difficulties locating materials, and excessive

movements to counteract these inefficiencies, tend to highlight how layout can influence the operational performance of the site. Figure 1 illustrates that SLP can assist with the transformation of flow logic into spatial and sequential decisions regarding where a production area is located, the proximity of areas to one another, and the sequence of production areas relative to each other. To create a flow logic model, one must always start with a true picture of the process. That is, one should gather information about the flow of materials and how items in different areas interact with one another throughout the process, from when profiles and plates are received until when they are either assembled, welded, polished (if applicable), or otherwise shipped out, delivered, or pre-installed, etc. Therefore, SLP models will also take into account any auxiliary flows (e.g., consumables, gases, tools, jigs, lifting equipment, etc.) that help maintain continuity in the work processes. This “big picture” approach to using SLP will enable users to readily identify which relationships need to be closely located and, conversely, those that can tolerate at least moderate distances.

Once the relationships are developed, the next step involves applying the relational analysis of SLP to establish the appropriate degree of proximity among activities based on the intensity of the interaction, the criticality of the flow, and the degree of coordination necessary between the activities. This takes into consideration several transportation “distance factors.” In addition to just the transportation “frequency” of use, one must also consider the total cost associated with the distance (i.e., transport time, lifting, safety, congested traffic conditions, and simultaneous operation conflict). Additionally, when working with large or heavy components, it is also critical that designers of layout designs incorporate concepts associated with turning radius, safe zones, and accessibility for cranes and/or forklifts (elevated work servers or stackers). Hence, this model's relational design goes beyond focusing merely on transportation; it will include the requirements of operating and safeguarding within a specific working environment. The result of this design approach will either diminish or eliminate design solutions that theoretically make efficient use of resources but are not practical to implement in the real world.

Once the relationships among activities are established, the subsequent process of this model includes generating and comparing alternative layout configurations. Instead of assuming that there is one layout solution, the model allows users to compare many different configurations using quantifiable criteria. The alternatives are evaluated for their capability to create a linear flow of product(s), control backtracking, minimize the number of long movement (or transportation) paths, and eliminate cross movements between work in process and finished products. Given that a structure can consume a considerable amount of space, the model accentuates preserving enough room for workers to

manoeuvre and remain accessible. This includes delineating functional work areas so that they have defined boundaries and therefore avoid the possibility of uncontrolled accumulation of Work-In-Process (WIP) materials; this ultimately harms the effectiveness of an orderly operation.

In addition, the model provides clarity with respect to the balance between fixed and flexible spaces. Some workstations, such as cut-off saws or paint booths, are fixed in terms of their location, while the assembly area and associated preparation areas are more flexible. The application of SLP provides subjectivity that allows the placement of fixed elements first before designing their contiguous space. Furthermore, the designation of flexible space is based on the work function as opposed to tradition, enabling enhanced readability on the floor and supporting navigation based on standardized work methods.

The SLP process provides a methodology for determining a layout before implementation through the process of practical verification. Due to SMEs' sensitivity to capital investments, the SLP places a high priority on lowering costs associated with experimentation (i.e., using floor marking for temporary relocation purposes and performing flow tests with actual work orders) to reduce the risk associated with adopting layouts that will not function as anticipated once implemented in a live environment. Additionally, the verification process creates a basis of support and credibility among the staff for successfully implementing change and provides direct evidence to support improving the effectiveness and efficiency of the flows of work, accessibility of the product, and coordination of the product between concurrent work.

In addition, the visual representation of the layout supports Lean through visual management. The SLP includes a layout for the types and locations of informational points (e.g., signs), and visual control points of product status and progress. Metalworking Processes

For metalworking operations, in which tasks may take days and involve several operators, visibility of the process is important. This need aligns naturally with the third element, since improved layout results in an increase in information visibility and improved information systems help to maintain spatial order over time.

The SLP element represents the "structure" of flow in the model. It is aimed at more than just the movement of equipment, but to provide logical walking paths for materials using standardized work, as well as to reduce the loss of material due to transport and waiting, and to establish physical environments that promote standardized work. The SLP structure stabilises the spatial environment, thus allowing organisations to decrease internal logistical

improvisation, enabling organisations to move toward a more planned and structured production flow.

3.2.3. Component 3: Improvement of information records through Kanban cards for visual control and coordination

The third component of the model is focused on improving the visibility of the information regarding the movement of materials through Kanban cards to establish better coordination between operations and decrease losses caused by poor visibility. In many Small and Medium-sized metalworking Enterprises (SMEs), many performance problems occur not from technical capacity, but rather from disruptions due to partially completed or fragmented information, including unclear work orders, undocumented design change requests, poor clarity around priorities, and missing records of inspections and releases, etc. Without the systematic management of this information, operations must often proceed because of assumptions, and because of this, they create excessive rework and waiting time. Therefore, the model incorporates the use of Kanban as a visual control tool to connect the standardised work to the optimised layout and the management of daily production planning.

The Kanban system, as designed in the model, is adjusted for the types of jobs and workflows characteristic of metalworking production. Kanban is primarily used for managing workflow and information rather than being a main replenishment method in job shops due to the high volume of project-based or low-repeat jobs; therefore, in practice, Kanban's are a form of a "carrier" for key operational information, including job ID, the current stage of the job, critical requirements, verification status and responsibility – the goal is for information to travel with the "work in progress", therefore removing the need for an informal communication channel.

To identify which operational decisions need to be visible each day, we first determine what jobs are taking place in each workshop. With many jobs competing for the same resources (assembly space, welding machines, lifts, finishing areas), it can be difficult to coordinate schedules and know who is using which resources. So, the fundamental questions we need to be able to answer using Kanban cards are: What are we producing? What is next? What is stuck? What resources do you require? What was the agreed priority? Being able to answer these basic questions avoids a lot of unnecessary discussions and allows people to take the appropriate action without constant oversight.

Once the basic questions have been established, we define the flow structure of the Kanban process – in the same way that all of the production process stages flow through the manufacturing plant – a red/green indicator signal will indicate progress throughout the process (as each job progresses and status changes are recorded) and therefore no job will remain "live" without its being detected (i.e., idle, out

of sight). In this way, information that has been improved is viewed not as an administrative burden but rather as operational communications that actively communicate.

The guiding principle for this component is simplicity: if companies operating within physically demanding environments abandon Kanban systems that are too complicated. Kanban cards contain only the minimum amount of information needed to facilitate the recording of progress (e.g., coded numbers, tick boxes, and visual indicators). Lean philosophy is reflected in the removal of administrative waste and the integration of recording with the actual work. The model emphasises visibility by placing control boards and points at locations where decision makers are situated and aligning them to an optimised layout.

To ensure that the information used in making decisions is reliable, a Kanban system establishes basic rules for updating, responsibility, and interpretation of status. Due to the nature of metalworking operations, which involve numerous exceptions like rework or material shortages, Kanban makes these disruptions obvious rather than hidden. As such, identifying the reasons and causes for blocking and the organisation understands where flow interruptions occur, allowing feedback to feed into the standardisation of layout and operations.

Kanban also allows coordination between design, production, and assembly without requiring complex organisational structures. In SMEs, design changes are commonly shared verbally, leading to rapid decision-making but a heightened risk of confusion. The Kanban system provides a visual representation of all relevant design changes, conveying a common set of expectations for operational teams and preserving quality in the flow.

Implementation of Kanban can be accomplished using lightweight review routines where the Kanban board facilitates synchronisation of activities. These short meetings help to define and align what is most important, identify obstacles, and agree upon what actions need to be taken promptly, and therefore decrease opportunities for improvisation throughout the course of a day. The use of these practices also reinforces the discipline of Lean and provides sustaining momentum around visible information in a management rhythm.

Finally, the Kanban model makes it clear that Kanban is not an independent operating system or entity but rather a mechanism to support and provide stability for the entire Lean system. Over time, standardised material without visual controls disintegrates. The layouts optimised without the ability to track them fall prey to disorder. Kanban implemented without a process is symbolic. Therefore, the third component in Figure 1 represents an operational closure of the entirety of this proposed model. This representation is

indicative of a second-tier management approach rather than a one-off improvement exercise.

3.2.4. Model integration: coherence between method, space, and visual control to sustain improvement

The methodological contribution of the model in this figure is evident from the integration of its elements and internal coherence in how it can be executed. At a metalworking SME dealing with the design, fabrication, and assembly of metallic structures, face these problems at once: variability from project to project, physical constraints, dependence on techniques, and the need for constant coordination. The model does not seek to eliminate this complexity but rather builds on an improvement architecture that meets the most frequent sources of waste and disorder: work method variability, impractical internal movement, and degraded operating information.

Lean Manufacturing provides the philosophy of the process and urges for scrupulous elimination of non-value-added activities and a zealous pursuit of stable flow. Standardization through Methods Study brings this common baseline, while SLP empowers a natural flow controlling logic into the plant layout. Kanban cards then provide the capacities of a commonsense visual control tool, improving traceability, tipping blockages, and sustaining our daily drudgery.

Integration becomes evident in how these components communicate with one another. Standardizing clarifies sequences and resource requirements, which becomes layout redesigning; a layout optimized for flow reduces standard execution overhead and offers natural control points; the kanban systems tell us there is deviation to address, which the reflection generates steps to refine the standard and update spatial arrangements. Out of this interaction, the model becomes a stability-embodiment cycle, for it ensures how work is made, where it is made, and how it comes together.

In summary, we advance a thorough and practical methodology for the metalworking SME, avoiding ideals and employing known tools to generate purity, visibility, and profusion. It aims to consolidate production management but prescind from preferences on how implementation may prioritize operational visibility, lower variability, and shared coordination. For this, we condense Figure 1 to an informed suggestion that internally knits philosophy and tools within a realistic application framework, also providing a clear outline to guide intervention.

3.3. Model Indicators

The model indicators were established to facilitate the benchmarking of the proposed production model based on Lean Tools and Systematic Layout Planning, with the end goal of improving the efficiency of the production process of a metalworking SME that specializes in the planning,

manufacture, assembly, and refurbishment of metal component structures. These indicators were selected to reflect the operational behaviour of the system post-implementation of systematic improvement initiatives; they allowed for an ongoing, consistent assessment of process productivity and operational coherence. The development of these performance indicators provided a more in-depth view of the impact of the proposed model upon production dynamics, while also creating an organized structure to allow for continual measurement of the effectiveness of results and support the capacity for informed decision-making during validation.

3.3.1. Production Efficiency (%)

This indicator measured the degree to which the manufacturing area utilized its installed capacity. It reflected the relationship between actual monthly output and the maximum achievable production level, providing a clear view of how effectively available resources were transformed into finished units.

$$\begin{aligned} \text{Production Efficiency (\%)} \\ &= \frac{\text{Monthly units produced}}{\text{Monthly plant capacity}} \times 100 \end{aligned}$$

3.3.2. Total Travel Time (days)

This indicator quantified the total time required for a product to move across all production areas during manufacturing. It captured delays generated by plant layout and material flow, highlighting inefficiencies related to excessive movement within the facility.

$$\begin{aligned} \text{Total Travel Time (days)} \\ &= \sum_{i=1}^n \text{Travel time across production areas} \end{aligned}$$

3.3.3. Manufacturing Time per Unit (hours)

This indicator represented the total number of hours needed to manufacture a single unit from start to completion. It provided insight into process duration and operational complexity, supporting the identification of inefficiencies within production activities.

$$\begin{aligned} \text{Manufacturing Time per Unit (hours)} \\ &= \text{Total hours required to manufacture one unit} \end{aligned}$$

3.3.4. Information Recording Error Rate (%)

This indicator assessed the proportion of errors generated during information recording activities. It reflected the reliability of operational data and the effectiveness of documentation practices used throughout the production process.

$$\text{Information Recording Error Rate (\%)} = \frac{\text{Number of information recording errors}}{\text{Total number of information records}} \times 100$$

4. Validation

4.1. Validation Scenario

A research project based on a small and medium-sized company in the metalworking industry of Lima, Peru, was conducted to validate our approach to the solution. The organization has been operating in the marketplace for many years, with an extensive production facility where it prepares, assembles, and finishes metallic structures for industrial and construction projects. Although they have experience, the case study had difficulty with on-time delivery to their customers, which severely affected both operational performance and competitive advantage. Most of this limitation occurred in the manufacturing area, where low levels of production efficiency and high levels of time wasted were accumulating delays in the production stream. Specifically, the assembly process carried an excessive amount of operational burden and acted as a bottleneck, causing interruptions in complying with the production schedule and maintaining operational stability for the case study.

4.2. Initial Diagnosis

The diagnosis formulated in the case study shows that the principal subject matter was the low efficiency of production, reflected by a technical gap of 10.6%, which indicates that the company's actual production efficiency is 80.2% when compared to its targeted production efficiency of 90.8%. The estimated economic loss associated with the low efficiency of production is USD 2,120,742.97, which represents 8% of the total revenue for the company. The low efficiency of production was primarily the result of the low productivity rate of 39% of the identified production process problem. This low productivity was primarily caused by incorrect information being recorded 15% of the time and by the absence of standard operating procedures 24% of the time. In addition, the remaining 43% of the identified production process problems were due to unproductive time, which included excessive travel time (23%) and long production time (20%). Finally, the remaining 18% of the identified production process problems were attributed to other contributing factors, which included poor communication (10%) and unclear objectives (8%). Overall, the results indicated that the various factors contributing to the overall performance of the production process were all understood in depth.

4.3. Validation Design

To validate the proposed production model and test its effectiveness, a pilot implementation was used to implement Lean and Systematic Layout Planning (SLP) tools into the SME's production process of the design, fabrication, and assembly of metallic parts and components under actual working conditions for use by metalworking SMEs. The pilot

implementation enabled an evaluation of the proposed production model in an actual production environment, providing insight into how a combination of reconfiguration of the layout and process standardisation leads to improved productivity through increased operational efficiencies while also ensuring that the model is methodologically consistent and practically feasible, taking into account the characteristics of the metalworking environment, such as resource limitations.

4.3.1. Implementation Strategy of the Proposed Model

The proposed model was implemented as a formalized and phased-in implementation in a four (4) month pilot study to increase productivity in the manufacturing processes of a Small and Medium-sized Enterprise (SME) dedicated to the design, manufacture, and assembly of fabricated steel structures. Through this pilot, an emphasis was placed directly on solving the operational issues identified in the diagnosis phase, beginning with issues related to low efficiency, high non-productive times, and a lack of recorded information. An integrated approach combining Lean Manufacturing techniques with Systematic Layout Planning was utilized and implemented sequentially and logically. The pilot will allow the ability to implement several improvements in the work process, the layout of the processes, and the manner in which information is processed; therefore, the enhancements made during the pilot were based upon actual operations, were tested during actual production, and could be maintained for the long term.

4.3.2. General Design Approach Applied to the Production Process

Since there are many steels produced frequently (and many operations occurring with a lot of workload), the manufacturing process for making steel columns had the most impact on the model of steel column production. The model itself consisted of a combination of different tools; the main purpose of each tool was the improvement of performance through improved coordination, reduction of motion (or movement), and better traceability of operations. In the context of the case study, three distinct development areas were identified: (1) a standardized working methodology, using the Method Study as an aid; (2) optimizing the layout of the steel column workshop using the Systematic Layout Planning method; and (3) improving the recordkeeping of the individual steel columns by using Kanban cards. To ensure that these development areas were truly representative of the actual production process, the information was obtained from the shop floor, prior to implementation in the production process.

4.3.3. Application of the Method Study for process Standardization

This first phase of the implementation involved Method Study as it applied to the process of steel column fabrication in order to develop a consistent process that reduced

operational variances. Initially, this analysis used direct observations of the activities taking place at each operation within this fabrication; materials received, through final assembly with the associated tasks of marking, cutting, fitting, welding, and finishing. During these initial observations, it became apparent that certain tasks exhibited high levels of operational variances from operator to operator. As a result, there were significant differences in production cycle times and the sequence of work for each operator.

Utilizing the observations made on site during the first phase of this study, the method activity diagrams were created to illustrate how steel column fabrication was broken down by defining those tasks as: productive, transport, wait, and inspection activities. The analysis indicated that most of the total time spent on manufacturing was spent on non-value-adding activities, creating significant amounts of lost time due to the excessive amount of time involved in internal transports, waiting on materials, and rework due to incomplete or inaccurate data. Therefore, an average manufacturing time for a steel column had been identified to be 41.3 hours per unit for the baseline conditions.

Upon completion of this analysis, new manufacturing processes were developed to define optimal sequences of operations by eliminating redundant activity and reorganizing the order of activities to minimise interruptions and waste. Standardisation of processes will provide clearly defined tasks for each workstation; minimum quality requirements for transitioning to the next stage of production; and the requirements for starting workstation operation without generating idle time. Furthermore, during this first stage, the introduction of pre-production inspections and checks was established (e.g., material availability, dimension validation, critical tool inspections), thereby reducing delays during subsequent production execution.

In utilising Method Study as a basis for developing a baseline to the manufacturing process, a reduction of manufacturing cycle time per unit of steel column to 37.4 hours was achieved at this stage of validation, which indicates a significant improvement because of standardising work methods. In addition to reducing manufacturing cycle times, the introduction of new sequence and reference times within the standards has created increased coordination between the various production areas by reducing improvisation during execution.

4.3.4. Production layout optimization through Systematic Layout Planning

In the second phase of developing a solution, Systematic Layout Planning was used to provide the best production layout necessary to reduce travel time and enhance material flow through the plant. To start the analysis, a map of the actual flow of the production process was created, which

included the paths the steel columns took from the time they were first fabricated until they left the production area. This analysis determined that there were long distances to travel, many areas where there were unnecessary crossings, and several congested areas where columns must wait before they could continue to the next stage of production.

After gathering the needed information, an assessment was made to evaluate the proximity relationships between production areas, using first those areas that had high-frequency interaction and transfer rates. After determining these interactions and transfers, a new layout configuration was created to allow for a more logical flow of materials aligned with the sequence of production. The new configuration minimized the number of unnecessary movements, improved access to workstations, and allowed for a more continuous flow of materials.

The layout optimization resulted in a reduction in the amount of total time a column spent in the plant for pilot validation from 12.3 to 11.3 days. The improvement resulted in a substantial decrease in non-productive time due to internal transportation and created a smoother production flow. Also, the new layout supports the implementation of the standardized method of working by reducing interfering activities and enhancing coordination between the multiple stages of production.

4.3.5. Improvement of information records using Kanban cards

The last module of this plan focused on improving the management of information flow using Kanban cards to reduce errors in the recording of information, in addition to improving the traceability of processes. During the diagnosis stage, a large percentage of errors was identified because of records that were incomplete or not consistent. As a result, there was an increase in rework and delays, along with uncertainty surrounding the status of the production orders.

Implementing the Kanban system standardised the recording of all relevant information at each step of the production process. Key pieces of data that were recorded included the progress of production, product identification, and confirmation that all critical activities were completed. The Kanban cards were incorporated into the flow of production, which allowed the information to be moved with the product and eliminated the need for informal communication.

As a result, the number of errors recorded during the validation stage declined to 23% from 58%. This was a large improvement in the dependability of operational information and aided in increasing the coordination of all areas involved in the fabrication process. The Kanban cards also assisted in reinforcing a visual control of the process, which aided in making decisions quickly and reducing the amount of downtime caused by unplanned interruptions.

4.3.6. Integration of tools and consolidation of the model

The successful integration of these tools constituted a cohesive and comprehensive solution to the new product. By designing the implementation of each of these tools in a coordinated way, the improvement attained by implementing the first tool not only provided benefits but also supported further refinements and enhancements of the second tool(s). The certainty gained from the standardization of processes allowed for the further enhancement of process layout through layout optimization; therefore, an improved physical layout of the manufacturing process would yield higher productivity with respect to the use of the Kanban system.

The entire model was validated during the 4 months of piloting by using the new product under normal production conditions, which demonstrated its viability for enhancing production efficiency and alleviating several of the major operational issues identified during the diagnostic phase. The complete design of the production model demonstrated how the structured combination of Lean Tools and Systematic Layout Design provided an effective, sustainable solution to the defined research problem within the scope of this case study.

4.4. Results

The major achievements attained from the validation of the production model proposed are summarized in Table 1. All critical performance indicators of the production process showed positive trends and an enhancement compared to baseline values. The operational industry was improved from 80.20% at baseline to 90.80%, which means a 13.22% improvement over baseline levels. Total travel time was reduced from 12.3 to 11.3 days, or by 8.13%. The manufacturing time for each unit has been reduced from 41.3 to 37.4 hours, or 9.44% improvement. Also, the rate of error when recording data has improved dramatically, as this went from 58% to 23% for a negative variation of 60.34%. These improvements, as outlined above, verify that the model has succeeded in resolving the author's research issue.

Table 1. Results of the pilot

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Efficiency rate	%	80.20%	91%	90.80%	13.22%
Total travel time	days	12.3	11	11.3	-8.13%
Manufacturing time per unit	hours	41.3	36	37.4	-9.44%
Information recording error rate	%	58%	18%	23%	-60.34%

5. Discussion

The results observed from the integrated production model are aligned with previous empirical studies reported in the Lean Manufacturing and layout literature. Gain in production efficiency from 80.20% to 90.80%, is consistent with performance gains in Lean based interventions in metalworking SMEs; Huang et al. [1] report on structured Lean frameworks leading to operational discipline and throughput stability improvements in a metal product industry which is closely similar to the efficiency gains in this study, while Soriano [3] stated that Lean frameworks for SMEs when small, should focus more on process stabilization compared to just using standalone tools, which is also implemented in the integrated production model.

The reduction in manufacturing time per piece and total travel time correlates with the similar findings when combining Systematic Layout Planning (SLP) with Lean tools; Arbizu-Huaraca et al. [2] show cycle times decrease through the joints of SMED and SLP in the Peruvian SME, which is like the reduction of manufacturing time in this case study. Also, the decrease in internal transportation time is similar to that of Suhardi et al. [5] and Febri and Susilawati [6], who indicate layout redesign using SLP, especially when cumulated with workplace organization practices, is effective in decreasing non-value-adding movements and improving continuity of material flows.

Another contribution of the higher reduction of information recording errors, from 58% to 23%, is to strengthen the findings of visual control in holding production systems stable. Prior works have explored and emphasized information flow and the elimination of waste through tools such as Value Stream Mapping [8] and Lean Manufacturing for delivery reliability [10]. Accordingly, we have found that Kanban-based visual control is crucial to improving the reliability of this source of data in highly variable metalworking. This reinforces the work of Manotas-Duque and Rivera-Cadavid [17] in pointing out that Lean performance improvements are closely tied to the reliability of operating information. Finally, it removes any doubt that process standardization, layout redesign, and visual information control reinforce each other's accomplishments all the more than if the same tools had been applied separately, as was done in prior studies.

5.1. Study Limitations

The mentioned limitations of the present work are directly related to the scope of the empirical validation. The proposed production model is validated in a case study of a metalworking SME located in Lima, Peru. Additionally, this validation period is restricted to a pilot implementation of four months duration, which, despite being sufficient to assess operational improvements in the short term, does not consider whether the observed performance will be sustained in the long term in the face of varying demand and personnel

turnover. Finally, this analysis is based on operational indicators gathered internally by the company: contextually dependent factors such as learning effects and short-term managerial focus in the pilot study may also come into play.

5.2. Recommendations for SMEs Based on Results

From a practitioner's perspective, the results yield interesting implications for SMEs in metalworking and other project-based manufacturing contexts: companies can make salient strides in efficiency, lead time, and reliability of information without resorting to heavy capital outlay and heavy IT, but instead developing systematization in the adoption of Lean Manufacturing tools and Systematic Layout Planning. The development of such a roadmap provides an adaptable format for addressing many issues typical in operational practice in terms of internal transportation, variability, and low visibility of information. Here, in principle at least, we consider that using kanban cards not only as replenishment carriers, but also as information carriers, works also well for the strain in SMEs operating under high product variety and low repeatability: it provides an avenue for more effective interplay between production, assembly, and planning.

5.3. Future Works

Future work may apply the proposed integrated model across a series of metalworking SMEs (including "competing" SMEs), and further work will also consider long-term sustainability by reviewing performance over time under conditions of varying demand and manpower turnover. The incorporation of digital tools such as e-kanban or other real-time information gathering might also enhance accuracy and decision-making in the model. Finally, a simulation or optimization component may strengthen further the basis of the model, bringing both insights into alternative configurations and broader system performance.

6. Conclusion

The contributions of this research indicate that the joint effect of the process standardization, Systematic Layout Planning, and Kanban-based visual control improves the operational performance in a metalworking SME, with the production efficiency increasing from 80.20% to 90.80% (+ 13.22%) and the manufacturing time each unit rising from 41.3 to 37.4 hours (- 9.44%). Total travel time is lowered from 12.3 to 11.3 days, and the information recording errors drop from 58% to 23%. These results demonstrate the effectiveness of synchronously linking method stabilization, spatial reconfiguration, and information management strategies into a single improvement model.

The relevance of the research stems from the nature of operational gold mining reality, the oddities of a little SME, with little resource availability, and exploiting the variability between orders. The results show that for consistent

improvements to become standard practice, execution, physical layout, and control information should be carried out jointly instead of just using a tool at a time. The contribution of the proposed study lies in the evidence it shows of such effects of the surrounding environment made of Lean Manufacturing tools and Systematic Layout Planning with visual control. The results contribute in a novel way with systematization of improvement, by proving that their standardization, layout change, and method change strengthen each other when aided by adequate carriers of

information. And of course, formations of such improvements of a replicable, systematic, and instructive form for the reader of project-based manufacturing systems. Future research could focus on making the model more robust in more than one small- and medium-sized enterprise and point over a greater time horizon to check if this trend becomes more relevant in terms of sustainability. Further studies could also enhance the analytical depth even more, using a digital Kanban system, simulation techniques, or even optimization models.

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