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Metodologías de estandarización del trabajo, diseño antropométrico y 8Ds como estrategia de mejora de procesos de manufactura: estudios de caso
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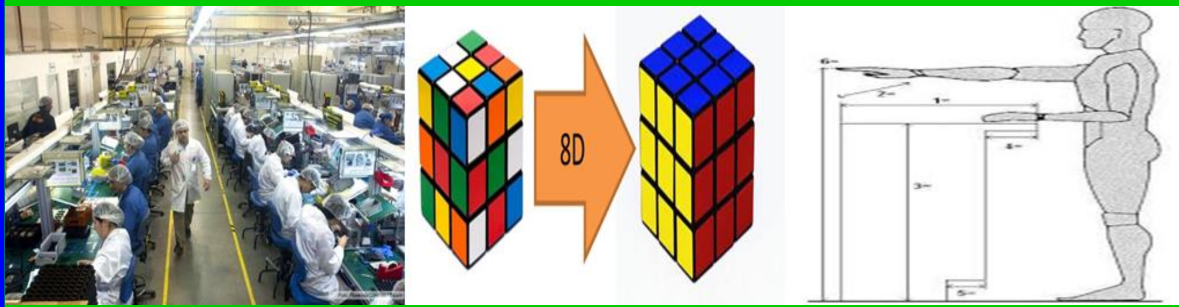

Tesis Doctoral

METODOLOGÍAS DE ESTANDARIZACIÓN DEL TRABAJO, DISEÑO ANTROPOMÉTRICO Y 8DS COMO ESTRATEGIA DE MEJORA DE PROCESOS DE MANUFACTURA: ESTUDIOS DE CASO

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RIOJA

Dedicatoria

En los momentos difíciles, siempre se requiere de una fuente de motivación para seguir adelante y superar los obstáculos. Hoy quiero dedicar a este logro a quienes han sido mi fuente de motivación en mi desarrollo académico y profesional.

- A mis padres por siempre brindarme su apoyo y ayudarme a salir adelante.
- A mi hermana y mis sobrinos por enseñarme a ser mejor persona y también enseñarme lo que realmente vale en esta vida.
- A todos aquellos líderes que Dios ha puesto en mi vida y que, con su ejemplo y su esfuerzo, me han ayudado a llegar hasta donde estoy el día de hoy.

Arturo Realyvásquez Vargas

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Arturo Realyvásquez Vargas

Índice

Resumen

Este documento expone dos estudios de caso que aplican herramientas de Ingeniería Industrial tales como estandarización del trabajo, estudio de tiempos y movimientos, balanceo de líneas, diseño antropométrico de estaciones de trabajo y el método de las 8 Disciplinas (8Ds). Las primeras cuatro herramientas se aplican en una imprenta con la finalidad de aumentar la productividad y optimizar el bienestar de los trabajadores. Por otro lado, el método de las 8Ds se aplica en una empresa de manufactura con la finalidad de disminuir el número de defectos en motores.

En el caso específico de la imprenta, ésta cuenta con 150 operadores, que tienen tareas manuales y mecánicas en el departamento de ensamblaje de cajas con cuatro líneas de producción. La capacidad actual es de 350 cajas por día, pero la demanda es de 650 unidades, y la compañía paga muchas horas extras. Utilizando la estandarización del trabajo, estudiando los movimientos de los trabajadores, el tiempo y el rediseño de las estaciones de trabajo, el objetivo principal era aumentar los índices de productividad y el bienestar de los trabajadores. Después de aplicar esas herramientas, los movimientos ineficientes en los operadores disminuyeron de 230 a 78, eliminando el 66% de los movimientos innecesarios, el tiempo estándar en una estación de trabajo disminuyó de 244 a 199 segundos (18.44%) para cada caja ensamblada, y la tasa de producción aumentó en 63.2%; es decir, 229 unidades por línea de montaje por día, y las horas extra se redujeron a cero. Por lo tanto, la integración del trabajo estandarizado, el estudio de tiempos y movimientos, el balanceo de líneas de producción, y el diseño antropométrico, permiten aumentar la sostenibilidad de la empresa y el bienestar de los operadores al hacer un mejor uso del factor humano, eliminar las horas extra, y aumentar la capacidad de producción.

Por otro lado, en el caso de los defectos en motores, se sabe que, hoy en día, la satisfacción del cliente es un elemento clave para la supervivencia y la competitividad de las empresas de manufactura. En el caso tratado en esta investigación la empresa presenta varias quejas de los clientes debido a ensambles defectuosos de cables personalizados que están integrados en un motor. El objetivo de este estudio de caso era encontrar una solución a este problema, así como prevenir su recurrencia mediante la implementación del método de las 8Ds, para: 1) Desarrollar un equipo, 2) Describir el problema, 3) Desarrollar un interino acción de contención, 4) Determinar y verificar las causas raíz, 5) Desarrollar acciones correctivas permanentes, 6) Definir e implementar acciones correctivas, 7) Prevenir recurrencias, y 8) Reconocer y felicitar el trabajo en equipo y las contribuciones individuales. Por lo tanto, se propone una herramienta de software para realizar una prueba funcional en las líneas de ensamblaje. Después de la prueba, el problema se detectó y redujo con éxito, porque de 67 motores que fueron identificados con problemas, 51 fueron rediseñados antes de ser enviados a los clientes, lo que disminuyó la cantidad de productos defectuosos

en un 75%, mientras que los 16 motores restantes fueron reemplazados por nuevos motores. En conclusión, el objetivo de la investigación se logró, y el método 8Ds demostró ser un modelo útil para aumentar la motivación y la participación de los empleados durante el proceso de resolución de problemas.

Abstract

This document presents two case studies that apply Industrial Engineering tools such as standardization of work, study of times and movements, line balancing, anthropometric design of workstations, and the 8 Disciplines (8Ds) method. The first four tools are applied in a printing press in order to increase productivity and optimize the well-being of workers. On the other hand, the 8Ds method is applied in a manufacturing company in order to reduce the number of engine defects.

In the specific case of the printing press, it has 150 operators, who have manual and mechanical tasks in the box assembly department with four production lines. The current capacity is 350 boxes per day, but the demand is 650 units and the company has to pay a lot of overtime. Using the standardization of work, studying the movements of workers, time, and redesign of workstations, the main objective was to increase rates of productivity and well-being of workers. After applying those tools, inefficient movements in operators decreased from 230 to 78, eliminating 66% of unnecessary movements, standard time at a workstation decreased from 244 to 199 seconds (18.44%) for each assembled box, and the production rate increased by 63.2%, that is, 229 units per assembly line per day, and overtime was reduced to zero. Therefore, the integration of standardized work, the study of times and movements, the balancing of production lines, and anthropometric design, allow increasing the sustainability of the company and the well-being of operators by making better use of the human factor, eliminating overtime and increasing production capacity.

On the other hand, in the case of engine defects, it is known that, currently, customer satisfaction is a key element for the survival and competitiveness of manufacturing companies. In the case discussed in this research, the company files several customer complaints due to faulty custom cable assemblies that are integrated into one motor. The objective of this case study is to find a solution to this problem, as well as to prevent its recurrence by implementing the 8Ds method to: 1) Develop a team, 2) Describe the problem, 3) Develop an interim containment action , 4) Determine and verify root causes, 5) Develop permanent corrective actions, 6) Define and implement corrective actions, 7) Prevent recurrences, and 8) Recognize and congratulate teamwork and individual contributions. Therefore, a software tool is proposed to perform a bump test on assembly lines. After testing, the problem was successfully detected andreduced , since of 67 engines that were identified as having problems, 51 were redesigned before being shipped to customers, reducing the number of defective products by 75%, while the remaining 16 engines were replaced by new engines. In conclusion, the research objective was achieved, as well as the 8Ds method proved to be a useful model to increase employee motivation and participation during the problem solving process.

1. Introducción

1.1 Problemas en los sistemas de manufactura

Hoy en día, para mantener un nivel de competitividad en el mercado global, las empresas de manufactura deben implementar diversas metodologías para la solución de problemas relacionados con la producción de bienes. Tales problemas pueden incluir entregas tardías, paros de línea, cuellos de botella, líneas de producción desbalanceadas, tiempo extra, manejo de material ineficiente, diseño disergonómico de las estaciones de trabajo, movimientos ineficientes, y altos costos de producción, por mencionar algunos. En el caso de entregas tardías, Peng y Lu [1] realizaron un análisis sobre el impacto del rendimiento de entrega en las transacciones de los clientes, lo cual afectó los montos de las transacciones de los clientes y los precios de los productos. Por otro lado, Fazlollahtabar [2] reportó un estudio de caso aplicado a una línea de ensamble en la cual las entregas tardías de productos fueron la fuente de un bajo rendimiento en el sistema de producción. Para resolver este problema, este autor propuso una línea paralela de ensamblaje autónomo de vehículos guiados. Las entregas tardías son el reflejo de una infraestructura logística de baja calidad, que representa, hoy en día, una barrera para la sostenibilidad [3].

En el caso de las líneas de producción desbalanceadas y los cuellos de botella, diferentes autores han confirmado que estos problemas disminuyen la capacidad y productividad en los sistemas de manufactura [4,5]. Esto se debe a que los cuellos de botella pueden provocar paros de línea [6,7], lo que a su vez afecta negativamente el rendimiento del sistema de manufactura. Por ejemplo, Ren *et al*. [4], así como Zupan y Herakovic [8], presentaron estudios de caso en los cuales los cuellos de botella y las líneas de producción desbalanceadas provocaron un bajo nivel de productividad en el área de ensamblaje. En ambos casos, este problema fue resuelto balanceando las líneas de producción y rediseñando su distribución. Además, Gu *et al*. [6] afirman que los problemas de mantenimiento pueden provocar cuellos de botella en los sistemas de manufactura complejos, lo que resulta en una pérdida de producción. En otras palabras, las líneas de producción desbalanceadas crean problemas de organización, disminuyen el rendimiento de la cadena de suministros y aumentan los costos de producción. Por lo tanto, el balanceo de líneas de producción es una estrategia de producción tradicional que ayuda a reducir los cuellos de botella en los sistemas de manufactura.

Además, con respecto a los paros de líneas de producción, éstos son causantes de pérdidas de producción [9] y de los aumentos en los costos de producción [10,11], especialmente cuando éstos ocurren de manera inesperada. Como consecuencia, las operaciones de producción posteriores se ven afectadas [12]. De acuerdo con Hossen *et al*. [13], las pérdidas debidas a la inactividad y fallas de maquinaria y equipo representan el 89.3% de las pérdidas totales debido al tiempo de inactividad en un sistema de manufactura. Sin embargo, Peng y Zhou [10] mencionan que las líneas de ensamblaje de modelos mixtos son actualmente adoptadas ampliamente en la industria automotriz con la finalidad de lograr una personalización continua, ya que no está permitido tener escasez de material debido a que puede ser extremadamente costoso a causa de los paros de las líneas de producción que pueden ocasionar.

Del mismo modo, Sonmez *et al*. [9] afirman que los paros de líneas de producción, debido a fallas de maquinaria y equipo, causan pérdidas de producción en los sistemas de manufactura. Además, Zhao *et al*. [14] desarrollaron un modelo de mantenimiento preventivo (MP) basado en tiempos de retraso para los sistemas de manufactura en el área siderúrgica. De manera específica, los paros de líneas de producción son consecuencia de la escasez de materia prima. Finalmente, Peng y Zhou [11] investigaron un problema de programación de múltiples servidores en una línea de ensamblaje automotriz, donde el suministro de piezas justo a tiempo (JIT, empleando el acrónimo más conocido de su denominación en inglés, como haremos directamente en otros términos en este documento) era un problema crítico y costoso.

Con respecto a las horas extras, Hansson *et al*. [15] realizaron un estudio para determinar si el proceso de preparación de un kit de lotes afecta la eficiencia del trabajo cuando se compara con la preparación de un solo lote. En este estudio, estos autores mencionaron que el *kitting* está asociado con tiempo extra para operaciones en la alimentación de materiales. De hecho, realizaron dos experimentos y descubrieron que la preparación de un solo kit tomó más tiempo que la preparación de lotes, y también representó un costo más alto, es decir, tiempo adicional, y más inversiones. Del mismo modo, varios estudios sostienen que las horas extra son un aspecto específico de ciertas tareas o departamentos asociados con los sistemas de fabricación. Por ejemplo, Wang *et al*. [16] indican que la planificación deficiente del proceso hace que los operadores trabajen más tiempo, lo que se traduce en mayores costos de producción.

Además, El-Namrouty y Abushaaban [17] mencionan que el proceso de manejo de materiales y los movimientos o posturas ineficientes del cuerpo no agregan valor a un producto, generan un largo tiempo de ciclo de producción o hacen ineficiente la implementación del recurso humano. En cuanto a los movimientos y posturas corporales, éstos implican una implementación inadecuada de la ergonomía en el sistema de manufactura, ya que los operadores tendrán que realizar tareas peligrosas, como estirarse, doblarse o levantar objetos, cuando no sea necesario. Por ejemplo, Kamat *et al*. [18] y Gómez-Galán *et al*. [19] mencionan que las posturas corporales incómodas, así como los movimientos repetitivos, representan un factor de riesgo para los empleados, ya que pueden causar trastornos musculoesqueléticos y afectar negativamente su salud y su rendimiento, alterando además su bienestar. Del mismo modo, Yeow *et al*. [20] mostraron que los movimientos repetitivos pueden causar fatiga y pérdida de concentración al realizar una tarea, lo que aumenta la probabilidad de cometer errores y afecta negativamente su rendimiento. Estos problemas pueden ser generados por un diseño deficiente de las estaciones de trabajo, lo que genera posturas incómodas, causa trastornos musculoesqueléticos y, en consecuencia, afecta el rendimiento laboral y el bienestar [21], además de causar altos costos de producción [17].

En conclusión, todos estos problemas causan altos costos, una falta de ventaja competitiva y una posición débil en el mercado, lo que, junto con los tiempos de los turnos de trabajo, la falta de rendimiento y bienestar del recurso humano, representan una barrera para la sostenibilidad [3,22].

Además de estos problemas, en la industria manufactura existen siete desperdicios, los cuales afectan de manera negativa la calidad de los productos, los tiempos de entrega y los costos de producción [23,24]. Un desperdicio se define como toda aquella actividad que consume recursos pero que no agrega valor directamente al producto o servicio que la empresa ofrece al cliente [25]. Los siete desperdicios son sobreproducción, inventario, procesos, movimientos, tiempos de espera, transporte, y defectos [17,26].

En cuanto a los defectos, durante los procesos de fabricación, las empresas reciben material o componentes de sus proveedores. Luego, esos materiales o componentes se cambian para obtener un producto final, que debe entregarse a los clientes a tiempo y sin defectos [27]. Sin embargo, los defectos continúan estando presentes en la industria manufacturera hoy en día. De hecho, varios autores mencionan que los defectos son la principal causa de daños en los productos finales u otros componentes [28–31], lo que representa una situación crítica para el sector industrial y manufacturero [32].

Además, la satisfacción del cliente es un requisito que debe considerarse para cualquier negocio de distribución que pretenda seguir siendo competitivo a nivel mundial [33,34]. Sin embargo, si los gerentes desean satisfacer las necesidades del cliente, se debe incluir un proceso de diseño de producto apropiado [35]. En este sentido, una de las principales necesidades del cliente son los productos de calidad no defectuosos [36], ya que los defectos del producto conducen a la insatisfacción del cliente, la disminución de las ventas, las bajas ganancias financieras y los mayores costos unitarios [37,38]. Con el fin de mejorar la eficacia y la eficiencia de los procesos de producción, ofreciendo productos de calidad y evitar los últimos problemas, las empresas de manufactura confían en una amplia gama de métodos y técnicas para la mejora de la producción [39], incluida la filosofía de gestión Seis Sigma, DMAIC (es decir, definir, medir, analizar, mejorar y controlar) [40], Diagrama de flujo de proceso [41], el ciclo de Deming o Planear- Hacer-Verificar-Actuar (PDCA) [42,43], y el método de las 8 disciplinas (8Ds) [44], entre otros.

1.2 Estrategias implementadas por los sistemas de manufactura para la solución de problemas

Los sistemas de manufactura implementan múltiples estrategias para mitigar problemas en el proceso de producción. Por ejemplo, en la etapa de selección de proveedores, prestan mucha atención a atributos como la puntualidad y la confiabilidad que son cruciales para el éxito de cualquier negocio y permiten a las empresas atraer a sus clientes a ordenar más productos o pagar un precio más alto por algún producto en específico [1]. Otro claro ejemplo de una estrategia competitiva es el servicio logístico *Fulfillment by Amazon* (FBA), que brinda a los vendedores una mayor flexibilidad en sus prácticas de venta. FBA gestiona el cumplimiento completo de un producto o artículo de un vendedor externo una vez que se compra. Una encuesta reciente informó que el 73% de los vendedores de FBA informaron aumentos en las ventas de unidades superiores al 20% [45]. Además, un estudio de empresa a empresa (B2B) realizado por *Bain & Company* indica que las empresas con un buen rendimiento de entrega pueden cobrar precios más altos por sus productos y atraer a sus clientes a que soliciten más [46]. Por el contrario, el bajo rendimiento de la entrega provoca una disminución de las ventas o incluso pérdidas.

1.2.1 Trabajo estandarizado

El trabajo estandarizado (TE o SW) es una herramienta vital para resolver problemas de fabricación, y ofrece resultados casi inmediatos en términos de desempeño organizacional al aumentar la productividad y reducir los tiempos de entrega [47]. El TE es probablemente el método más conocido para realizar un trabajo específico, lo que a su vez lo convierte en el método más seguro y eficiente para cumplir con las entregas a tiempo, ordenadas y de calidad [48]. El TE es el conjunto de instrucciones específicas que se necesitan para fabricar un producto de la manera más eficiente, y permite definir los mejores métodos y tareas secuenciadas para cada proceso y operador, reduciendo así el desperdicio

[47,49,50]. TE define cómo cada operador debe realizar cada tarea o trabajo en el sistema de producción, evitando así que los trabajadores ejecuten tareas aleatorias [47,51] que pueden afectar negativamente los tiempos del ciclo de vida. De hecho, el TE recurre al tiempo *takt* para garantizar el cumplimiento oportuno de la demanda [52]. En este sentido, el objetivo de SW implica eliminar *mura* [53], que es un término japonés que denota desigualdad, irregularidad o inconsistencia en materia física o condición espiritual humana, y también es un concepto clave en los sistemas de mejora del rendimiento, ya que es uno de los tres tipos de residuos (*Muda*, *Mura*, y *Muri* en terminología japonesa) [54]. Sin embargo, TE no significa que una rutina de trabajo nunca se pueda cambiar, sino que implica "ésta es la mejor manera en que sabemos cómo hacer este tipo de trabajo hoy" [51,55]. Además, TE se compone de tres elementos [47]: tiempo *takt* (es decir, la velocidad a la que se debe completar un producto terminado para satisfacer la demanda del cliente); la secuencia de trabajo precisa en la que un operador realiza tareas dentro del tiempo *takt*; y el inventario estándar, incluidas las unidades en máquinas, necesario para mantener el proceso fluyendo sin problemas.

Algunos estudios reportan aplicaciones de TE para resolver problemas en los procesos de producción. Por ejemplo, Nallusamy y Saravanan[56] implementaron balanceo de línea y TE en una pequeña empresa de fabricación y lograron reducir los tiempos de ciclo a 350 segundos y aumentar la productividad. Posteriormente, Nallusamy [57] aplicó las mismas dos herramientas en la industria de control numérico por computadora (CNC) y redujo el 17% de las actividades sin valor agregado, mientras que la producción aumentó significativamente, de cinco unidades por día por dos operadores a siete unidades por día por un solo operador. Desde una perspectiva similar, Villalba-Diez y Ordieres-Mere [58] aplicaron TE a la comunicación entre procesos en una empresa de fabricación de automóviles y lograron una optimización del rendimiento del 4%. Además, Mor *et al*. [47] implementaron SW en el proceso de producción central en una empresa de manufactura y lograron una reducción de 31.6 segundos en los tiempos de ciclo y un aumento del 6.5% en la producción.

Las múltiples aplicaciones de TE revelan que este método hace mucho más que controlar procesos de producción; también minimiza los costos y maximiza la eficiencia [59]. El TE es una herramienta eficiente de manufactura esbelta que ayuda a aumentar la competitividad en las empresas. En el caso particular de las pequeñas y medianas empresas (PYMEs), el TE es un método excelente que puede compensar la falta de tecnología de manufactura avanzada (TMA) en el proceso de producción; sin embargo, el TE a menudo está mal implementado, no se cuida adecuadamente, o se entiende mal [47].

Según la literatura, desde un enfoque de realismo crítico, la metodología de investigación de estudio de caso único es suficiente para generalizar los hallazgos empíricos y teóricos. Por ejemplo, Easton [60] señala que el realismo crítico es una posición filosófica coherente, rigurosa y novedosa que no solo respalda la investigación de un solo caso como método de investigación, sino que también proporciona implicaciones útiles tanto para el desarrollo teórico como para el proceso de investigación. Además, Tsang [61] afirma que el realismo crítico reconoce el papel de una investigación de estudio de caso en generalización empírica, generalización teórica y pruebas de teoría. Este último autor señala que la falibilidad del conocimiento implica que una vez que se desarrolla una teoría, es necesario someterla a otras pruebas empíricas, y los estudios de casos son una forma adecuada de realizar tales pruebas. Por lo tanto, un solo estudio de caso es suficiente para generalizar los resultados [62].

1.2.2 Diseño antropométrico

Lee *et al*. [63] definen la antropometría como una medición del cuerpo humano, que es necesaria para el diseño de estaciones de trabajo. La literatura reporta diversos casos de aplicación de antropometría. Por ejemplo, Colim *et al*. [64] estudiaron una estación de trabajo de ensamblaje de muebles, donde la mayoría de los empleados estuvieron continuamente expuestos a factores de riesgo de trastornos musculoesqueléticos. Estos autores rediseñaron la estación de trabajo teniendo en cuenta los datos antropométricos de los empleados. Como resultado, se mejoró la postura corporal y el riesgo de sufrir trastornos del musculoesquelético fue eliminado. Del mismo modo, Kibria y Rafiquzzaman [65] indican que trabajar durante largos períodos en una posición sentada frente a la computadora causa varios tipos de dolor, incomodidad y problemas de salud en los profesores universitarios, y por lo tanto se propusieron diseños de estaciones de trabajo con un enfoque antropométrico. Finalmente, Lee y Cha [66] mencionan que los operadores de consolas en plantas de energía nuclear enfrentan problemas de interacción humano-computadora debido al diseño inapropiado de la consola, y por consiguiente, rediseñaron las consolas considerando la antropometría. En conclusión, según los ejemplos anteriores, el uso correcto de la antropometría en el rediseño de las estaciones de trabajo mejora el bienestar, la salud, la comodidad y la seguridad de los operadores [67].

El diseño de la estación de trabajo influye en las posturas y movimientos que los operadores realizan durante la ejecución de la tarea [68]. Los movimientos más básicos se llaman *therbligs*. Este término fue introducido por Frank B. Gilbreth, quien, en sus primeros trabajos en el estudio de los movimientos, desarrolló ciertas subdivisiones o eventos que consideraba comunes a todo tipo de trabajo manual. El término se refiere a 17 subdivisiones elementales o movimientos básicos. Según Palit y Setiawan [69], los *therbligs* pueden ser efectivos o inefectivos. Por un lado, los *therbligs* efectivos avanzan directamente el progreso del trabajo y, a menudo, pueden acortarse, pero generalmente no pueden eliminarse por completo. Por otro lado, los *therbligs* inefectivos no adelantan el progreso del trabajo y deben eliminarse si es posible. Algunos de los 17 *therbligs*, junto con sus símbolos, son: Alcanzar (AL), Mover (M), Agarrar (AG), Ensamblar (E), y Desensamblar (DE), por mencionar algunos. Para una visión completa de los 17 *therbligs* (efectivos o inefectivos), sus definiciones y símbolos, se puede leer Palit y Setiawan [69] y Freivalds y Niebel [70]. De acuerdo con Jia *et al*. [71], Therblig es uno de los conceptos básicos en el estudio de movimientos, que se define como una unidad básica de demanda de energía. La idea básica del estudio de movimientos es dividir la operación del trabajador en elementos de movimiento simples, que son los *therbligs* [71].

Con respecto a la relación entre antropometría y sostenibilidad, la literatura menciona que un diseño deficiente del lugar de trabajo es un factor de riesgo importante responsable de las condiciones incómodas a las que están expuestos los operadores en las líneas de ensamblaje, especialmente cuando los operadores trabajan varias horas al día, lo que disminuye su bienestar [72]. Como se mencionó anteriormente, un pobre diseño de las estaciones de trabajo genera posturas incómodas, causando trastornos musculoesqueléticos. El diseño antropométrico de las estaciones de trabajo facilita el desarrollo sostenible del lugar de trabajo y, por lo tanto, de los operadores [72].

Diferentes autores, tales como Kim *et al*. [73], y Nadadur y Parkinson [74] mencionan que la antropometría es esencial para mejorar la sostenibilidad y la idoneidad física del diseño de un lugar de trabajo. Además, estos autores sugieren que la antropometría impacta positivamente en la sostenibilidad al reducir el consumo de materias primas, aumentar la vida útil de los productos (incluidas las estaciones de trabajo) y considerar la variabilidad entre la población de usuarios. Por lo tanto, el diseño antropométrico permite mejorar la sostenibilidad global al utilizar eficientemente los recursos disponibles, prolongar el tiempo de uso de los productos y aumentar su versatilidad al satisfacer a las diferentes poblaciones de usuarios.

1.2.3 Metodología de las 8Ds

Las 8Ds representan un método de resolución de problemas orientado al trabajo en equipo que tiene como objetivo identificar la causa raíz de un problema para resolverlo mediante un procedimiento guiado por acciones correctivas[44]. Desde una perspectiva empresarial, el método de las 8Ds busca encontrar las causas principales del problema, identificar sus posibles soluciones y evaluar su impacto en las empresas [75]. Originalmente, el método se desarrolló en *Ford Motor Company*, y se introdujo en 1987 en un manual titulado "Solución de Problemas Orientados al Equipo" [76]. Desde entonces, el método se ha aplicado ampliamente en la industria de la manufactura, principalmente en el sector automotriz, para resolver problemas relacionados con productos y servicios, como defectos, quejas de clientes, desviaciones del proceso de fabricación, compras devueltas, mantenimiento deficiente de maquinaria y problemas de calificación de proveedores, entre otros [75,76].

La metodología de las 8Ds se centra en [44]: D1) desarrollar un equipo, D2) describir el problema, D3) desarrollar una acción de contención provisional, D4) determinar y verificar las causas raíz, D5) elegir/verificar acciones correctivas permanentes, D6) implementar y validar acciones correctivas, D7) evitar recurrencias, y D8) reconocer y felicitar el trabajo en equipo y las contribuciones individuales. Las 8Ds representan un método poderoso porque ayuda a crear actividades apropiadas para identificar las causas fundamentales de un problema, además de proporcionar soluciones permanentes para eliminarlos. Además, el método de las 8Ds es una herramienta especial de la norma ISO / TS 16949: 2009 que se ha aplicado ampliamente en las industrias automotrices para el servicio, incluidos los problemas relacionados con la confirmación de la calificación del proveedor, las desviaciones del proceso, mantenimiento, quejas de clientes y compras.

De hecho, la literatura menciona varios estudios de casos exitosos donde se aplicó el método de las 8Ds. Por ejemplo, Mitreva *et al.* [77] implementaron el método de las 8Ds para resolver el problema de un diodo LED que no realizaba su función en una placa de circuito, informando una disminución de los defectos operativos después de su implementación, así como un aumento en la eficiencia de los paquetes de software en la aplicación de métodos y técnicas estadísticos. Del mismo modo, Bremmer [78] aplicó el método de las 8Ds y otras técnicas para analizar la cadena de suministro global de Scania, se demostró cómo la empresa puede garantizar la calidad de los productos. Como resultado, este autor pudo encontrar el problema y sus causas principales. De manera similar, Pacheco-Pacheco [79] buscó optimizar los tiempos de entrega de los productos de alteración de la ropa (alto de basta y alto de camisa) en una sastrería mediante la implementación del método de las 8Ds. Como resultado, el autor obtuvo que los tiempos de producción disminuyeron en un 2.46% en dos productos mixtos. En ambos productos, los tiempos de demora en la entrega disminuyeron un 33.33%. Asimismo, Zasadzień [80] empleó el método de las 8Ds para reducir los tiempos de inactividad de la máquina causados por cuellos de botella.

Del mismo modo, Titu [81] implementó el método de las 8Ds para reducir las quejas por una parte defectuosa en una empresa. Como resultado, 60 días después de que se implementaron las acciones correctivas, no se identificó ningún otro producto defectuoso, y los clientes decidieron retirar la queja. Además, Kumar y Adaveesh [82] realizaron un estudio en una fabricación de resortes y estampados para resolver una alta tasa de rechazo (de 17.07%) de resortes de válvulas debido a defectos. Para resolver este problema, se aplicó el método de las 8Ds y, como resultado, la tasa de rechazo disminuyó significativamente en 6 meses en un 4.91%.

De acuerdo con Chelsom *et al*. [83] y Vargas [84], el método de las 8Ds puede aplicarse a cualquier tipo de problema o actividad a fin de proporcionar asistencia para lograr una comunicación efectiva entre los departamentos que comparten un objetivo común. Sin embargo, el método 8Ds se aplica popularmente para resolver problemas de calidad; normalmente se requiere cuando se presenta al menos uno de los siguientes eventos [85]:

- La empresa recibe quejas de los clientes.
- Se han descubierto problemas de seguridad o normativos.
- Los rechazos internos, desperdicios, desperdicio, bajo rendimiento o fallas en las pruebas ocurren a niveles anormales.
- Las preocupaciones sobre la garantía indican tasas de falla mayores a las esperadas.

Aunque el método de las 8Ds es flexible y se puede adaptar a diferentes situaciones, circunstancias y varias aplicaciones exitosas, tiene algunas desventajas, tales como [86]:

- Puede llevar mucho tiempo y ser difícil de desarrollar.
- Los empleados que participan en su implementación deben recibir la capacitación adecuada al respecto.
- Se requiere una comunicación constante entre los participantes y la aplicación de un programa de mejora continua.

1.3 Problema de investigación

La investigación presentada en esta tesis doctoral se lleva a cabo en dos empresas maquiladoras ubicadas en la ciudad de Tijuana, Baja California, México. Una maquiladora es una fábrica que opera bajo programas arancelarios preferenciales establecidos en México que tienen oficinas centrales en otros países y que apuntan a operaciones de ensamblaje con alta mano de obra requerida. Los materiales, componentes de ensamblaje y equipos de producción utilizados en las maquiladoras pueden ingresar a México libres de impuestos. Actualmente, en

México hay 5,144 maquiladoras que dan 2,678,633 empleos directos. Sin embargo, el estado de Baja California tiene 914 maquiladoras (17.76% de nacionales) que dan 333,392 empleos directos [87].

En una empresa se pretende descubrir el impacto del TE, del balanceo de las líneas de producción y del diseño antropométrico en la productividad y la sostenibilidad. Por otro lado, en la segunda empresa se pretende descubrir el impacto de la metodología de las 8Ds en la calidad de los productos.

1.3.1 Problemas de productividad y bienestar de los trabajadores

Para demostrar el impacto del TE, el balanceo de líneas de producción y el diseño antropométrico, se presenta un estudio de caso realizado en una imprenta, que emplea a 150 trabajadores y que tiene una infraestructura operativa que comprende tareas mecánicas y tareas manuales. Las tareas mecánicas son preimpresión, impresión, grapado, encuadernación y corte, entre otros, mientras que las tareas manuales consisten en plegar, cotejar y ensamblar cajas. Los principales servicios que ofrece la compañía son la impresión y publicación de manuales, ensamblaje de cajas y empaques, que representan el 70% de las operaciones de la compañía. El 30% restante incluye la fabricación de etiquetas, carpetas de archivos, revistas, libros y catálogos. La compañía tiene seis departamentos principales: Edición, Preimpresión, Trabajos con máquinas, Trabajos manuales y Ensamblaje de cajas.

Esta investigación se lleva a cabo en el departamento de Ensamblaje de cajas, ya que surgen problemas de producción en diferentes modelos. Sin embargo, la investigación no incluye la etapa de empaque del producto. El proceso de producción comprende cuatro líneas de ensamblaje, y cada línea está a cargo de cinco operadores, un inspector de calidad y un operador de empaque, como se muestra en la Figura 1.1.

La empresa ofrece una variedad de servicios a sus clientes, sin embargo, muestra múltiples oportunidades de mejora, como una mayor producción, entregas más puntuales, mejor manejo de inventario e implementación de ayudas visuales, por nombrar solo algunos. El modelo de caja más común que se fabrica es el modelo A.

Una línea de ensamblaje produce un promedio de 350 unidades diarias, sin embargo, la demanda es de 650 unidades diarias, lo que equivale a un día y medio de trabajo extra (ver Tabla 1.1). Desafortunadamente, las horas adicionales implican mayores costos de producción y, a veces, los trabajadores informan fatiga y dolor de espalda debido a las largas horas de trabajo. Se descubrió que las líneas de ensamblaje en el departamento de Armado de cajas experimentan al menos uno de los siguientes eventos indeseables: cuellos de botella, demoras en la producción, entregas tardías de productos, pago de horas adicionales a los trabajadores, movimientos innecesarios cuando los empleados realizan sus tareas, adopción de posturas corporales incómodas, y altos costos debido a líneas de producción desbalanceadas. Por lo tanto, los costos por unidad aumentan y la imagen de la empresa se ve afectada negativamente por su incapacidad para satisfacer la demanda. El ensamblaje de la caja es la última etapa del proceso de producción, antes de enviar el producto final a los clientes. Sin embargo, la empresa a menudo no puede satisfacer la demanda a tiempo.

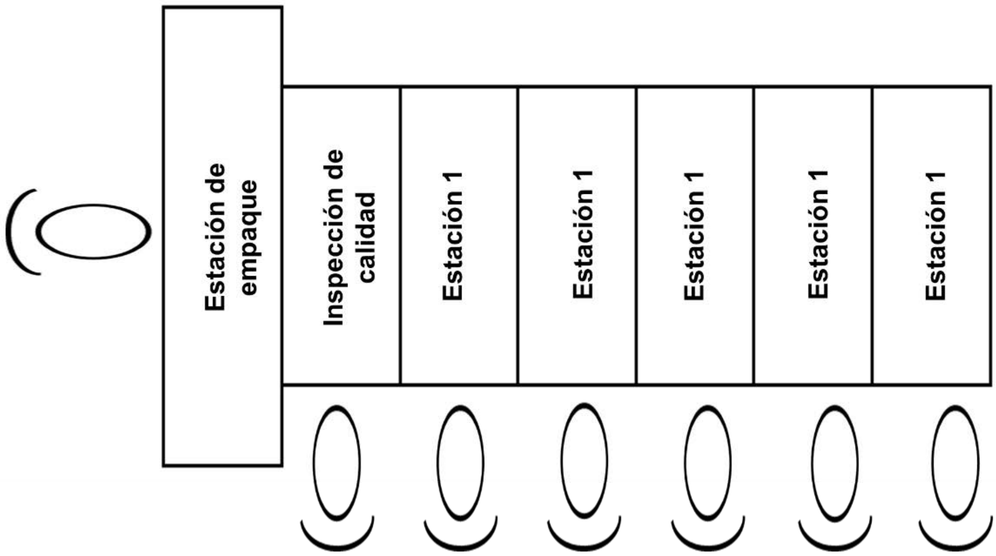


Figura 1.1 Distribución actual de la línea de ensamblaje

Tabla 1.1 Diferencia de producción y su equivalencia en tiempo extra de trabajo

Periodo	Diferencia en producción	Equivalencia en horas extra de trabajo	Equivalencia en días extra de trabajo
Día	300	33.33	3.7
Semana	1750	194.44	21.6
Mes	7000	777.77	86.41

El tiempo extra provoca que los empleados estén cansados o sufran de dolor de espalda, o un tipo de dolor en sus brazos o pies debido a largas horas de trabajo, donde se ven obligados a adoptar posturas corporales incómodas debido al pobre diseño de las estaciones de trabajo (durante el período de junio a agosto de 2019 se informaron al menos 20 casos con molestias). Además, existen riesgos de absentismo o resignación por parte de los operadores si no se mejora el diseño de la estación de trabajo para eliminar posturas corporales incómodas. La Figura 1.2 muestra las posiciones adoptadas por los operadores.

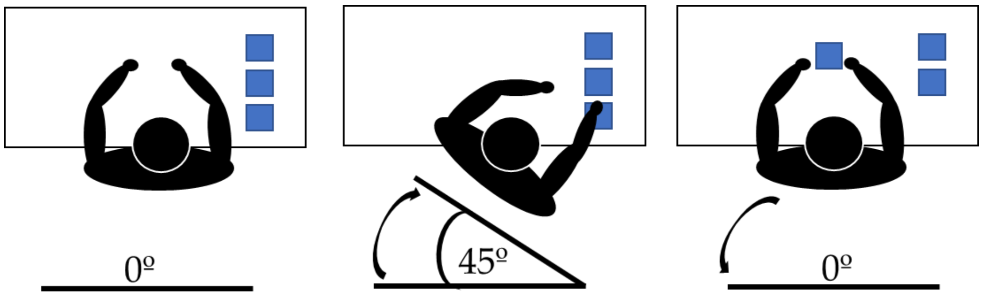


Figura 1.2 Posturas adoptadas por los trabajadores

Este estudio de caso se utiliza para demostrar el impacto del TE, el balanceo de líneas de producción y el diseño antropométrico en la productividad y la sostenibilidad. La razón para usar este caso de estudio se debe a que, desde la perspectiva del realismo crítico, generalizar los hallazgos empíricos y teóricos no es suficiente, como lo indica Tsang [61], porque el falibilismo implica que, una vez que se desarrolla una teoría, debe ser probada empíricamente, donde los estudios de caso representan una manera adecuada de lograrlo. Del mismo modo, Easton[60] propone el realismo crítico como una posición filosófica coherente, rigurosa y novedosa, que apoya la investigación de un solo caso como un enfoque de investigación, pero proporciona implicaciones útiles para un marco teórico.

1.3.2 Problemas de calidad

El segundo problema trata sobre la fabricación de cables eléctricos personalizados. La calidad de cada cable se prueba a través de una serie de programas asistidos por computadora para una inspección completa. Esta estrategia permite a la compañía construir y mantener relaciones a largo plazo con sus clientes, por lo tanto, ayuda a la compañía a alcanzar sus objetivos y tener éxito. Sin embargo, la compañía últimamente ha experimentado problemas de defectos. Como consecuencia, los clientes se están quejando debido a 67 ensambles devueltos.

El problema se refiere a un motor de paso a paso, uno de los componentes principales del ensamblaje, que tiene un número de parte que se llamará número de parte A. Los clientes proporcionan los motores a la compañía, que luego los introduce en el proceso de producción. Los cables del motor se cortan en una medida específica, y la placa y las terminales se remachan, luego, las terminales se insertan en unidades de conectores en las que se realiza una prueba funcional. Finalmente, algunos defectos que se encuentran en este proceso de ensamblaje incluyen cables invertidos, longitud de cable incorrecta y la falta de una etiqueta de identificación. Para resolver estos problemas, se implementa el método de las

8Ds destinado a disminuir la tasa de productos defectuosos, así como a aumentar la satisfacción del cliente.

Se realizan estos estudios de caso porque, según Easton [88], el enfoque de realismo crítico (CRA) establece que una sola metodología de investigación de estudio de caso es suficiente para generalizar los hallazgos teóricos y empíricos, dando una posición filosófica nueva, rigurosa y coherente que ayuda a desarrollar el proceso teórico y de investigación. Del mismo modo, Tsang [61] afirma que CRA destaca el impacto de una investigación de estudio de caso sobre el proceso teórico, la generalización empírica y la evidencia teórica. Además, Tsang presenta la falibilidad del conocimiento que establece que toda teoría desarrollada requiere ser sometida a pruebas empíricas y evaluaciones, en ese sentido, los estudios de caso son estrategias de investigación apropiadas para ilustrar y analizar las teorías propuestas. Por lo tanto, solo un estudio de caso es suficiente para generalizar los resultados [62]. Recientemente, se han publicado varios estudios de caso en el sector manufacturero en revistas con un alto de factor impacto. Estos estudios de caso incluyen la aplicación de metodologías, como el mapeo de flujo de valor [89,90], el ciclo PDCA [43], Lean Seis Sigma [40], y trabajo estandarizado [91], por mencionar algunos.

1.4 Objetivos

1.4.1 Objetivo general

El objetivo principal de esta investigación es, por lo tanto, demostrar el impacto del TE, del diseño antropométrico y del balanceo de líneas la productividad y bienestar de los trabajadores de la línea de ensamble de armado de caja. Asimismo, se tiene como objetivo demostrar la eficacia del método de las 8Ds en la calidad de los motores en la segunda empresa.

1.4.2 Objetivos específicos

Los objetivos específicos de esta investigación son los siguientes:

- Aumentar la tasa de producción en la imprenta y mejorar el rendimiento de los trabajadores mediante la estandarización del proceso de producción del armado de cajas.
- Reducir el tiempo estándar del proceso de armado de cajas en al menos un 15% y reducir los costos por unidad en un 40%.
- Rediseñar las estaciones de trabajo de la línea de ensamble desde un enfoque antropométrico.

1.5 Aportación al conocimiento

La novedad de esta investigación es que permitirá generalizar los resultados del impacto del TE, del diseño antropométrico, del balanceo de líneas y de la metodología de las 8Ds en los procesos de producción en el sector manufacturero con un único estudio de caso basado en la perspectiva del realismo crítico.

Específicamente, esta investigación implementa el enfoque de estudio de caso único, ya que la contribución principal es que permite generalizar el impacto positivo del TE, el balanceo de líneas de producción y el diseño antropométrico en la productividad y bienestar de los trabajadores. Además, también permite generalizar el impacto del método de las 8Ds en la reducción de defectos en los procesos de fabricación con un solo estudio de caso, que es respaldado por la CRA. Luego, este trabajo contribuye a ilustrar cómo se puede aplicar una técnica única y fácil para mejorar el sistema de producción en una industria maquiladora.

El resto del documento está organizado en 3 secciones: la sección 2 aborda una descripción de los materiales y métodos que se implementan en la presente investigación, la sección 3 muestra los resultados obtenidos, y, finalmente, la sección 4 presenta las conclusiones y las implicaciones industriales con respecto a la implementación del trabajo estandarizado, el balanceo de líneas de producción, el diseño antropométrico de estaciones de trabajo, y la metodología de las 8Ds.

2. Metodología

La metodología presentada en esta investigación comprende dos vertientes, dependiendo del problema a resolver. Una de estas vertientes es para resolver el problema sobre el nivel de productividad de las cajas del modelo A y el bienestar de los trabajadores, mientras que la otra vertiente es para resolver el problema de calidad (defectos) detectados en los motores. La Figura 2.1 muestra los pasos de la metodología para las dos vertientes. Como se puede observar, ambas vertientes coinciden en los tres primeros pasos, así como en el último paso. La vertiente para el problema de productividad y bienestar de los trabajadores tiene la numeración X.a, mientras que la vertiente para el problema de calidad comprende la numeración X.b. Los pasos encerrados en el cuadro color naranja corresponden a los pasos del método de las 8Ds.

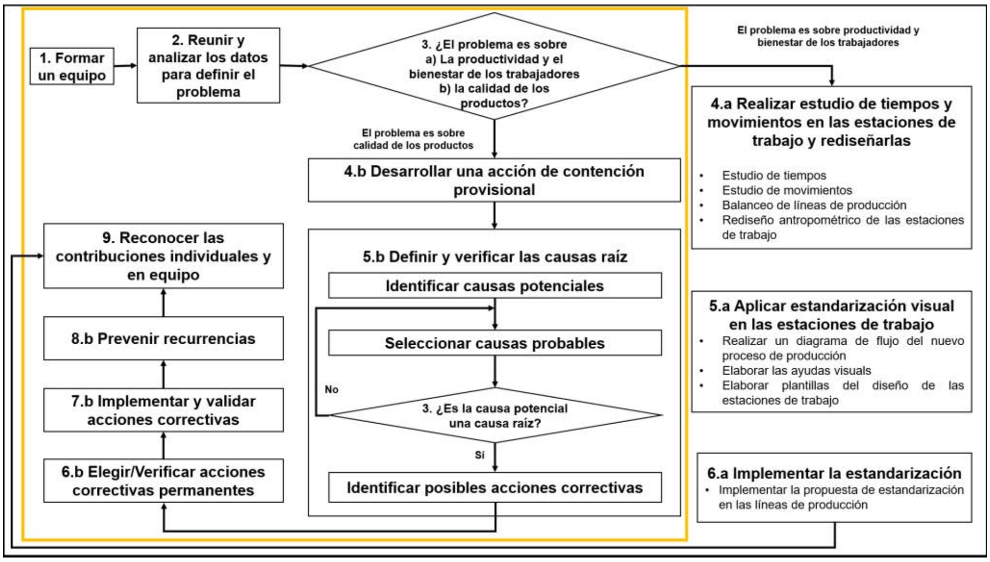


Figura 2.1 Metodología aplicada para la solución de los problemas de productividad, bienestar y calidad

A continuación se explica cada uno de estos pasos.

2.1 Formar un equipo

En este paso se organiza un equipo de trabajo interfuncional que debe tener el conocimiento suficiente sobre el producto / proceso para tratar con éxito las quejas de los trabajadores, clientes o las desviaciones de calidad en la fase de resolución de problemas [44,76]. Además, el trabajo en equipo debe ser interdisciplinario, integrado por trabajadores de varios departamentos (es decir, manufactura, ingeniería y mercadotecnia, por mencionar algunos), así como diferentes campos de conocimiento para crear una fuerza de trabajo sólida [92],ya que la experiencia de los miembros es un elemento clave para implementar cualquier método de resolución de problemas [93].

Además, se asigna un líder de trabajo en equipo, el cual se asegura de que todas las actividades se lleven a cabo y que el informe se actualice regularmente. Además, debe de haber un campeón; es decir, una persona en un puesto directivo con suficiente autoridad para ayudar y liderar el trabajo en equipo cuando existan dificultades o en caso de que se requieran recursos adicionales [94]. Del mismo modo, cualquier solución permanente puede requerir la participación posterior del trabajo en equipo [83]. Con base en estos hechos, las empresas manufactureras emplean a cientos, o incluso miles de personas con diferentes tipos de habilidades, ideas y valores, que deben ser útiles para la empresa.

2.2 Reunir y analizar los datos para definir el problema

Este paso implica explicar el problema que afecta la productividad, el bienestar, la calidad, o no satisface a los trabajadores o clientes [44]. Este paso tiene como objetivo obtener información del estado actual en el proceso de producción y hacer un análisis preliminar. El problema debe explicarse en detalle, identificando en términos cuantificables quién, qué, cuándo, dónde, por qué, cómo y cuántos problemas están involucrados en el problema [76].

Las principales actividades para realizar son las siguientes:

- Describir las estaciones de trabajo.
- Hacer diagramas del actual proceso de producción.
- Monitorear y analizar el proceso de producción.
- Identificar índices de producción críticos.
- Proponer un proyecto a gerencia para mejorar los índices.

En esta etapa, se presenta la propuesta de proyecto a los gerentes de las empresas, primero resumiendo las deficiencias del proceso de producción actual y luego, describiendo la propuesta basada en TE, balanceo de líneas de producción, diseño antropométrico y el método de las 8Ds, destacando así los beneficios potenciales (por ejemplo, tiempos y costos de proceso reducidos, mayor prestigio de la empresa y disminución de la fatiga del trabajador, reducción o eliminación de piezas defectuosas). A continuación, se analiza el proceso de producción con la ayuda de los operadores, que son quienes lo conocen mejor. Además, se monitorean las tareas de producción para identificar oportunidades potenciales de mejora.

Hasta aquí, estos dos primeros pasos se aplican a los dos problemas a resolver. Los siguientes tres pasos se aplican exclusivamente para el problema de productividad y bienestar de los trabajadores.

2.3 Realizar estudio de tiempos y movimientos en las estaciones de trabajo y rediseñarlas

Este paso consiste en asumir que existe una autorización del gerente para aplicar el TE en el proceso de producción y tiene como objetivo analizarlo con estudio de tiempos y movimientos en las estaciones de trabajo, lo que exige la colaboración de los operadores. Las tareas principales son:

- Estudio de tiempos
- Estudio de movimientos
- Balanceo de líneas de producción
- Rediseño antropométrico de las estaciones de trabajo

Esas tareas tienen como objetivo descubrir y, en consecuencia, eliminar las ineficiencias de tiempos y movimientos para establecer procedimientos estandarizados y optimizados para la ejecución de la actividad y medir el rendimiento del operador frente a ellos [95]. En cuanto al análisis de tiempo, primero se define el número de ciclos a observar, según lo recomendado por General Electric (GE) [70]. Luego, se estima el tiempo promedio observado (OT) para cada ciclo de trabajo repetitivo, así como el tiempo normal (TN) para cada tarea, considerando los cuatro factores del sistema de calificación de *Westinghouse* para calificar el desempeño [70,96]. Del mismo modo, se estima el tiempo estándar (TS), considerando las asignaciones constantes y variables recomendadas por la Organización Internacional del Trabajo (OIT). El tiempo normal y el tiempo estándar se obtuvieron al aplicar las ecuaciones (2.1-2.2) [70].

$$TN = (\sum Holguras\ de\ desempeño + 1) \times TO \quad (2.1)$$

$$TS = \sum(Holguras\ constantes\ y\ variables + 1) \times TN \quad (2.2)$$

En cuanto al estudio del movimiento, se analizan *therbligs* efectivos e inefectivos realizados por los operadores y se utiliza la información para construir el gráfico de proceso bimanual. Los *therbligs* inefectivos deben eliminarse, ya que causan cuellos de botella. En este sentido, el estudio de movimientos ayudó a determinar qué herramientas manuales usan los operadores con más frecuencia para ubicarlas de manera más cercana al rediseñar las estaciones de trabajo [70].

La siguiente tarea en esta etapa implica el equilibrio de línea, que se refiere a la asignación de tareas dentro de una línea de ensamblaje para cumplir con la tasa de producción requerida para fines de optimización [97]. Con este fin, se realiza un análisis de costo por unidad de la siguiente manera: se describen las tareas de cada ciclo de trabajo, se convierte el tiempo al formato decimal, se define el número de operadores requeridos por estación de trabajo y se calculan los totales requeridos por línea. Además, se estima el tiempo en la línea, el porcentaje de equilibrio en cada línea de producción, el ciclo de trabajo ajustado y la producción por hora, turno y departamento. Posteriormente, se calcula el número aproximado de piezas producidas por operador y los costos de producción por unidad. A continuación, se define una posible secuencia de trabajo en la que las tareas se pueden realizar para mantener tiempos similares en todas las estaciones de trabajo propuestas. Con este fin, se determina tanto la eficiencia como el tiempo de actividad en cada línea. Finalmente, se calcula el número de operadores necesarios para cada línea de producción que pueden satisfacer la demanda. Las ecuaciones (2.3-2.9) se aplican para realizar este análisis [98].

$$Porcentaje\ de\ balanceo = \frac{Tiempo\ total\ del\ operador}{Tiempo\ en\ línea} \times 100 \quad (2.3)$$

$$Ciclo\ de\ trabajo\ ajustado = \frac{Ciclo\ de\ control}{Porcentaje\ de\ Balanceo} \times 100 \quad (2.4)$$

$$Producción\ por\ hora = \frac{60\ minutos}{ACiclo\ de\ trabajo\ ajustado} \quad (2.5)$$

$$Producción\ por\ turno = \frac{Unidades}{Hora} \times \frac{Horas}{Turno} \quad (2.6)$$

$$Producción\ por\ departamento = Producción\ por\ turno \times Número\ de\ líneas\ de\ ensamble \quad (2.7)$$

$$\frac{Unidades}{operadores} = \frac{Unidades\ por\ turno}{Total\ operadores} \quad (2.8)$$

$$Costo\ por\ unidad = \frac{Total\ operadores \times Salario\ diario}{Unidades\ por\ turno} \quad (2.9)$$

La última tarea consiste en rediseñar las estaciones de trabajo. Para este fin, se utiliza la tabla de proceso bimanual desarrollada anteriormente en esta etapa. Luego, se realiza un estudio antropométrico entre los trabajadores para definir las zonas de alcance mínimo y máximo. Para ello, se utiliza el quinto percentil del antebrazo y el brazo estirado, así como el percentil 95 del hombro [99]. A continuación, se rediseñan las estaciones de trabajo, especificando la posición de las zonas de alcance mínimo y máximo, donde el área de trabajo representaba el ancho de la espalda de los operadores. Posteriormente, se determina la ubicación de las herramientas manuales en las estaciones de trabajo de acuerdo con su frecuencia de uso. Las dimensiones finales de las estaciones de trabajo son obtenidas aplicando la ecuación (2.10) [99].

$$P_k = \bar{X} + \sigma Z \quad (2.10)$$

En la ecuación (10), P_k representa la longitud obtenida para el percentil k, $\bar{X}$ es el promedio de los datos de las mediciones para una determinada parte del cuerpo, σ representa la desviación estándar de los datos y Z representa el valor de la distribución normal para el percentil k. Finalmente, se realizan corridas experimentales en líneas de producción con el método original y propuesto para comparar los tiempos, movimientos y posturas que se utilizan, así como el costo de producción por unidad.

2.4 Aplicar estandarización visual en las estaciones de trabajo

En esta etapa se supone que el análisis de datos de las líneas de producción está terminado y que un nuevo método está listo para ser aplicado. El objetivo en esta etapa es brindar apoyo visual al método propuesto y las tareas principales son:

- Hacer diagramas de flujo del proceso para el proceso rediseñado
- Elaborar ayudas visuales para los operadores.
- Diseñar nuevas plantillas para las estaciones de trabajo.

En esta etapa, se desarrollaron varios diagramas de flujo con respecto al nuevo método para representar visualmente la estandarización en el proceso de producción. Los cuadros se utilizaron para ilustrar la secuencia precisa de trabajo de las tareas que deben realizarse en algún momento, como se estima en el cuadro de progreso bimanual. Luego, se elaboraron ayudas visuales para cada estación de trabajo con fotografías tomadas de las tareas para resaltar los puntos más importantes de cada tarea e indicar las herramientas manuales necesarias. Las ayudas visuales se desarrollaron teniendo en cuenta la creatividad y criterios de los analistas, prestando especial atención a aspectos como la simplicidad, la claridad, la visibilidad y la sencillez para garantizar que tengan una buena aceptación por parte de los operadores.

La última actividad en este paso consistió en hacer plantillas de diseño para las estaciones de trabajo con el fin de indicar las posiciones de las herramientas manuales y ayudar a los operadores a ubicar estas herramientas por sí mismos. Las plantillas se utilizaron para garantizar que el proceso en cada estación de trabajo se ejecute sin problemas y sin cuellos de botella. Las plantillas se diseñaron en tamaño real, utilizando imágenes de estaciones de trabajo y un cuadro de progreso bimanual, y se diseñaron para permanecer fijas a un lado de la estación de trabajo correspondiente.

2.5 Implementar la estandarización de trabajo

Esta etapa tiene como objetivo implementar el nuevo método y el TE en las líneas de producción. Una vez que el nuevo diseño de las estaciones de trabajo y las ayudas visuales están listas, se realiza la siguiente tarea:

- Implementar propuesta de estandarización en líneas de producción.

En este paso, se comparan los resultados obtenidos con los objetivos inicialmente planteados para determinar si se lograron. Si el método demuestra ser efectivo, las líneas de producción se instalan con el nuevo método de producción, y las estaciones de trabajo rediseñadas se instalan junto con sus correspondientes ayudas visuales y plantillas diseñadas.

Hasta aquí, se hace una breve pausa en cuanto a la descripción de los pasos para resolver el problema de productividad y bienestar de los trabajadores. Sin embargo, se retoma en el último paso de la metodología mostrada en la Figura 2.1: Reconocer las contribuciones individuales y en equipo. Lo siguientes seis pasos son exclusivos para resolver el problema de calidad de los productos (motores).

2.6 Desarrollar una acción de contención provisional

Dado que los miembros del trabajo en equipo tienen suficiente conocimiento sobre el producto / proceso, por lo tanto, se deben emprender posibles acciones correctivas para controlar el problema y evitar su expansión. Los miembros del trabajo en equipo deben definir e implementar aquellas acciones intermedias que protegerán al cliente del problema hasta que se implementen acciones correctivas permanentes. Además, las acciones de contención provisionales deben seguir la norma de calidad ISO / TS 16949: 2009[1] y basarse en el enfoque actual para determinar y verificar adecuadamente la efectividad de estas acciones. Además, este paso tiene como objetivo preservar la evidencia y evitar que el resultado se amplíe irremediablemente antes de que se pueda resolver el problema y alcanzar el objetivo. Algunas tareas deben ser monitoreadas para garantizar el cumplimiento de los requisitos, como documentar, planificar el control, programar, así como asignar las necesidades específicas de acuerdo con el problema que se está resolviendo [44].

2.7 Definir y verificar las causas raíz

Este paso se refiere a la identificación de todas las causas aplicables que podrían explicar por qué ocurrió el problema, así como las razones por las cuales el problema no se percibió la primera vez que ocurrió. Todas las causas serán verificadas o probadas, y no determinadas por supuestos. Los expertos recomiendan usar los diagramas de cinco porqués de Ishikawa para mapear las causas contra el efecto identificado [76]. El método 5W2H se utiliza para hacer diagramas sobre los requisitos del cliente, la revisión del proceso de resolución de problemas y el análisis del problema [44].

2.8 Elegir/Verificar acciones correctivas permanentes

Dependiendo de las diferentes causas del problema, se deben proponer varias estrategias adecuadas. Por lo tanto, se deben revisar los resultados, así como los

[1] ISO/TS 16949:2009 es una especificación técnica que define los requisitos del sistema de gestión de calidad para el diseño, desarrollo, producción, instalación relevante y servicio de productos relacionados con el automóvil [44].

ajustes necesarios o se deben tomar algunas medidas correctivas permanentes [44]. Finalmente, se debe realizar un método cuantitativo a través de programas de preproducción para confirmar que las correcciones seleccionadas resolverán el problema [76].

2.9 Implementar y validar acciones correctivas

En este paso, se definen e implementan las mejores acciones correctivas para garantizar que se alcance el objetivo y que se resuelva el problema. Además, es necesario controlar o monitorear cualquier efecto potencial [44,75,76].

2.10 Prevenir recurrencias

En este paso, los sistemas de gestión, los sistemas operativos, las prácticas y los procedimientos deben modificarse y controlarse para evitar su recurrencia o cualquier otro problema similar, evitando quejas de los clientes [76].

2.11 Reconocer las contribuciones individuales y en equipo

Finalmente, en este paso, los problemas ya están resueltos, por lo tanto, se comparten el conocimiento y los resultados. Además, se reconocen los esfuerzos colectivos de los miembros del trabajo en equipo, proporcionando comentarios positivos y siendo formalmente reconocidos. Se establecen registros de capacitación y educación y se sigue el ciclo PDCA para lograr una mayor satisfacción del cliente y los trabajadores [44,75,76].

3. Resultados

Los resultados se presentan por estudio de caso. En primer lugar, se presenta el caso sobre productividad y bienestar de los trabajadores en la imprenta, y en segundo lugar, se presenta el caso de problemas de calidad de los motores.

3.1 Resultados del caso de productividad y bienestar de los trabajadores

3.1.1 Planteamiento del problema

Para demostrar la importancia del TE, se presenta un estudio de caso realizado en una imprenta, que emplea a 150 trabajadores y tiene una infraestructura operativa que comprende tareas mecánicas y tareas manuales, las tareas mecánicas son preimpresión, impresión, grapado, encuadernación y corte, entre otros, mientras que las tareas manuales consisten en plegar, cotejar y ensamblar cajas. Los principales servicios que ofrece la compañía son la impresión y publicación de manuales, ensamblaje de cajas y empaques, que representan el 70% de las operaciones de la compañía. El 30% restante incluye la fabricación de etiquetas, carpetas de archivos, revistas, libros y catálogos. La compañía tiene seis departamentos principales: Edición, Preimpresión, Trabajos con máquinas, Trabajos manuales y Ensamblaje de cajas.

Esta investigación se llevó a cabo en el departamento de ensamblaje de cajas, ya que surgen problemas de producción en diferentes modelos, pero no incluye la etapa de empaque del producto. El proceso de producción comprende cuatro líneas de ensamblaje, y cada línea está a cargo de cinco operadores, un inspector de calidad y un operador de empaque. La compañía ofrece una variedad de servicios a sus clientes, sin embargo, muestra múltiples oportunidades de mejora, como una mayor producción, entregas más puntuales, mejor manejo de inventario e implementación de ayudas visuales, por nombrar solo algunos. El modelo de caja más común que se fabrica es el modelo A.

Una línea produce un promedio de 350 unidades diarias, pero la demanda es de 650 unidades diarias, lo que equivale a un día y medio de trabajo extra. Desafortunadamente, las horas adicionales implican mayores costos de producción y, a veces, los trabajadores informan fatiga y dolor de espalda debido a las largas horas de trabajo.

Se detectó que las líneas de ensamblaje en el departamento de Armado de cajas experimentan al menos uno de los siguientes eventos indeseables: cuellos de botella, demoras en la producción, entregas tardías de productos, pago de horas adicionales a los trabajadores, movimientos innecesarios cuando los empleados realizan sus tareas y altos costos debido a las líneas de producción desbalanceadas. Por lo tanto, los costos por unidad aumentan y la imagen de la empresa se ve afectada negativamente por su incapacidad para satisfacer la demanda. El ensamblaje de la caja es la última etapa del proceso de producción, antes de enviar el producto final a los clientes. Sin embargo, la empresa a menudo no puede satisfacer la demanda a tiempo. El objetivo general de este caso es, por lo tanto, aumentar la tasa de producción de la compañía y mejorar el rendimiento de los trabajadores mediante la estandarización del proceso de producción del modelo de caja A en el departamento de ensamblaje de cajas. Del mismo modo, los tres objetivos específicos de la investigación incluyen aumentar los niveles de producción en un 20%, reducir el tiempo estándar en al menos un 15% y reducir los costos por unidad en un 40%.

3.1.2 Resultados de la etapa 1

Después de definir el problema, en esta etapa se desarrolla un diagrama de flujo con el sistema de producción actual de la compañía, como se muestra en la Figura 3.1 y, para tener una mejor comprensión del proceso de fabricación del modelo A, se da una breve descripción de las operaciones requeridas. El operador en la estación de trabajo 1 toma la pieza en su lado derecho y la coloca frente a él y coloca una pequeña tira de cinta adhesiva de doble cara en la parte posterior de la caja, donde más tarde se colocará una etiqueta con el nombre del cliente. A continuación, el operador coloca cuatro tiras de cinta de doble cara en el contorno de una perforación cuadrangular, que luego se retiran, dejando la goma en exhibición. Finalmente, la pieza se envía a la estación de trabajo 2. En la estación de trabajo 2, el operador coloca una tira de cinta de doble cara que se dobla al lado de la caja. Posteriormente, coloca una tira de cinta de mostaza de doble cara y un plástico cuadrangular en la goma, exponiendo las tiras de cinta colocadas en la estación de trabajo 1. Finalmente, el operador limpia el plástico con una bola de algodón humedecida en alcohol para eliminar las huellas dactilares y pasa la pieza a la estación de trabajo 3.

En la estación de trabajo 3, el operador toma la pieza y retira la cara de la cinta de etiquetas de doble cara colocada en la estación 1. Posteriormente, coloca la etiqueta con el nombre del cliente. A continuación, coloca otra cinta plegable de doble cara. Además, también coloca dos imanes positivos en las aberturas que se encuentran en el plástico de forma cuadrangular. Luego, los imanes se cubren con tiras de cinta negra y envían la pieza a la estación de trabajo 4. En la estación 4, el operador toma la pieza y retira el mostrador de la cinta de mostaza y la cinta de doble flexión. Luego, coloca dos imanes en la parte inferior y superior de la caja. Posteriormente, coloca la cinta doble la caja para pegar la tapa y envía la pieza a la estación de trabajo 5. Finalmente, el operador en la estación de trabajo

5 toma la pieza y coloca una cinta de doble cara en la base de la caja. Hecho esto, coloca una cinta de doble cara en una pestaña de la caja y la retira. Luego, pega una pestaña al otro lado de la caja para darle forma. Al finalizar, la caja se envía a la estación de calidad.

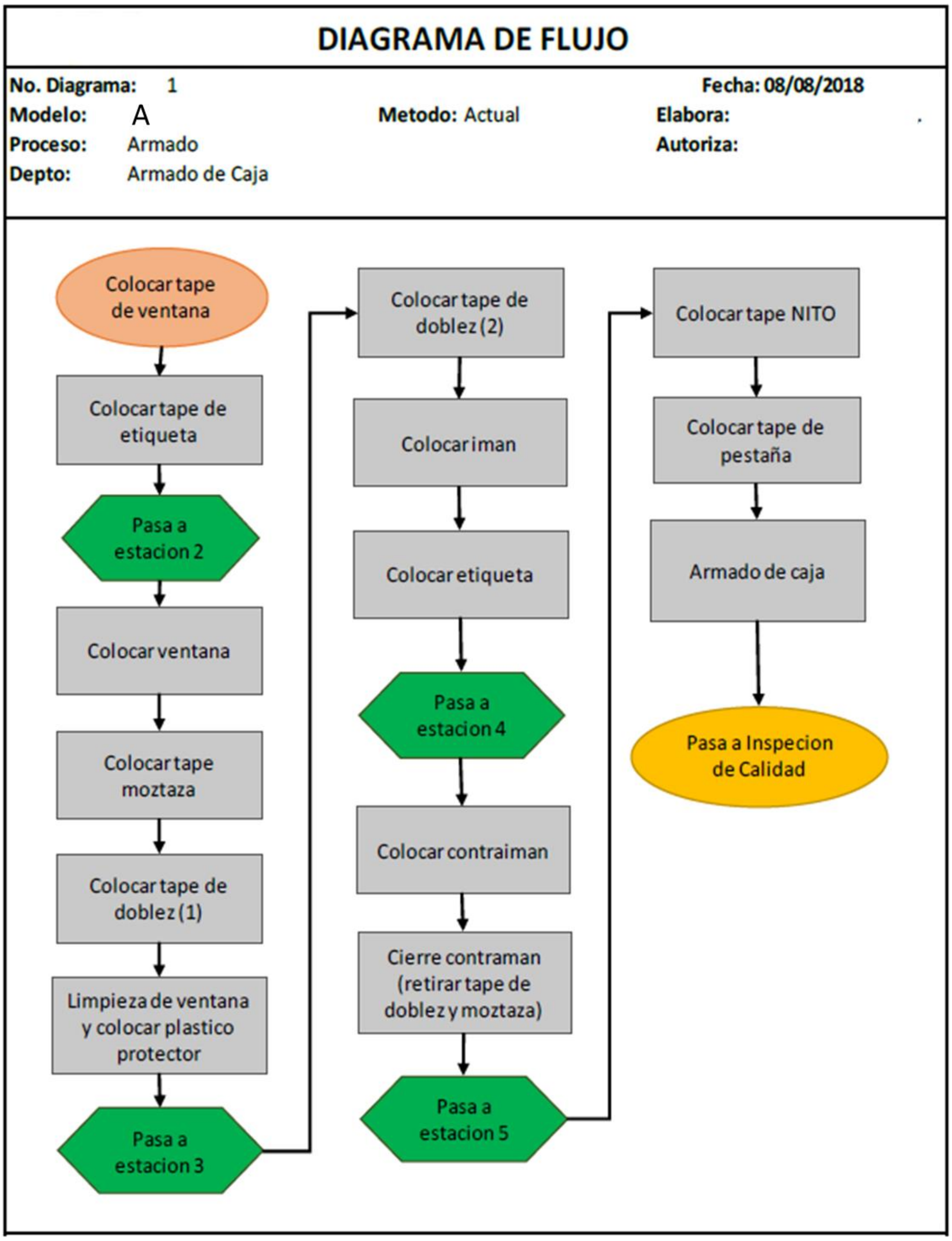


Figura 3.1 Diagrama de flujo del actual proceso de producción de modelo A.

3.1.3 Resultados del estudio de tiempos

La Tabla 3.1 muestra la información sobre los factores de rendimiento y las holguras asignadas a cada estación de trabajo original. Por ejemplo, en el caso de los factores de rendimiento, la holgura del factor Habilidad para la estación de trabajo 1 (operador 1) fue de 0.06, lo que indica la que operadora tuvo una buena habilidad. En el caso del factor Esfuerzo, se obtuvo una holgura de 0.03 en la estación 1, lo que indica la que operadora realizada un buen esfuerzo. Lo mismo procedió con las demás holguras de los demás factores para cada estación de trabajo. Al final, se sumaron las holguras para cada estación de trabajo, se le agregó 1 y se obtuvo el total. El mismo procedimiento aplicado para obtener las tolerancias constantes y variables.

Tabla 3.1 Holguras de desempeño, constantes y variables en las estaciones de trabajo originales

Holguras de Desempeño					
Ítem	**Estación 1**	**Estación 2**	**Estación 3**	**Estación 4**	**Estación 5**
Habilidad	0.06	0.03	0.02	0.03	0.03
Esfuerzo	0.03	0.02	0.03	0.02	0.02
Consistencia	-0.02	0.01	-0.03	-0.03	-0.02
Condiciones	-0.03	-0.03	0	-0.02	-0.03
Total	1.04	1.03	1.02	1.0	1.0
Holguras Constantes y Variables					
Ítem	**Estación 1**	**Estación 2**	**Estación 3**	**Estación 4**	**Estación 5**
Personal	.05	.05	0.05	0.05	0.05
Fatiga Básica	.04	.04	0.04	0.04	0.04
Estar de Pie	.02			0.02	
Trabajo Fino		.02			
Total	1.11	1.11	1.09	1.11	1.0

La Tabla 3.2 muestra el TO, TN y TS estimados. El TS en las estaciones de trabajo 3 y 4 informó una diferencia de 17 y 35 segundos, respectivamente, con respecto al TS más corto (estación de trabajo 5). La suma de todos los ST equivalió a 4.07 minutos para las líneas de producción originales.

Tabla 3.2 Tiempos estimados en estaciones de trabajo originales

	Tiempo por estaciones de trabajo (segundos)				
	Estación 1	Estación 2	Estación 3	Estación 4	Estación 5
Tiempo observado (TO)	37	36	48	64	36
Tiempo normal (TN)	38	37	49	64	36
Tiempo Estandard (TS)	43	41	53	71	36

La Tabla 3.3 resume los resultados del análisis de movimientos. Se identificaron 230 *therbligs* inefectivos, 33 de los cuales se detectaron en la tarea número 9 (es decir, colocar cinta de plástico), siendo así la tarea con el mayor número de movimientos inefectivos. Por otro lado, la Tabla 3.4 resume los resultados del análisis de balanceo de líneas de costo por unidad de la línea de ensamblaje original con cinco operadores. Como se puede observar, el tiempo de producción total para una caja del modelo A es de 4.12 minutos, el ciclo de control es de 1.18 minutos, y corresponde al tiempo más alto entre los tiempos de operaciones. El tiempo en línea es de 5.92 minutos, y representa el producto de multiplicar el ciclo de control por el número de operadores (5 en este caso). Las líneas de ensamblaje están equilibradas en un 70%, y el costo por unidad es de $ 1.39 pesos mexicanos (es decir, $ 0.072 USD).

Tabla 3.3 Therbigs inefectivos en el método de trabajo original

Tarea	Descripción	Mano izquierda	Mano derecha	Total
1	Colocar cinta adhesiva de ventana	8	9	17
2	Colocar plástico protector	10	23	33
3	Colocar cinta adhesiva de etiqueta	8	5	13
4	Colocar ventaja de caja	7	1	8
5	Colocar cinta adhesiva amarilla	12	12	24
6	Colocar cinta adhesiva de doblez	12	12	24
7	Limpiar ventana de caja	12	6	18
8	Colocar plástico protector	10	23	33
9	Colocar imán	0	5	5
10	Colocar etiqueta	10	4	14
11	Colocar contraimán	4	4	8
12	Cerrarr contraimán	4	3	7
13	Colocar cinta adhesiva negra	13	6	19
14	Colocar cinta adhesiva de pestaña	10	15	25
15	Ensamblar la caja	9	6	15
Total				230

Tabla 3.4 Resultados del análisis de costo por unidad – balanceo de líneas

Estación	Descripción	Tiempo	Min	Operadores
			0:01:00	
1	Colocar cinta de doble cara	0:00:42	0.7	1
2	Colocar la ventana de caja, cinta amarilla y cinta diagonal	0:00:41	0.68	1
3	Colocar el imán, cinta adhesiva y etiqueta, y limpiar la ventana de la caja	0:00:53	0.88	1
4	Colocar el imán opuesto y cerrarlo	0:01:11	1.18	1
5	Colocar cinta de aleta y cinta de plástico, ensamblar la caja	0:00:40	0.67	1
Total Σ		0:04:07	4.12	5
Ciclo de control			1.18	
Número de operadores			5	
Tiempo en línea			5.92	
Porcentaje de balanceo			70%	

Ciclo de trabajo ajustado	1.7
Producción por hora	35
Producción por turno	318
Producción por departamento	1588
Unidades/Operadores	64
Costo por unidad	$1.39 (pesos)

Después de estos resultados, se determina que las tareas 1, 7, 8, 9, 10 y 11 (ver Tabla 3.3) podrían realizarse al mismo tiempo antes de las tareas restantes. Del mismo modo, se concluye que antes de que se pueda realizar la tarea 14, se deben completar las primeras 13 tareas. Dichos resultados se usaron junto con el informe del peso posicional de cada tarea (obtenido después de estimar los tiempos de ciclo de las tareas) para hacer una nueva distribución del proceso de ensamblaje de cajas en solo cuatro estaciones de trabajo, como se muestra en la Tabla 3.5. Esto es, la longitud de un la línea de producción puede reducirse re-balanceando la línea de ensamblaje debido a los tiempos de las nuevas tareas [100]. Además, con esta nueva distribución, la mayor diferencia de tiempo entre dos tareas es de ocho segundos, lo que reduce la brecha en 27 segundos, en comparación con la distribución original del proceso.

Tabla 3.5 Rediseño de las operaciones para el proceso de ensamblaje de la caja

Estación 1		Estación 2		Estación 3		Estación 4	
Colocar cinta de doblez	(16)	Colocar cinta de ventana	(43)	Colocar ventana de caja	(31)	Colocar contraimán	(8)
Colocar cinta amarilla	(8)	Colocar plástico protector	(8)	Colocar imán	(8)	Cerrar contraimán	(35)
Colocar cinta adhesiva	(7)			Colocar cinta del plástico	(8)	Ensamblar caja	(16)
Colocar cinta de etiqueta	(8)			Limpiar ventana de caja	(4)		
Colocar etiqueta	(14)						
Total	53		51		51		59

*Los números entre paréntesis indican el tiempo en segundos para cada operación.

La Figura 3.2 muestra las estaciones de trabajo rediseñadas, donde A) ilustra la propuesta general, mientras que B), C), D) y E) representan los rediseños individuales para las estaciones de trabajo 1, 2, 3 y 4 con sus ubicaciones respectivas de las partes y herramientas.

Los resultados indican que el TS estimado en la línea de producción fue de 3.32 minutos; es decir, 45 segundos más corto que el ST original (es decir, reducción de tiempo del 18%). La Tabla 3.6 enumera las estimaciones de tiempo en cada nueva estación de trabajo y, como se puede observar, la diferencia de tiempo entre dos estaciones de trabajo no es mayor de seis segundos. Con respecto al análisis de tiempos en el proceso rediseñado, se encontraron solo 78 Therbligs inefectivos, lo que representa una reducción del 66.1%, en comparación con el proceso original. La Tabla 3.7 resume los resultados obtenidos y, como se puede observar, la tasa más alta de movimientos inefectivos se encontró en la tarea 1.

La Tabla 3.8 resume los resultados del costo por unidad y el análisis de balanceo de líneas realizado al proceso rediseñado. Tenga en cuenta que el balanceo de líneas aumentó del 70% al 97%, lo que indica que la producción puede fluir sin problemas y sin cuellos de botella. Del mismo modo, el costo por unidad disminuyó en 58.27%; es decir, de $ 1.39 a $ 0.58 pesos mexicanos (es decir, de $ 0.072 a $ 0.030 USD).

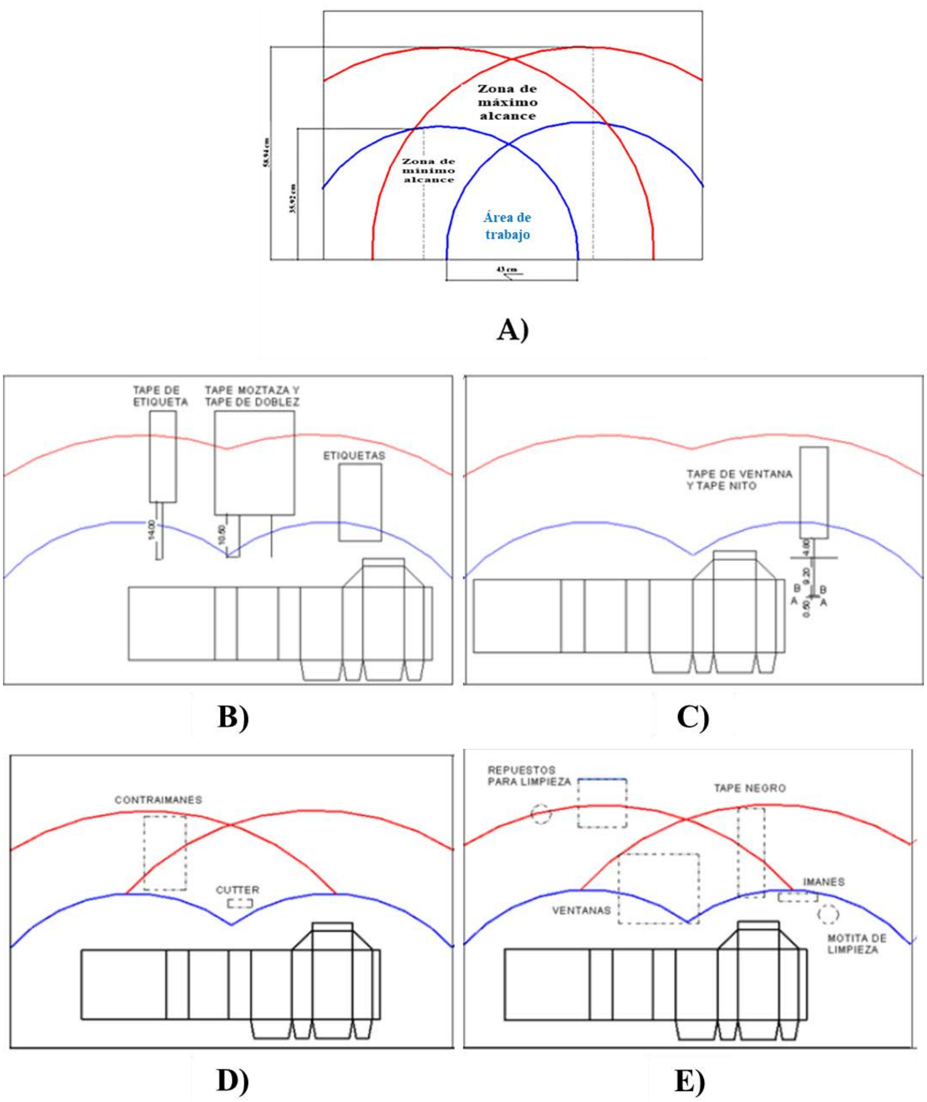


Figura 3.2 Diseños de estaciones de trabajo: A) Diseño general, B) Estación 1, C) Estación 2, D) Estación 3, E) Estación 4

Tabla 3.6 Estimaciones de tiempos para el proceso rediseñado

	Tiempo por estaciones de trabajo (segundos)			
	Estación 1	Estación 2	Estación 3	Estación 4
Tiempo observado (TO)	48	43	48	47
Tiempo normal (TN)	47	42	47	47
Tiempo Estándar (TS)	51	46	51	51

Tabla 3.7 *Therbligs* inefectivos en el proceso rediseñado

Estación de trabajo	Tarea	Mano izquierda	Mano derecha	Total
1	Colocar cinta de doblez	20	9	29
	Colocar cinta amarilla			
	Colocar cinta adhesiva			
	Colocar cinta adhesiva de etiqueta			
	Colocar etiqueta			
2	Colocar cinta de ventana	17	7	24
	Colocar cinta de plástico			
3	Colocar ventana de caja	6	9	15
	Colocar imán			
	Colocar plástico			
	Limpiar ventana de caja			
4	Colocar contraimán	8	2	10
	Cerrar contraimán			
	Ensamblar caja			
Total		51	27	78

Tabla 3.8 Resultados del análisis de costo por unidad – balanceo de líneas del proceso rediseñado

Estación	Descripción	Tiempo	Min 0:01:00	Operadores
1	Colocar cinta amarilla, cinta adhesiva de doblez (2), cinta adhesiva etiqueta, cinta adhesiva de pestaña, Etiqueta	00:00:51	0.86	1
2	Colocar cinta adhesiva de ventana, cinta adhesiva nito	00:00:46	0.76	1
3	Colocar Ventana, imán, cinta adhesiva negro, limpieza,	00:00:51	0.86	1
4	Colocar contraiman, Doblado y Armado de Caja	00:00:51	0.85	1
Total Σ		0:03:19	3.32	**4**
Minuto total del operador			3.32	
Ciclo de control			0.86	
Número de operadores			4	
Tiempo en línea			3.43	
Porcentaje de balanceo			97	
Ciclo de trabajo ajustado			0.885359958	
Producción por hora			68	

Producción por turno	610
Producción por departamento	3050
Unidades/Operadores	152.4803542
Costo por unidad	$0.58 (pesos)

3.1.4 Resultados de la estandarización visual de las estaciones de trabajo

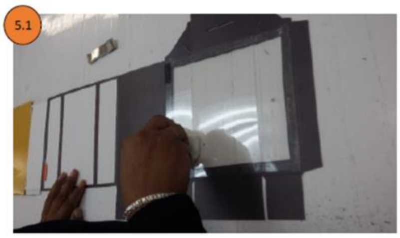
En esta etapa, se generaron ayudas visuales y plantillas para las estaciones de trabajo rediseñadas. Los encabezados de los formularios de ayuda visual incluían la siguiente información: nombre del departamento, número de línea de producción, número de estación de trabajo, nombre de la tarea, modelo de caja, número de hoja, fecha de emisión y fecha de última revisión. Del mismo modo, el lado derecho del formulario incluye información importante sobre la tarea a realizar. Esta información no forma parte de las instrucciones, pero recuerdan a los operadores la importancia de los detalles de cada tarea. Debajo de la sección de detalles, todas las ayudas visuales deben enumerar las herramientas que son necesarias en la tarea. En este sentido, los operadores deben asegurarse de tener todos los materiales y herramientas en su lugar antes de comenzar a completar una tarea. Finalmente, debajo de la sección de material, el formulario de ayuda visual incluye información que deben completar quienes desarrollan las ayudas visuales. Las ayudas visuales también contienen una imagen de cada paso de la tarea. Para este fin, se les pide a los operadores que realicen los pasos, uno por uno, mientras se toma una fotografía. Las fotografías deben estar lo más ordenadas posible y deben ilustrar claramente lo que el operador debe hacer en un paso en particular. Además, prestamos mucha atención a escribir descripciones claras y concisas sobre cómo se realiza cada paso de la tarea. Una descripción acompaña cada imagen de la ayuda pero no está sobrecargada de información, ya que las imágenes son la clave de las ayudas. Finalmente, numeramos cada paso de la tarea para establecer una secuencia precisa y lógica de eventos de trabajo y así evitar errores y confusiones. En total, desarrollamos seis ayudas visuales: las estaciones de trabajo 1 y 2 instalaron una ayuda visual cada una, mientras que las estaciones de trabajo 3 y 4 instalaron dos ayudas cada una. Las Figuras 3.3 y 3.4 presentan dos ejemplos de las ayudas visuales desarrolladas.

La Figura 3.5 ilustra el diagrama de flujo del proceso del proceso rediseñado. Como se puede observar, la metodología propone un proceso de 16 tareas con un tiempo total de 144 segundos. Tenga en cuenta que las tareas 4 y 5 se realizan antes del proceso de ensamblaje de la caja o cuando no hay demanda para el modelo de caja A. Esto permite a los operadores tener muchas partes (por ejemplo, etiquetas y cinta adhesiva correspondiente) listas antes de iniciar el proceso de ensamblaje de la caja. Se obtuvo un tiempo de procesamiento de 197 segundos, pero se le restó 15 minutos de las tareas 4 y 5. Por lo tanto, el TO estimado fue de 182 segundos, un valor lo suficientemente cercano al que se muestra en la Tabla 3.6 (es decir, 186 segundos).

	INSTRUCCIÓN DE OPERACIÓN ESPECÍFICA					Hoja: 4 de 6 Fecha: 22/10/2018 Revisión: 0
	Departamento Armado	Línea 1	Estación 3	Nombre de la Operación Colocación Ventana	Modelo CAJA PLEGABLE	No. Parte

5.- Limpieza de ventana
Tomar la motita con alcohol y limpiar toda la superficie de la ventana.

5.1



6.- Colocar protector de ventana
Doblar la caja y colocar el plastico protector en la superficie por fuera de la ventana, procurando que quede cubierta completamente y extendida.

6.1

Al finalizar pasar a Estacion 4

Puntos Criticos:
1.- Limpiar toda la superficie de la ventana
2.- Colocar el plástico completamente extendido
3.- Cuidar que no se quede algun elemento extraño en la ventana

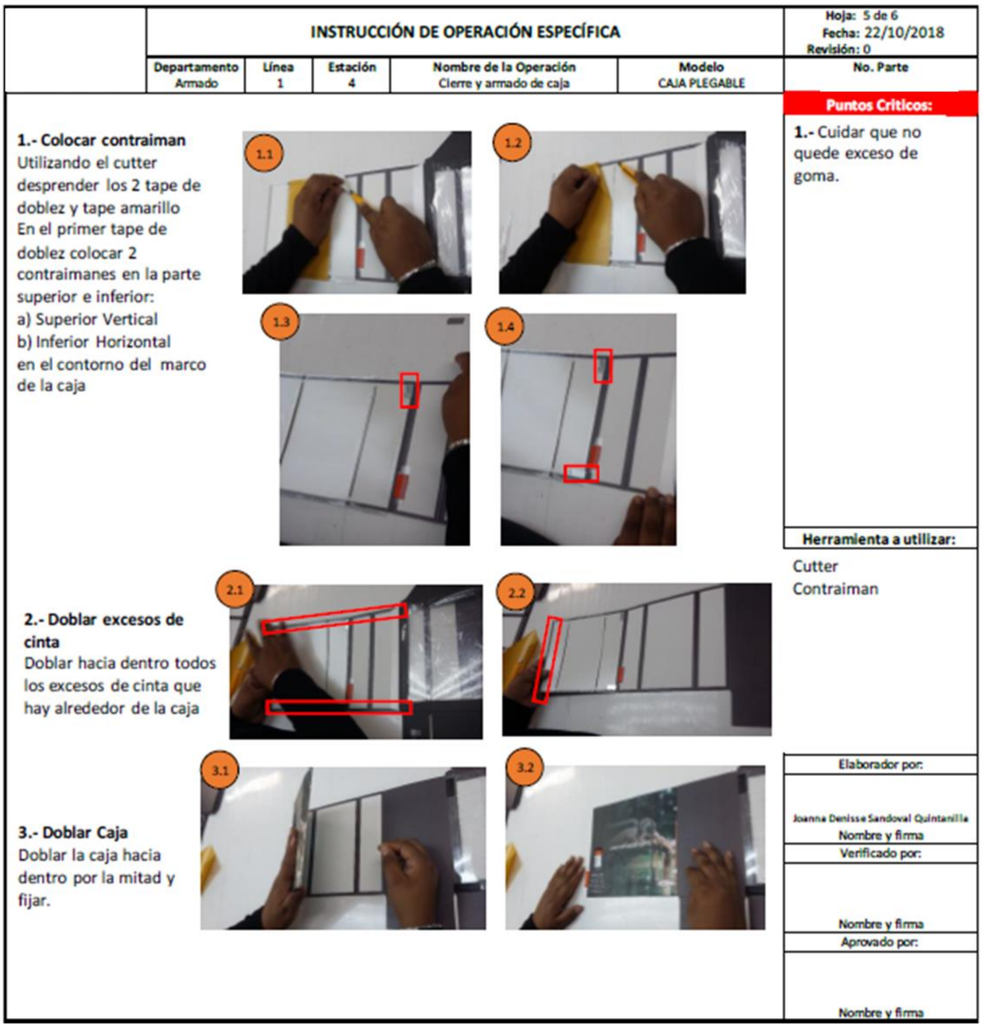
Herramienta a utilizar:
Motita de limpieza
Alcohol
Plastico protector

Elaborador por:
Joanna Denisse Sandoval Quintanilla
Nombre y firma

Verificado por:
Nombre y firma

Aprovado por:
Nombre y firma

Figura 3.3 Ayuda visual para la estación 3 rediseñada


INSTRUCCIÓN DE OPERACIÓN ESPECÍFICA					Hoja: 5 de 6 Fecha: 22/10/2018 Revisión: 0
Departamento Armado	Línea 1	Estación 4	Nombre de la Operación Cierre y armado de caja	Modelo CAJA PLEGABLE	No. Parte

1.- Colocar contraiman
Utilizando el cutter desprender los 2 tape de doblez y tape amarillo
En el primer tape de doblez colocar 2 contraimanes en la parte superior e inferior:
a) Superior Vertical
b) Inferior Horizontal
en el contorno del marco de la caja

2.- Doblar excesos de cinta
Doblar hacia dentro todos los excesos de cinta que hay alrededor de la caja

3.- Doblar Caja
Doblar la caja hacia dentro por la mitad y fijar.

Puntos Criticos:
1.- Cuidar que no quede exceso de goma.

Herramienta a utilizar:
Cutter
Contraiman

Elaborador por:
Joanna Denisse Sandoval Quintanilla
Nombre y firma
Verificado por:
Nombre y firma
Aprovado por:
Nombre y firma

Figura 3.4 Ayuda visual para la estación 4 rediseñada

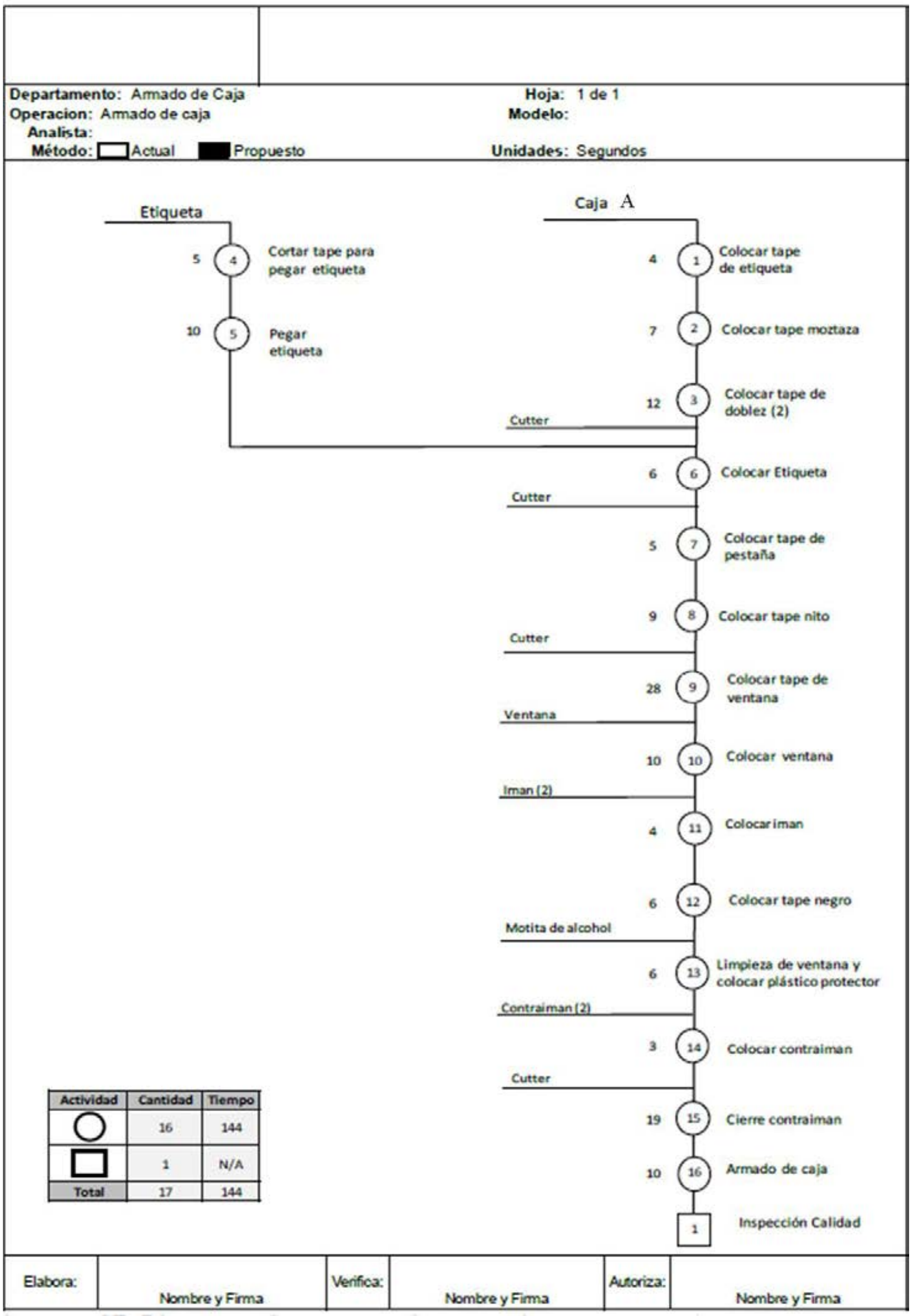


Figura 3.5 Diagrama de flujo del proceso para el proceso rediseñado

3.1.5 Resultados generales

Una vez que el proceso de producción se estandarizó, se monitorearon cuatro líneas de ensamblaje con cuatro operadores cada una durante una semana para evaluar el aumento de la producción. Las primeras tres líneas de montaje funcionaron bajo el proceso rediseñado, mientras que la cuarta línea funcionó bajo la metodología original. Como lo indica la Tabla 3.9, se obtuvo un aumento significativo de la producción en la línea de ensamblaje 3, donde se ensamblaron 2,971 unidades; es decir, 1,158 unidades más que en la línea de producción 4 (es decir, la metodología anterior). La Figura 3.6 presenta visualmente tales resultados.

Tabla 3.9 Comparación del incremento de producción: Metodología original vs. Metodología propuesta

Línea de ensamblaje	Operadores	Producción diaria					Total
		Lunes	Martes	Miércoles	Jueves	Viernes	
1	4	549	570	595	613	615	2942
2	4	555	578	610	609	611	2963
3	4	547	584	614	614	612	2971
4	5	340	359	380	374	360	1813

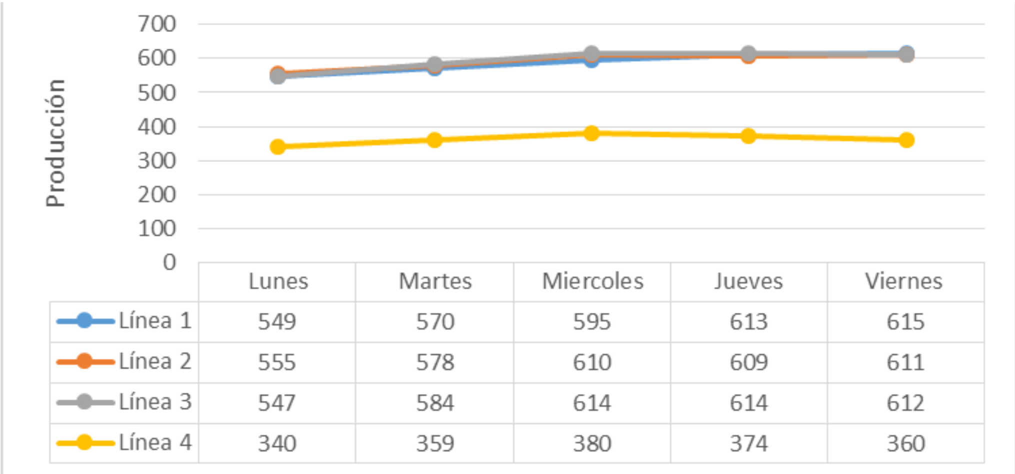


Figura 3.6 Comparación del incremento de producción: Metodología original vs. Metodología propuesta

Con las cinco líneas de ensamblaje trabajando completamente bajo el proceso rediseñado, la compañía reportó un aumento de producción del 42.62%. Además, al ejecutar cinco líneas de ensamblaje en lugar de cuatro, la compañía aumentó la producción en un 45.9%. Más específicamente, la compañía aumentó la producción diaria promedio de 1400 a 3050 unidades, lo que representa un aumento de 1650 unidades. La Tabla 3.10 resume los resultados de este análisis.

Tabla 3.10 Análisis del incremento de producción

	Metodología original	Metodología propuesta	Incremento de producción	Porcentaje de incremento
Producción por línea	350	610	+260	+42.62%
Producción total	1400	3050	+1650	+45.9%

Finalmente, es conveniente mencionar que en los registros de la compañía no se informaron lesiones y enfermedades en los operadores en el área de ensamblaje de cajas, sí mostraron dolor en los brazos, la espalda y las piernas, además de la fatiga física. Esto se debe a las posiciones que se vieron obligadas a adoptar con el diseño original de las estaciones de trabajo y el tiempo de exposición (horas de trabajo más tiempo extra). El rediseño antropométrico de las estaciones de trabajo, así como el método de trabajo, afectarían positivamente la salud y la seguridad de los operadores. En el caso específico del diseño antropométrico de estaciones de trabajo, esto evitaría que los operadores adopten posturas corporales incómodas [101]. Por otro lado, el rediseño del método de trabajo elimina los movimientos repetitivos y, según la literatura, las posturas corporales incómodas y los movimientos repetitivos son causa de trastornos musculoesqueléticos (TME) [102]. Por lo tanto, con el nuevo método de trabajo, se evitará que los operadores sufran TME o que sufran fatiga física al eliminar las horas extra.

3.1.6 Productos de investigación obtenidos

De la investigación de este caso de estudio se obtuvieron dos productos de investigación (ver Anexo I y Anexo III), los cuales se describen en la Tabla 3.11.

Tabla 3.11 Productos de investigación obtenidos del estudio de caso de productividad y bienestar de los trabajadores

Producto 1	
Título	Implementation of Production Process Standardization—A Case Study of a Publishing Company from the SMEs Sector
Autores	Arturo Realyvásquez-Vargas, Francisco Javier Flor-Moltalvo, Julio Blanco-Fernández, Joanna Denisse Sandoval-Quintanilla, Emilio Jiménez-Macías Jorge Luis García-Alcaraz
Revista	Processes (2227-9717)
Factor de impacto	1.963
Producto 2	
Título	Work Standardization and Anthropometric Workstation Design as an Integrated Approach to Sustainable Workplaces in the Manufacturing Industry
Autores	Arturo Realyvásquez-Vargas, Karina Cecilia Arredondo-Soto, Julio Blanco-Fernandez, Joanna Denisse Sandoval-Quintanilla, Emilio Jiménez-Macías, Jorge Luis García-Alcaraz
Revista	Sustainability (2071-1050)
Factor de impacto	2.592

3.2 Resultados del caso de calidad de los motores

Los resultados obtenidos para cada etapa de la metodología 8Ds se muestran a continuación.

3.2.1 Formar un equipo

El trabajo en equipo incluyó un ingeniero de mantenimiento, un ingeniero de procesos, un ingeniero interno, un gerente de línea de producción y dos inspectores de calidad. Los objetivos principales del trabajo en equipo son determinar un proceso de fabricación adecuado para la parte número A, así como definir la causa raíz de los defectos. Para lograr estos objetivos; se asigna una tarea a cada miembro del trabajo en equipo como se resume en la Tabla 3.12. Tenga en cuenta que cada paso del ciclo PDCA comprendía al menos una disciplina, ya que el método de las 8Ds sigue la lógica de este ciclo [86,103]. Además, las disciplinas se asignan a un miembro diferente del trabajo en equipo, es decir, no se asignó más de una disciplina a más de un miembro. Una vez que las tareas han sido asignadas a los miembros del equipo de trabajo, debe implementar un sistema de comunicación eficiente para mantenerse informados entre sí y, como resultado, garantizar la participación de todos los miembros en el proceso de resolución de problemas. De manera similar, se diseñó un formulario PDCA en Microsoft Excel® para que cada miembro del trabajo en equipo informe sus tareas correspondientes del ciclo PDCA.

Tabla 3.12 Asignación de tareas a los miembros del equipo

Método de las 8Ds	Ciclo PDCA	Miembro del equipo
Formar el equipo (D1)	Planear	Ingeniero de mantenimiento
Describir el problema (D2)		
Desarrollar una acción de contención provisional (D3)	Hacer	
Definir y verificar las causas raíz (D4)		Gerente de producción
Elegir/Verificar acciones correctivas permanentes (D5)		Ingeniero interno
Implementar y validar acciones correctivas (D6):	Verificar	Inspector de calidad 1
Prevenir recurrencias (D7):	Actuar	Inspector de calidad 2
Reconocer las contribuciones individuales y en equipo (D8):		Todos los empleados involucrados

3.2.2 Describir el problema

Como se mencionó anteriormente, los clientes devolvieron a la compañía 67 conjuntos de cables, que se quejaron por el bajo rendimiento del producto o por características inaceptables. El principal problema es que el ensamblaje no funcionaba; sin embargo, pudo deberse a varios tipos de defectos. La Tabla 13 enumera los seis tipos diferentes de defectos que se encontraron en los conjuntos de cables. Específicamente, los datos en la Tabla 3.13 se usan para crear un diagrama de Pareto como se muestra en la Figura 3.7. El diagrama ayudó a definir qué problemas o defectos debían priorizarse, de acuerdo con su frecuencia. En este sentido, el defecto más frecuente fueron los cables invertidos, seguidos de un motor desfigurado. Aunque tanto la longitud incorrecta del cable como la falta de una etiqueta de identificación fueron problemas menos frecuentes, también tuvieron que resolverse desde la raíz.

Tabla 3.13 Defectos encontrados en motores rechazados por el cliente

Defecto	Frecuencia	Porcentaje	Porcentaje acumulativo
Cables invertidos	35	52%	52%
Motor desfigurado	10	15%	67%
Motor ruidoso	9	13%	81%
Motor no funciona	7	10%	91%
Falta de etiqueta de identificación	4	6%	97%
Mala longitud del cable	2	3%	100%
Total	67	100%	

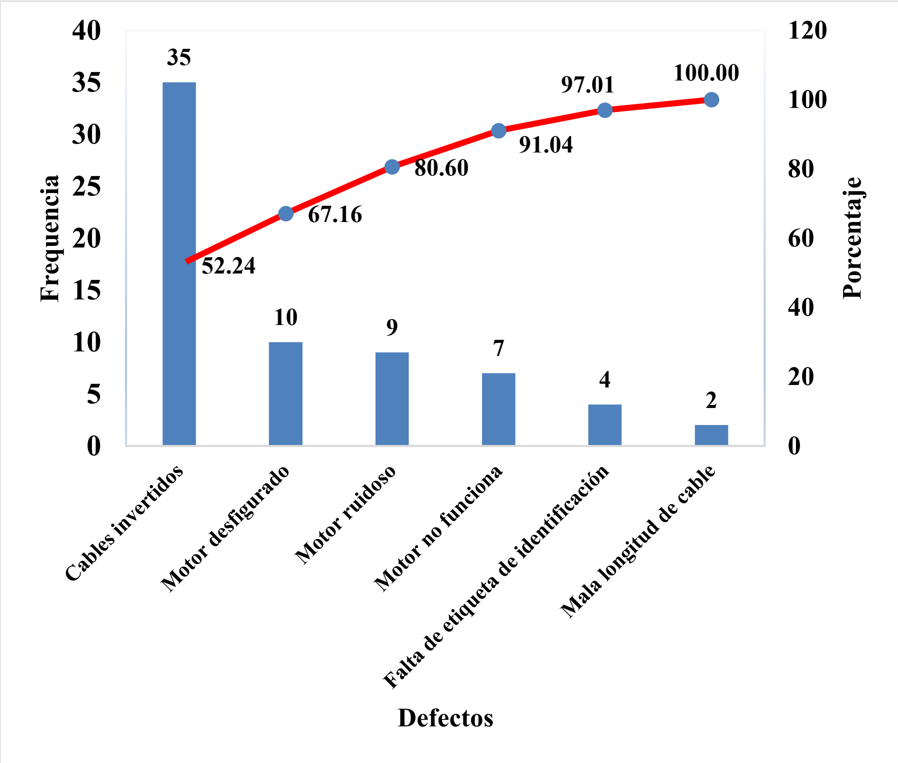


Figura 3.7 Diagrama de defectos en el ensamble de cables

3.2.3 Desarrollo de una acción de contención provisional

Se implementaron intervenciones provisionales y rápidas para resolver la mayoría de los seis defectos, incluidos los relacionados con cables invertidos, motores desfigurados, falta de etiqueta de identificación y longitud de cable incorrecta. Se desarrolló una serie de ayudas visuales provisionales para ayudar a los empleados a ensamblar los componentes. Con respecto a los cables invertidos y los motores desfigurados, se crea un documento para informar las condiciones tanto del motor paso a paso como de los cables antes y después de ser manipulados por el empleado. Además, como se muestra en la Figura 3.8, se crea una señal provisional para ayudar a los empleados a insertar los cables de ensamblaje no solo en la posición correcta, sino también en el orificio de entrada correcto utilizando los colores del cable como referencia. Del mismo modo, el letrero está destinado a ayudar a los empleados a garantizar que cada extremo del cable sea el requerido por los clientes.

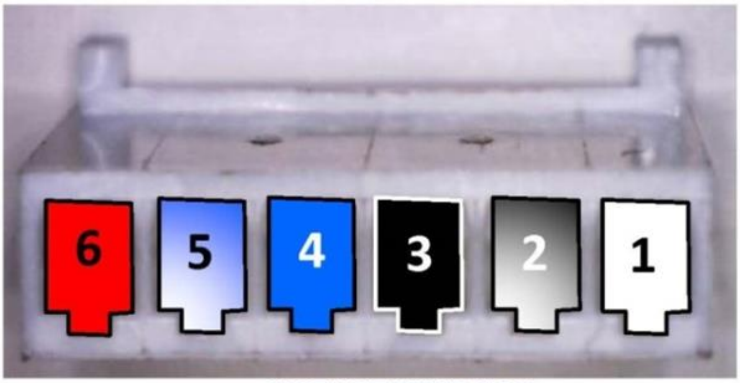
Finalmente, AutoCAD® se utiliza para diseñar una plantilla 2D escala 1:1 personalizable de un dibujo proporcionado por los clientes para que los ensambles verifiquen que los clientes demandados se cumplen, como aparece en la Figura 3.9. Quizás la mayor ventaja de esta plantilla electrónica es que puede almacenarse en una base de datos y actualizarse para nuevas especificaciones (es decir, nueva longitud del cable) si es necesario. Las actualizaciones se pueden realizar de forma rápida y efectiva sin comprometer la función de la plantilla.

Después de implementar este sistema de soluciones (es decir, la hoja de cálculo, el signo y la plantilla 2D), se observó que los errores más insignificantes se solucionaron de inmediato; en consecuencia, cuatro de los seis problemas fueron resueltos. Para confirmar esto, un inspector de calidad evaluó las asambleas y luego confirmó que los problemas se habían resuelto con éxito.

Páginas: 1 de 1

Método de Inserción

Operación: INSERCION DE CONECTOR	Número de Ensamble:	Fecha: 09/SEPTIEMBRE/2014 Rev cliente: B



VISTA DE INSERCION

POS	COLOR
1	BLANCO
2	BLANCO/NEGRO
3	NEGRO
4	AZUL
5	BLANCO/AZUL
6	ROJO

Equipo y/o herramienta necesaria:	Puntos de inspección:
- MANUAL	- VERIFICAR QUE LOS NUMEROS DE PARTE SEAN LOS CORRECTOS. - VERIFICAR QUE SE INSERTARON LOS CONDUCTORES EN LA POSICION CORRESPONDIENTE.

Aprobado por:

Ingeniero:	Firma:	

Figura 3.8 Ayuda visual provisional para inserción de cable

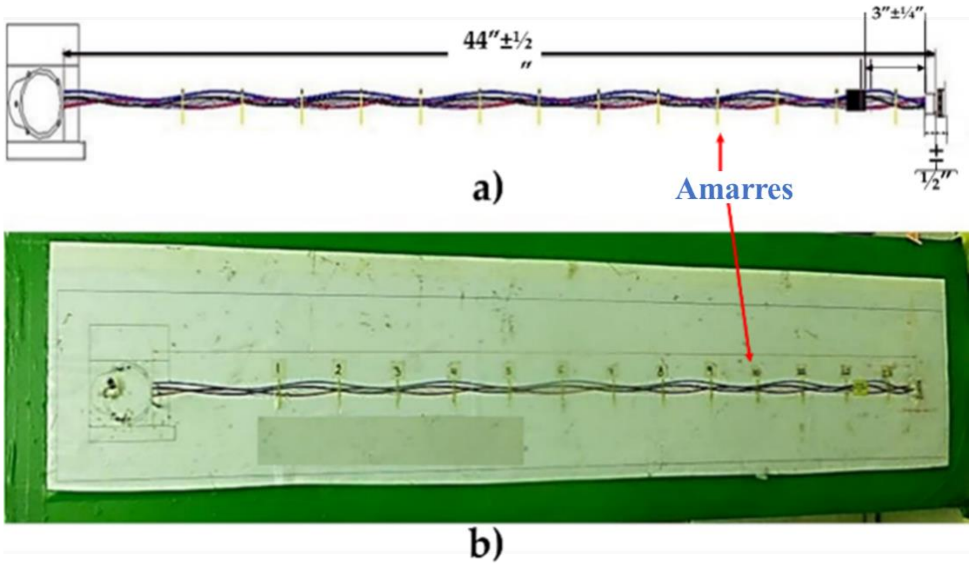


Figura 3.9 Plantilla del dibujo proporcionado por el cliente: a) imagen de la plantilla realizada en AutoCAD; b) imagen de la plantilla impresa.

3.2.4 Definir y verificar las causas raíz

Esta disciplina tiene como objetivo encontrar las causas profundas de los problemas. Según Škůrková [104], los diagramas de causa-efecto se pueden usar para mapear causas con sus efectos o problemas correspondientes. El problema general en este estudio de caso es que el ensamblaje no funciona; por lo tanto, se desarrolla un diagrama de espina de pescado, también conocido como diagrama de Ishikawa, como se muestra en la Figura 3.10 para identificar la causa raíz. Como se puede observar, se identificaron varias causas en cinco aspectos: materiales, métodos, medio ambiente, mano de obra y maquinaria.

Con respecto al medio ambiente, la razón por la cual los ensambles devueltos eran defectuosos es porque la compañía carecía de una prueba funcional para confirmar que funcionaban. Sin embargo, para realizar esta evaluación, los cables primero tenían que estar correctamente ensamblados, y aun así, habría sido imposible saber si los ensamblajes funcionaban correctamente. En cuanto a los materiales, se descubrió que los terminales del extremo del cable eran incorrectos, ya que los empleados del almacén proporcionaron por error el tipo incorrecto a los operadores. Además, dos causas más del problema se asociaron con el método de trabajo. Por lo general, los motores suministrados a la compañía vienen con cables ya integrados, y los empleados solo necesitan cortar estos cables según lo especificado por los clientes, y luego remachar el exceso. Sin embargo, a veces los cables no siempre se cortan a la longitud correcta o se invierten.

Figura 3.10 Diagrama de causa-efecto para encontrar la causa raíz del problema

En términos de maquinaria, se descubrió que las herramientas de la empresa eran obsoletas y se deben reemplazar. Finalmente, con respecto al aspecto de la fuerza laboral, el diagrama indicó que los cables de ensamblaje no siempre se remacharon correctamente, pero el remachado correcto hace posible que el motor se conecte a los cables, lo que a su vez permite que la prueba funcional se realice con éxito. Del mismo modo, se descubrió que los empleados pueden manejar mal los motores y, en el caso de los conjuntos rechazados, esto podría tener un impacto en su rendimiento. Otra posible causa de tener conjuntos defectuosos es que los motores podrían haberse dañado durante su entrega.

Además, dado que la mayoría de los ensamblajes se devolvieron debido a cables invertidos, este problema se considera la causa principal del problema (consulte la Figura 3.7). En la mayoría de las asambleas, los cables negro, blanco y azul se habían invertido. Al principio, esto puede ser un problema relacionado con el método de trabajo de la empresa; sin embargo, una prueba funcional también podría haber resuelto el problema. Además, con una prueba funcional, la compañía podría haber evitado motores que no funcionan y problemas de ruido anormales. Durante las pruebas funcionales, los motores generalmente muestran un mensaje de "no funciona", en cuyo caso la posición de los cables debe revisarse a fondo. Finalmente, para evitar que el problema vuelva a ocurrir, se desarrolla un programa en Visual Basic® para realizar pruebas funcionales motoras (ver Figura 3.11). La prueba utiliza valores binarios (0 y 1) que permiten a los empleados confirmar una funcionalidad de ensamblaje antes de entregarla al cliente. La Figura 3.12 presenta la tabla de verdad para el motor, con valores 1 = verdadero (ON) y 0 = falso (OFF).

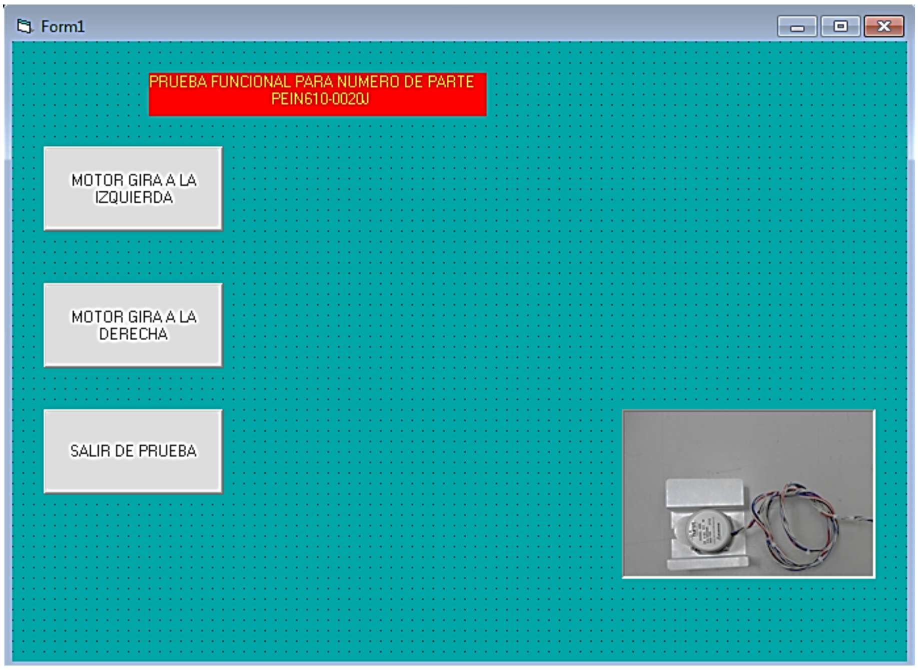


Figura 3.11 Ventana de formulario de la prueba funcional

	Ø4 White	Ø3 Black	Ø2 Blue	Ø1 Red	
CCW ROTATION ↑	1	0	1	0	CW ROTATION ↓
	1	0	0	1	
	0	1	0	1	
	0	1	1	0	

1 = ON, 0 = OFF

Figura 3.12 Valores de verdad para el motor

Los valores binarios se traducen en valores decimales para ser utilizados en el programa; primero se construye una tabla de fórmulas como se muestra en la Figura 3.13 donde cada fila corresponde a un cable. Luego, en cada fila, se muestran las primeras diez potencias de 2; es decir$2^0 = 1$, $2^1 = 2$, ..., $2^9 = 512$, de derecha a izquierda, y se le asigna un valor binario de la Figura 3.12 a una potencia correspondiente de dos, comenzando en $2^0 = 1$. Finalmente, cada valor binario en cada fila se multiplica por su potencia correspondiente de 2, y la suma de los productos es el valor decimal resultante que se informa en el lado derecho de cada fila. Una vez que se obtienen los cuatro valores decimales, se utilizaron en los comandos del programa que se ejecutarán, por lo tanto, comenzará un nuevo proyecto de acuerdo con las especificaciones del cliente.

						1	**0**	**1**	**0**	
512	256	128	64	32	16	8	4	2	1	**= 10**

						1	**0**	**0**	**1**	
512	256	128	64	32	16	8	4	2	1	**= 9**

						0	**1**	**0**	**1**	
512	256	128	64	32	16	8	4	2	1	**= 5**

						0	**1**	**1**	**0**	
512	256	128	64	32	16	8	4	2	1	**= 6**

Figura 3.13 Conversión de valores binarios a valores decimales

Una vez que se diseñó el programa en Visual Basic®, la aplicación de monitor de puerto paralelo de Parmon se usa para verificar que los valores decimales son correctos cuando se ejecuta el programa, como se muestra en la Figura 3.14. La columna Dec contiene los valores decimales correspondientes a los valores binarios de la columna binaria. En todos los valores decimales mostrados en la Figura 3.14, el motor que se estaba probando estaba encendido. Una vez que el motor finaliza su ciclo, el programa indica que el motor está girando en la dirección opuesta con respecto a la posición en la que había comenzado. El objetivo de esta prueba es confirmar que el motor funcionó correctamente sin ruido anormal.

3.2.5 Elegir/Verificar acciones correctivas permanentes

En esta disciplina, se implementaron las siguientes acciones correctivas:

- Método de inserción del conector: esta acción se implementó porque los cables invertidos fueron la causa principal del problema.

Figura 3.14 Aplicación del monitor de puerto paralelo de Parmon y funcionamiento del motor: (a) valor decimal 10 habilitado, el motor comienza a girar; (b) valor decimal 9 habilitado, el motor continúa su ciclo; (c) valor decimal 5 habilitado, el motor continúa su ciclo; (d) valor decimal 6 habilitado, el motor termina su ciclo.

- Prueba funcional: esta acción se implementó, ya que la falta de una prueba funcional fue una de las razones por las cuales los ensambles tenían cables invertidos. Las pruebas funcionales pueden ayudar a resolver los problemas de motores ruidosos y motores disfuncionales.
- Plantilla: los clientes exigieron esta acción, porque la plantilla garantiza que las características del componente de ensamblaje coincidan con las especificaciones del cliente.

Las tres acciones correctivas mejoraron significativamente el sistema de producción, ya que ayudaron a resolver problemas de cables invertidos, motores ruidosos, motores disfuncionales y características de componentes incorrectas. Además, el nuevo método de inserción se agregó en la hoja de datos del número de pieza A, y se almacenó en un archivo electrónico para actualizarlo cuando sea necesario. Sin embargo, un factor importante a tener en cuenta es que, independientemente de si el motor se ensambló correctamente o no, es probable que falle o genere ruido anormal

3.2.6 Implementar y validad acciones correctivas

Se desarrolló un método de operación para la prueba funcional (ver Figuras 3.15-3.17). Específicamente, cada conector que se probó solo tenía que conectarse a la caja que contenía el controlador. El tiempo de proceso establecido por el cliente fue de 7.28 minutos, pero se logró disminuir en 4.61 minutos (es decir, 36.68% menos de tiempo) después de que se documentó el proceso y se realizó una prueba funcional. Al final, el método de operación ayudó a los empleados a evitar errores al ensamblar el cable. Las acciones correctivas se validaron comparando los resultados del análisis de los ensambles defectuosos antes y después de implementar estas acciones. En realidad, los productos defectuosos disminuyeron en un 76%, lo que valida las acciones correctivas implementadas [82].

Páginas: 1 de 4

Método de operación

Operación: PRUEBA FUNCIONAL	Número de Ensamble:	Fecha: 30-Oct-14 Rev cliente: B Rev Documento: A

1. IDENTIFIQUE EL NUMERO DE PARTE PARA EL MOTOR, EN ESTE CASO A

2. SERCIORESE QUE LAS TERMINALES HALLAN SIDO INSERTADAS EN LA POSICION CORRECTA

6 5 4 3 2 1

Equipo y/o herramienta necesaria:	Puntos de inspección:
- MANUAL	- VERIFIQUE QUE LOS NUMEROS DE PARTE SEAN LOS CORRECTOS. - VERIFIQUE QUE SE INSERTO CORRECTAMENTE EN EL LUGAR CORRESPONDIENTE.

Aprobado por:

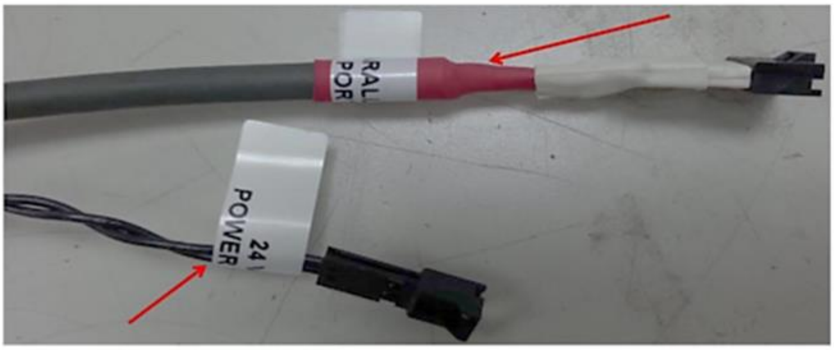
Ingeniero:	Firma:	

Figura 3.15 Primera ayuda visual para realizar la prueba funcional

		Páginas: 2 de 4
Método de operación		
Operación: PRUEBA FUNCIONAL	Número de Ensamble:	Fecha: 30-Oct-14 Rev cliente: B Rev Documento: A

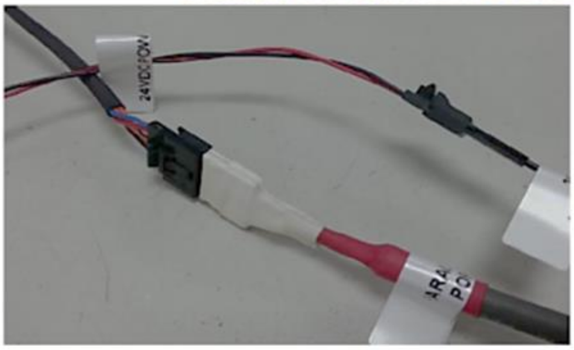
3. IDENTIFIQUE LOS DOS CABLES, UNO PARA LA CORRIENTE, OTRO PARA EL PUERTO PARALELO

PUERTO PARALELO



CORRIENTE 24V

4. CONECTE LOS CONECTORES DE LA SIGUIENTE MANERA



Equipo y/o herramienta necesaria:	Puntos de inspección:
- MANUAL	- VERIFIQUE QUE LOS NUMEROS DE PARTE SEAN LOS CORRECTOS. - VERIFIQUE QUE SE INSERTO CORRECTAMENTE EN EL LUGAR CORRESPONDIENTE.

Aprobado por:		
Ingeniero:	Firma:	

Figura 3.16 Segunda ayuda visual para realizar la prueba funcional

Figura 3.17 Tercera ayuda visual para realizar la prueba funcional

3.2.7 Prevenir recurrencias

El proceso de fabricación del número de pieza A comprende ocho tareas: corte manual de cables, remachado de cables semiautomático, inserción de terminales de extremo de cable, etiquetado de cables, realización de pruebas eléctricas y funcionales, realización de inspección final, embalaje y envío. Una vez que se identificaron estas tareas, se diseñó una serie de listas de verificación para monitorear su finalización exitosa y garantizar la continuidad en el proceso de fabricación. En la etapa de envío, a toda esta documentación se le asignó un número de revisión del cliente, lo que permitiría que la hoja de datos resultante se actualizara inmediatamente a medida que cambiaran las especificaciones del cliente, por lo tanto, informando a los departamentos de producción, calidad y corte de tales actualizaciones. Finalmente, en esta disciplina, se desarrolla una versión ejecutable del programa Visual Basic®. El programa prohíbe a los empleados cambiar cualquiera de sus configuraciones, ya que solo les permite abrirlo y realizar la prueba en un modo preconfigurado para evitar problemas de configuración incorrecta.

3.2.8 Reconocer el trabajo en equipo y las contribuciones individuales

En esta etapa, todos los miembros del trabajo en equipo fueron reconocidos por su desempeño individual y grupal. Aunque cada miembro tenía sus propias ideas y se propusieron diferentes sugerencias a lo largo del proceso de resolución de problemas, el trabajo en equipo permaneció unido y trabajó hacia un objetivo común.

3.2.9 Productos de investigación obtenidos

De la investigación de este caso de estudio se obtuvieron dos productos de investigación (ver Anexo II), los cuales se describen en la Tabla 3.13.

Tabla 3.13 Productos de investigación obtenidos del estudio de caso de calidad de los motores

Producto 1	
Título	Improving a Manufacturing Process Using the 8Ds Method. A Case Study in a Manufacturing Company
Autores	Arturo Realyvásquez-Vargas, Karina Cecilia Arredondo-Soto, Jorge Luis García-Alcaraz, Emilio Jiménez Macías
Revista	Applied Sciences (2076-3417)
Factor de impacto	2.217

4. Conclusiones e implicaciones industriales

4.1 Conclusiones sobre el caso de productividad y bienestar de los trabajadores

Las herramientas de ingeniería industrial, como son el trabajo estandarizado, el estudio de tiempos y movimientos, el diseño antropométrico de estaciones, y el método de las 8Ds, pueden tener un impacto significativo en el desempeño de las empresas de manufactura, ya que estas empresas compiten en los mercados internacionales y generalmente dependen de la TMA costosa. Además, estas herramientas ayudan a las empresas a ahorrar costos, satisfacer la demanda a tiempo, eliminar defectos, mejorar el desempeño y bienestar de los trabajadores, crear lugares de trabajo sostenible, incrementar la productividad, y aumentar la competitividad. Un análisis adecuado del proceso de producción en aspectos como el tiempo, los movimientos, el diseño de la estación de trabajo y la secuencia de tareas puede conducir a cambios que brinden excelentes resultados. La técnica de TE, combinada con el balanceo de líneas, es una herramienta eficaz para minimizar el desperdicio, como entregas tardías y sobreprocesamiento. Además, un análisis de los movimientos de los trabajadores y los estudios antropométricos son técnicas efectivas para rediseñar las estaciones de trabajo y, por lo tanto, reducir el número de *therbligs* inefectivos. De hecho, en el primer estudio de caso, los movimientos inefectivos se redujeron en un 66%; es decir, de 230 a 78, mientras que el tiempo estándar disminuyó de 244 a 199 segundos; es decir, en 18.44%.

Los resultados también demuestran que, cuando el trabajo está estandarizado, se requieren menos operadores por línea de ensamblaje. Esta es una oportunidad para que las empresas optimicen los recursos humanos mediante la instalación de nuevas líneas de ensamblaje con los otros operadores, y así aumentar la producción a un ritmo mucho más alto. En el primer estudio de caso, el número de operadores disminuyó en un 20%; es decir, de cinco a cuatro operadores. Como resultado, la compañía instaló una línea de ensamblaje más. Finalmente, los hallazgos permiten concluir que la implementación conjunta de TE y balanceo de líneas tiene un impacto positivo en el porcentaje de balanceo, lo que a su vez ayuda a minimizar los costos por unidad producida y aumentar las tasas de cumplimiento de la demanda. De hecho, en el estudio de caso, el porcentaje de equilibrio ascendió del 70% al 97%, mientras que la producción aumentó en un 63.2%; es decir, 229 unidades por línea de ensamblaje por día. Los resultados del primer estudio de caso son consistentes con los reportados en Mor *et al.* [47], Rahul y Kaler [105], More *et al.* [49], Bhardwaj *et al.* [106], Mor *et al.* [107], y

Garg *et al*. [108], donde se implementan técnicas simples entre las empresas de manufactura para promover una mayor producción y eficiencia.

Todos los resultados obtenidos en el primer estudio de caso son indicadores de que la empresa mejoró la gestión de sus recursos (materia prima, tiempo y recursos humanos), por lo tanto, mejoró su sostenibilidad. Del mismo modo, dentro de la empresa, los operadores mejoraron su calidad de vida y bienestar, ya que no tienen que adoptar posturas no deseadas o realizar movimientos de manos incómodos. Fuera de la compañía, los operadores mejoran su calidad de vida y bienestar, ya que se eliminaron las horas extra, no llegaron cansados a sus hogares y pasaron más tiempo con su familia.

Como valor práctico, estos resultados, y por lo tanto las técnicas aplicadas, pueden ser utilizados como una referencia de mejora por parte de las empresas de manufactura en procesos de producción masiva con múltiples operadores. Sin embargo, estos no tienen un valor práctico para aquellos procesos de producción en los que cada unidad producida se personaliza de acuerdo con los requisitos de un cliente específico, ya que no existe un proceso de producción específico para todas las unidades y, por lo tanto, no es posible la estandarización del trabajo.

El presente estudio de caso tiene las limitaciones de que se aplicó en una pequeña empresa, y solo en cuatro líneas de producción. Luego, la muestra de participantes para obtener datos antropométricos fue relativamente pequeña. Sin embargo, hay varios procesos en la imprenta que pueden estandarizarse, y la investigación futura debe centrarse en otras áreas de producción, como la línea de producción de libros o las líneas de estampado.

En las grandes empresas manufactureras, la recopilación de datos antropométricos puede llevar mucho tiempo, lo que puede representar una desventaja. Como las técnicas y herramientas se implementaron solo en el proceso de producción del modelo de caja A, el trabajo práctico futuro se debe dirigir para aplicar estas técnicas y herramientas en otros modelos de caja, tipo de productos (libros, estampado, por mencionar algunos) y departamentos dentro de la empresa. Del mismo modo, existe la oportunidad de aplicarlas este en otras empresas, ya sea que pertenezcan al sector manufacturero o a otro sector, independientemente de su tamaño. El trabajo teórico futuro debe estar dirigido a proponer y experimentar con la integración de más y diferentes tipos de herramientas que se aplican en los sistemas de fabricación, así como su impacto en la sostenibilidad.

4.2 Conclusiones sobre el caso de calidad de los motores

El objetivo principal de este estudio de caso se logró con éxito. El método 8Ds implementado en la empresa de manufactura logró disminuir el número de defectos de ensamblaje en la parte número A de 67 a 51, lo que representa una disminución del 76.12%. La Figura 4.1 muestra una comparación sobre la frecuencia de cada defecto antes y después de implementar el método 8Ds. Tenga en cuenta que la frecuencia de todos los defectos disminuyó. Por ejemplo, la frecuencia de los cables invertidos, el defecto más común, disminuyó de 35 a 2. De manera similar, la frecuencia del motor desfigurado disminuyó de 10 a 3, así como el motor ruidoso disminuyó de 9 a 3, por mencionar la frecuencia más alta defectos.

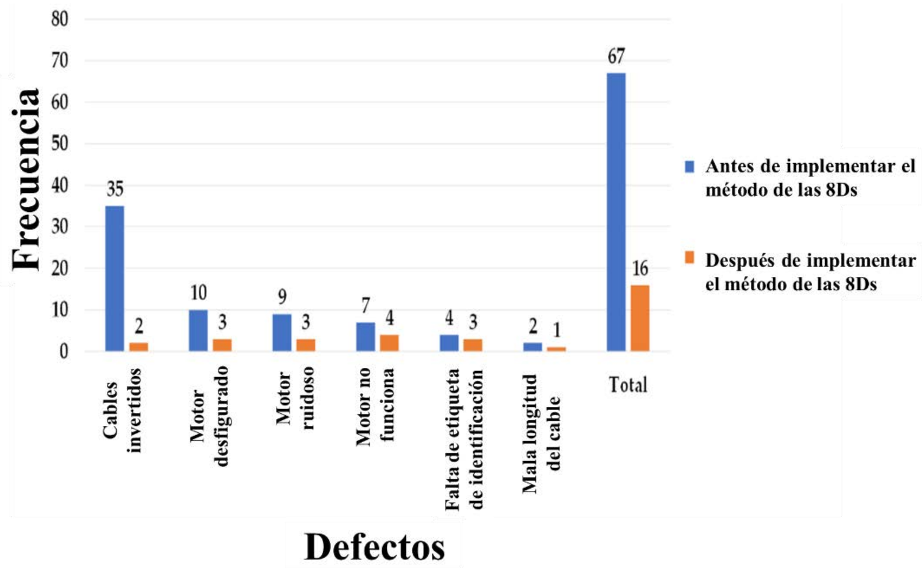


Figura 4.1 Comparación de la frecuencia de defectos antes y después de implementar el método de las 8Ds

Simultáneamente, la implementación del método 8Ds permitió aumentar la satisfacción del cliente. En anteriores casos de estudio reportados en la literatura, el método 8Ds se aplicó para ayudar a las corporaciones a cumplir con los tiempos de entrega, reducir los costos de desperdicios y defectos, implementar nuevos procesos o desarrollar nuevos productos, mejorar los sistemas de garantía de calidad, minimizar la cadena de suministro y las quejas de los clientes, y mejorar los servicios. Sin embargo, resolver este tipo de problemas implica tener un sistema de comunicación sólido y efectivo entre los departamentos afectados, que también debe compartir un objetivo común.

Además, al implementar el método de las 8Ds, la compañía logró disminuir el tiempo de producción, los tiempos de inactividad de la máquina, los costos de desperdicio, los defectos operativos, la tasa de entregas tardías y las quejas de los clientes. Con respecto al sistema de manufactura, el método de las 8Ds aumentó la eficiencia y la productividad en la aplicación de métodos y técnicas estadísticas a bajos costos operativos. La Tabla 4.1 muestra una comparación de los principales indicadores antes y después de implementar el método 8D. Es importante tener en cuenta que los defectos totales se redujeron en un 76.12%, mientras que las quejas de los clientes se redujeron en un 100%. De manera similar, los tiempos de producción, inspección y empaque para el número de pieza A se redujeron en más del 30%; y las paradas de máquinas se redujeron en más del 77%. Esta reducción de los ciclos de tiempo permitió aumentar el nivel de producción en 34.22%.

Tabla 4.1 Comparación de los principales indicadores antes y después de aplicar el método de las 8Ds

Indicador	Antes de implementar el método de las 8Ds	Después de implementar el método de las 8Ds	Diferencia
Defectos totales	67	16	-76.12%
Tiempo para el proceso de producción de la parte A	7.28 minutos	4.61 minutos	-36.68%
Tiempo para inspección y empaque de la parte A	6.5 minutos	4.28 minutos	-34.22%
Quejas del cliente	67	0	-100%
Paros de máquinas	155 minutos/día	35 minutos/día	-77.42%
Producción	850 productos/día	1141 productos/día	+34.22%

Además, la implementación del método de las 8Ds tuvo un impacto positivo en la competitividad de la empresa en términos de calidad y seguridad. Asimismo, el método tuvo un efecto positivo significativo en los empleados y la responsabilidad, participación y compromiso de la gerencia, lo que agilizó y mejoró el proceso de resolución de problemas de la compañía, especialmente al ayudar a delegar responsabilidades iguales a los niveles organizacionales más bajos. Finalmente, la implementación del método de las 8Ds permite recopilar información sobre un problema de manera rápida, así como también reduce el tiempo de comunicación entre el trabajo en equipo de calidad y los operadores.

Dado que, cuando surgen problemas, se debe implementar un método, técnica o herramienta abstracta para encontrar la mejor solución. En algunas ocasiones, el proceso de implementación puede requerir pequeñas modificaciones en la organización, mientras que, en otros casos, los ingenieros deben tener más cuidado para evitar las pérdidas de la compañía. Además, en la implementación de cualquier método, la comunicación es un elemento clave del éxito. Un sistema de comunicación sólido, rápido y efectivo alienta a los empleados a ser creativos y participar en el proceso de resolución de problemas, así como motivar a los empleados a estar preparados para cualquier cambio adicional. En otras palabras, el método de las 8Ds tiene un doble objetivo: resolver problemas y aumentar la participación activa de los empleados en el proceso de resolución de problemas. Para lograr estos objetivos, los expertos recomiendan las siguientes estrategias:

- Implementar el método 8Ds para resolver problemas con otros números de parte o en otras áreas (compra o venta, por ejemplo).
- Siempre considerar la opinión de cada empleado, ya que hará que su trabajo sea motivador.
- Involucrar las opiniones e ideas de los clientes para mejorar tanto los procesos de producción como su satisfacción.

Como trabajo futuro, y en base a los hallazgos obtenidos en el presente estudio de caso, se recomienda implementar el método de las 8Ds en empresas de la industria manufacturera para resolver problemas relacionados con productos defectuosos o eficiencia del proceso de producción. Además, se recomienda extender la implementación del método de las 8Ds, así como otras herramientas de ingeniería industrial (como el ciclo PDCA, trabajo estandarizado, diseño antropométrico, DMAIC, por mencionar algunos), no sólo a las empresas del sector manufacturero, sino también en otros sectores como la construcción, educación, agricultura, servicios alimenticios y otros.

Finalmente, se recomienda los investigadores del campo de la Ingeniería Industrial a publicar sus estudios de caso sobre la aplicación de diferentes técnicas, métodos o herramientas, con el apoyo del realismo crítico.

4. Conclusions and industrial implications

4.1 Conclusions on the case of productivity and workers well-being

Industrial engineering tools, such as standardized work, the study of times and movements, the anthropometric design of stations, and the 8D method, can have a significant impact on the performance of manufacturing companies, since these companies compete in international markets and generally depend on expensive advanced manufacturing technology (AMT). In addition, these tools help companies save costs, meet demand on time, eliminate defects, improve worker performance and well-being, create sustainable workplaces, increase productivity, and increase competitiveness. Proper analysis of the production process in aspects such as time, movements, workstation design and task sequence can lead to changes that deliver excellent results. The standardized Work (SW) technique, combined with line balancing, is an effective tool to minimize waste, such as late deliveries and overprocessing. Additionally, an analysis of worker movements and anthropometric studies are effective techniques for redesigning workstations and therefore reducing the number of ineffective therbligs. In fact, in the first case study, ineffective movements were reduced by 66%, that is, from 230 to 78, while the standard time decreased from 244 to 199 seconds, that is, by 18.44%.

The results also demonstrate that when work is standardized fewer operators are required per assembly line. This is an opportunity for companies to optimize human resources by installing new assembly lines with the other operators, thereby increasing production at a much higher rate. In the first case study, the number of operators decreased by 20%, that is, from five to four operators. As a result, the company installed one more assembly line. Finally, the findings allow concluding that the joint implementation of SW and line balancing has a positive impact on the balancing percentage, which in turn helps to minimize costs per unit produced and increase demand compliance rates. In fact, in the case study, the equilibrium percentage rose from 70% to 97%, while production increased by 63.2%, that is, 229 units per assembly line per day. The results of the first case study are consistent with those reported in Mor *et al.* [47], Rahul and Kaler [105], More *et al.* [49], Bhardwaj *et al.* [106], Mor *et al.* [107], and Garg *et al.* [108], where simple techniques are implemented among manufacturing companies to promote greater production and efficiency.

All the results obtained in the first case study are indicators that the company improved the management of its resources (raw material, time and human resources), improving therefore its sustainability. Similarly, within the company, operators improved their quality of life and well-being, as they do not have to adopt unwanted postures or make uncomfortable hand movements. Outside of the company, operators improve their quality of life and well-being by eliminating overtime, not coming home tired and spending more time with their family.

As a practical value, these results, and therefore the applied techniques, can be used as a reference for improvement by manufacturing companies in mass production processes with multiple operators. However, these do not have practical value for those production processes in which each unit produced is customized according to the requirements of a specific customer, since there is no specific production process for all units and, therefore, standardization of work is not possible.

This case study has the limitations that it was applied in a small company, and only in four production lines. Then, the sample of participants to obtain anthropometric data was relatively small. However, there are several processes in the press that can be standardized, and future research should focus on other production areas, such as the book production line or the stamping lines. In large manufacturing companies, collecting anthropometric data can be time consuming, which can be a disadvantage. Since the techniques and tools were implemented only in the production process of box model A, future practical work should be directed to apply these techniques and tools to other box models, product types (books, stamping, to name a few) and departments within the company. Similarly, there is an opportunity to apply this to other companies, whether they belong to the manufacturing sector or to other sectors, regardless of their size. Future theoretical work should be aimed at proposing and experimenting with the integration of more and different types of tools that are applied in manufacturing systems, as well as their impact on sustainability.

4.2 Conclusions on the engines' quality case

The main objective of this case study was successfully achieved. The 8Ds method implemented at the manufacturing company decreased the number of assembly defects in part number A from 67 to 51, representing a decrease of 76.12%. Figure 4.1 shows a comparison on the frequency of each defect before and after implementing the 8Ds method. Note that the frequency of all defects decreased. For example, the frequency of inverted cables, the most common defect, decreased from 35 to 2. Similarly, the frequency of the disfigured motor decreased from 10 to 3, as well as the noisy motor problem decreased from 9 to 3, due to the risk of highest frequency defects.

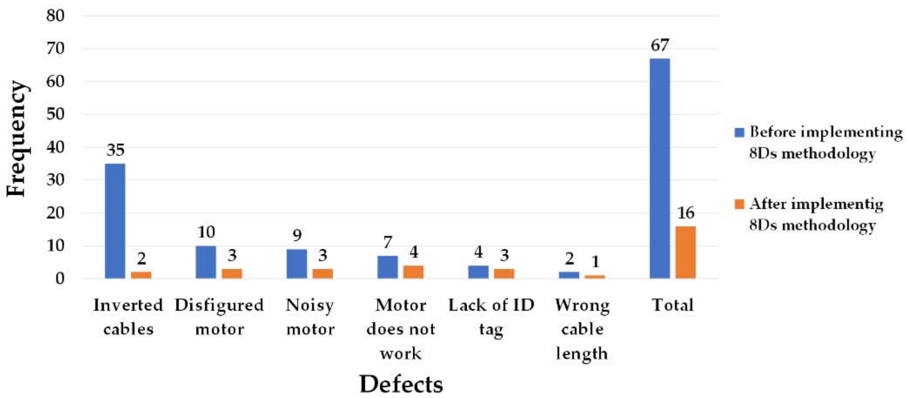


Figure 4.1 Comparison of the frequency of defects before and after applying the 8Ds method.

Simultaneously, the implementation of the 8Ds method increased customer satisfaction. In previous case studies reported in the literature, the 8Ds method was applied to help corporations meet delivery times, reduce waste and defect costs, implement new processes or develop new products, improve warranty systems for quality, minimize the supply chain and customer complaints, and improve services. However, solving this type of problem implies having a solid and effective communication system between the affected departments, which must also share a common objective. In addition, by implementing the 8Ds method, the company managed to decrease production time, machine downtime, waste costs, operational defects, late delivery rate, and customer complaints. With respect to the manufacturing system, the 8Ds method increased efficiency and productivity in the application of statistical methods and techniques at low operating costs. Table 4.1 shows a comparison of the main indicators before and after implementing the 8D method. It is important to note that total defects were reduced by 76.12%, while customer complaints were reduced by 100%. Similarly, production, inspection, and packaging times for part number A were reduced by more than 30%; and machine stops were reduced by more than 77%. This reduction in time cycles allowed the production level to increase by 34.22%.

Table 4.1 Comparison of the main indicators before and after applying the 8Ds method.

Indicator	Before implementing the 8Ds methodology	After implementing the 8Ds methodology	Difference
Total defects	67	16	-76.12%
Time for the production process of part number A	7.28 minutes	4.61 minutes	-36.68%
Time for the inspection and	6.5 minutes	4.28 minutes	-34.22%

packing of part number A			
Customer complaints	67	0	-100%
Machines stoppages	155 minutes/day	35 minutes/day	-77.42%
Production	850 products/day	1141 product/day	+34.22%

Furthermore, the implementation of the 8Ds method had a positive impact on the company competitiveness in terms of quality and safety. Furthermore, the method had a significant positive effect on employees and the responsibility, participation, and commitment of management, which streamlined and improved the company problem-solving process, especially by helping to delegate equal responsibilities to the highest organizational levels. Finally, the implementation of the 8Ds method allows collecting information about a problem quickly, as well as reducing the communication time between quality teamwork and operators. Since, when problems arise, an abstract method, technique, or tool must be implemented to find the best solution. On some occasions, the implementation process may require minor modifications to the organization, while in other cases, engineers must be more careful to avoid losses to the company. Furthermore, in the implementation of any method, communication is a key element of success. A robust, fast, and effective communication system encourages employees to be creative and participate in the problem-solving process, as well as motivate employees to be prepared for any further changes. In other words, the 8Ds method has a double objective: solving problems and increasing the active participation of employees in the problem solving process. To achieve these goals, experts recommend the following strategies:

- Implement the 8Ds method to solve problems with other part numbers and / or in other areas (buy or sell, for example).
- Always consider the opinion of each employee, as it will make their work motivating.
- Involve the opinions and ideas of customers to improve both production processes and satisfaction.

As future work and based on the findings obtained in the present case study, it is recommended to implement the 8D method in companies in the manufacturing industry to solve problems related to defective products and / or efficiency of the production process. In addition, it is recommended to extend the implementation of the 8Ds method, as well as other industrial engineering tools (such as the PDCA cycle, standardized work, anthropometric design, DMAIC, to name a few), not only to companies in the manufacturing sector, but also in other sectors such as construction, education, agriculture, food services, and others.

Finally, researchers in the field of Industrial Engineering are recommended to publish their case studies on the application of different techniques, methods or tools, with the support of critical realism.

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Anexo I

Artículo:

Implementation of Production Process Standardization—A Case Study of a Publishing Company from the SMEs Sector

processes

MDPI

Article

Implementation of Production Process Standardization—A Case Study of a Publishing Company from the SMEs Sector

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Featured Application: Work standardization supported by other basic industrial engineering methods, such as the study of time and motions can be applied in the manufacturing industry for increasing the productivity index. Those tools are easy to apply in production lines, where managers can obtain results in a short period of time.

Abstract: This paper reports a case study using a standardization process for increasing efficiency and a better optimization of resources in a printing company with 150 operators having manual and mechanical tasks in the box assembly department along with four production lines. The current capacity is 350 boxes per day, while the demand is 650 units, where the company is expected to pay large sums for overtime. Using work standardization, studying worker movements, timing, and workstations redesign, the main goal was to increase the efficiency and productivity indexes. After applying those tools, the inefficient movements in operators decreased from 230 to 78, eliminating 66% of the unnecessary movements, as well as the standard time in a workstation decreased from 244 to 199 s (18.44%) per each assembled box, and the production rate increased by 63.2%, that is, 229 units per assembly line a day, where overtime was reduced to zero.

Keywords: work standardization; line balancing; workstations redesign; optimization of productivity; inefficient movements

1. Introduction

In practical terms, in order to remain competitive, manufacturing companies must be able to effectively solve a range of production-related issues, such as bottlenecks and unbalanced production lines, shutdowns, late deliveries, extra work hours, inefficient material handling and movements, as well as high production costs, among others.

Regarding bottlenecks and unbalanced production lines, several studies have presented different types of case studies on manufacturing companies. For instance, Gu et al. [1] presented two case studies where maintenance problems were caused by bottlenecks in complex manufacturing systems. In these cases, the result was the production loss. Similarly, Ren et al. [2] displayed a case study where bottlenecks and unbalanced production lines caused low productivity in an assembly area. Specifically, in order to solve this problem, these authors performed a re-layout of the assembly and balanced in the production lines, therefore, productivity increased. Further, Zupan and Herakovic [3] presented a case study of two production lines where bottlenecks caused them to become unbalanced, consequently, the company had low productivity. Furthermore, to increase productivity, these authors implemented the balancing line approach.

Respecting the shutdowns, Sonmez et al. [4] addressed two case studies where shutdowns of equipment caused production loss in manufacturing systems. Likewise, Peng and Zhou [5] investigated a multiple server scheduling problem in automobile assembly lines, where just-in-time (JIT) part-supply had become a critical issue. The authors mentioned that expensive line shutdowns represent a cause of this type of issue. In another case, Zhou and Peng [6] mentioned that the mixed-model assembly lines are extensively adopted in the current automobile production to satisfy the ongoing customization, however, material shortages are not allowed, as it would be extremely expensive due to the production line shutdowns. Finally, Zhao et al. [7] presented a case study of delay-time-based preventive maintenance (PM) modelling for a production plant system in a steel mill. In this case, shutdowns were caused by waiting for raw materials.

Moreover, delays in deliveries represent another problem for manufacturing companies. The literature review provides some examples. For instance, Fazlollahtabar [8] presented a case of an assembly line where late deliveries of products caused a low overall manufacturing system performance. In order to solve this problem; this author proposed a parallel autonomous guided vehicle assembly line for a semi-continuous manufacturing system. Peng and Lu [9] examined the impact of the delivery performance on customer transactions. As a result, these authors found that the measures of delivery performance affect customer transaction quantity and unit price differently. In the case of extra work hours, Hansson et al. [10] performed a study to determine whether man-hour efficiency of picking is affected by the use of batch preparation, compared to the preparation of one kit at a time. In this study, these authors mentioned that kitting is associated with extra time for operations in the materials feeding. In fact, they performed two experiments, and they found that single-kit preparation took more time than batch preparation, and also represented a higher cost, i.e., extra time, more investments.

On the other hand, El-Namrouty and Abushaaban stated that inefficient material handling and movements do not add any value to the product. These authors pointed out that inefficient material handling between processing stages results in prolonging production cycle times, and the inefficient use of labor and space. In the case of movements, these involve poor ergonomics of production, where operators must stretch, bend, and pick up products when such actions could be avoided. All these problems cause high production costs [11].

Several studies have confirmed that bottlenecks can cause production shutdowns [1,12] that critically affect the performance of the entire production system. In general, bottlenecks decrease the productivity of manufacturing systems, thereby limiting the systems total production capacity [2,13]. Similarly, Zupan and Herakovic [3] declared that unbalanced production lines cause organizational problems, decrease performance, and increase costs. Specifically, production line balancing is a traditional production strategy that helps decrease bottlenecks. As for shutdowns, they may be responsible for production losses [4] and increasing costs [5,6], especially when they occur unexpectedly and affect subsequent operations [14]. In particular, according to Hossen et al. [15], idling and major stoppages and breakdown losses account for 89.3% of total stoppage losses.

Manufacturing systems implement multiple strategies to mitigate problems in the production process. For instance, at the supplier selection stage, they pay close attention to attributes, such as punctuality and reliability [9], which are crucial for the success of any business as well as allowing firms to entice their customers to order more products or pay a higher price for a specific item [9].

Another clear example of a competitive strategy is the Fulfillment by Amazon (FBA) logistics service, which provides sellers more flexibility in their selling practices. The FBA manages the entire back-end fulfillment of a product or item from a third-party seller once it is purchased. A recent survey reported that 73% of the FBA sellers mentioned that unit sales have increased over 20% [16]. Furthermore, a business-to-business (B2B) study conducted by Bain and Company indicated that firms with an appropriate delivery performance can charge higher prices for their products, and entice their customers to order more of them [17]. Conversely, poor delivery performance causes sales decrements, or even losses.

In addition, multiple studies support that working extra hours are a relevant characteristic for certain tasks or departments within manufacturing systems. For instance, Hanson et al. [10] undertook research on order batching and time efficiency in kit preparation, where it was found that kitting is associated with extra time for operators in the feeding of materials, where extra hours are usually necessary for achieving the proper overall performance of materials in a supply system that uses kitting. Moreover, Wang et al. [18] found that inappropriate process planning can cause workers work additional time, which ultimately translates in higher costs. For material handling and movements, El-Namrouty and Abushaaban [11] determined the effects of each of the seven manufacturing wastes (i.e., the overproduction, over-processing, waiting, defects, motion, transportation, and inventory) on the other six wastes, where it was found that insufficient worker motions caused unnecessary work-in-process and increased the rate of defective parts. Furthermore, it was found that non-standardized work increases both processing time, waste in the process, as well as the rate of defective parts, whereas insufficient and unsafe material handling equipment and machines lead to undue amounts of in-process inventory, product defects, and delays in final deliveries. As a result, all these problems cause major issues: low production levels and non-compliance with the demand.

Standardized work (SW) is a vital tool for solving manufacturing problems, which offers almost immediate results in terms of organizational performance by increasing productivity and reducing delivery times [19]. SW is probably the most known method for performing a specific job, which in turn makes it the safest and most efficient method for complying with timely, orderly, and quality deliveries [20]. SW is the set of specific directions that are needed to manufacture a product in the most efficient way, which allows defining the best methods and sequenced tasks for each process and operator, therefore, reducing wastes [19,21,22].

SW defines how each task or job must be performed by each operator in the production system, hence, preventing employees from executing random tasks [19,23] that can adversely affect lifecycle times. In fact, SW draws upon takt time to ensure timely compliance with demand [24]. In this sense, the aim of SW involves removing Mura [25], that is, the general term of inequality, irregularity, or inconsistency in physical matter or the human spiritual condition, and it is also a key concept in the performance improvement systems, because it is one of three types of waste (Muda, Mura, Muri) [26]. However, SW does not mean that a work routine can never be changed. Instead it implies "this is the best way we know how to do this type of work today" [23,27]. Furthermore, SW is integrated by three elements [19]: takt time (i.e., the rate at which a finished product needs to be completed in order to fulfill the customers' demand); the precise work sequence in which an operator performs tasks within takt time; and the standard inventory—including the units in machines—required to keep the process flowing smoothly.

Some studies report applications of SW to solve problems in production processes. For instance, Nallusamy and Saravanan [28] implemented both line balancing and SW in a small manufacturing company, where it was managed to reduce cycle times to 350 s as it increases productivity. Then, Nallusamy [29] applied the same two tools in the computer numerical control (CNC) industry, where non-value-added (NVA) activities were reduced by 17%, while production significantly increased, from five units a day per two operators to seven units a day per a single operator. From a similar perspective, Villalba-Diez and Ordieres-Mere [30] applied SW to inter-process communication in an automotive manufacturing enterprise, where a performance optimization of 4% was achieved. Additionally, Mor et al. (2018b) implemented work standardization in the core making process in a manufacturing company, where a reduction of 31.6 s in cycle times was reported, as well as an increment of 6.5% in production.

The multiple applications of SW reveal that this method does much more than controlling processes. It also minimizes costs and maximizes efficiency [31]. SW is an efficient lean manufacturing tool that helps increase competitiveness in firms. In the particular case of small and medium enterprises (SMEs), SW is an excellent method that can compensate for the lack of manufacturing technology (AMT) in the production process. However, SW is often under-implemented, not properly cared, or/and misunderstood [19].

According to the literature review, from a critical realism approach, the single case study research methodology is enough to generalize empirical and theoretical findings. For example, Easton [32] argued that critical realism is a coherent, rigorous, and a new philosophical position that not only substantiates single case research as a research method, but also provides helpful implications for both the theoretical development and research process. Moreover, Tsang [33] stated that critical realism recognizes the role of a case study research in empirical generalization, theoretical generalization, and theory testing. This last author describes that fallibility of knowledge implies that once a theory is developed, it is necessary to subject it to further empirical tests, where case studies are a suitable way of conducting this type of test. Therefore, a single case study is enough to generalize results [34].

According to that position, the main goal of this research is to demonstrate the impact of both SW and line balancing on the production process using a case study. Indeed, this study attempts to validate that these two tools can significantly reduce bottlenecks while increasing the production in SMEs. In other words, the current status of the company production process was analyzed, where several techniques and tools were applied to solve the identified problems in the production process. Then, this process was observed one more time to compare the before and after results. This case study was chosen due to two reasons: Firstly, the company reports several problems derived from the lack of balanced lines and standardized work, such as low production, a high rate in customers' complaints, high costs of extra time, and physical fatigue in operators. Secondly, this case study is part of a project of the manufacturing processes' improvement, where most participant companies are big companies. Therefore, before implementing SW and line balancing in a big company, it is implemented in a SME.

The innovation of this research is that it may allow the positive results to be shown from the impact of SW and line balancing on the production process in SMEs in the manufacturing sector with a single case study, which is based on the critical realism perspective.

2. Methodology

The methodology has a structure similar to the one proposed by Realyvásquez-Vargas et al. [35], which includes major tasks, such as (a) analyzing the current state of the production process, (b) studying times and movements in operators, (c) visually standardizing workstations, (d) implementing standardization, and (e) analyzing the redesigned production process. In this sense, the research methodology comprises four stages: (1) collect and analyze data, (2) study times and motion, (3) make visual standardization, and (4) implement standardization.

2.1. Stage 1. Data Collection and Analysis

This stage is aimed to get information from the current status of the production process to make some preliminary analysis. The main tasks are:

- Describe the workstation
- Make diagrams of current production process
- Monitor and analyze the production process
- Identify critical production indexes

- Propose a project to a manager to improve indexes

In this stage, the project proposal is presented to managers at the printing company, first by summarizing the shortcomings of the company current production process, and then, by describing the SW-based proposal, thus highlighting the potential benefits of a standardized process (e.g., reduced process times and costs, greater firm prestige, and decreased employee fatigue). Next, the production process is analyzed along with the operators, who know best the production process. In fact, the production tasks were monitored in order to identify potential opportunities for improvement. Subsequently, a process flowchart was designed to visually represent the precise work sequence in which the operators perform the observed tasks. Finally, a detailed description was made of each observed workstation and tasks, highlighting the precise way they must be performed as well as making a chart for each of them.

2.2. Stage 2. Study of Time and Motion

The second stage assumes that there is authorization from the manager to apply the SW in the production process, which is aimed at its analysis along with study time and motion in the workstations, demanding the collaboration from operators. The main tasks are:

- Study time
- Study motion
- Balancing production lines
- Redesign production lines

Particularly, those tasks are aimed to discover and consequently, eliminate the time and motion inefficiencies to establish standardized and optimized procedures for activity execution, as well as to measure the operator performance [36]. Regarding the time analysis, first, the number of cycles to observe is defined, as it is recommended by General Electric (GE) [37]. Then, the average observed time (OT) is estimated for each repetitive work cycle, as well as the normal time (NT) for each task, considering the Westinghouse Rating System's four factors for rating performance [37,38]. Similarly, the standard time (ST) is estimated, considering the constant and variable allowances recommended by the International Labor Organization (ILO). As for the study of motion, efficient and inefficient therbligs are analyzed, which are performed by the operators, therefore, the information is used to build the bimanual process chart. The inefficient therbligs must be removed since they cause bottlenecks. In this sense, the present motion study helped to determine which manual tools operators use more frequently and to place them at a closer distance from employees when redesigning the workstation [37].

The following task at this stage involves line balancing, which is concerned with assigning tasks within an assembly line to meet the required production rate for optimization purposes [39]. To this end, a cost per unit analysis was performed as follows: describe the tasks of each work cycle, convert time to decimal format, define the number of operators required by workstation, and estimate the totals required by line. Additionally, the time in the line was estimated, as well as the balancing percentage in each production line, the adjusted work cycle, and the production per hour, shift, and department. Subsequently, the approximate number of parts produced per operator and the production costs per unit were calculated. Next, a possible work sequence in which the tasks can be performed to maintain similar times across all the proposed workstations was defined. In addition, both efficiency and takt time in each line were determined. Finally, the number of operators required for each production line that can fulfill the needed demand was calculated.

The last step at this stage involved redesigning the workstations. Specially, the bimanual process chart developed earlier at this stage was used. Then, an anthropometric study among the women operators to define both minimal and maximum reach zones was performed. The 5th percentile forearm-length and stretched-arm-length was used, as well as the 95th-percentile shoulder-length [40]. Next, the workstations were redesigned, specifying the position of the minimum and maximum reach zones, where the work area represented the operators' back width. Further, the location of the manual tools in the workstations according to their frequency of use was determined. Finally, experimental runs with the same studies on time and motion used earlier at the stage were performed, as well as a cost per unit analysis and a comparison of the results. In order to confirm the validity of the method from the authors of this research, one of the production lines kept the original method during seven days for comparative purposes.

2.3. Stage 3. Visual Standardization of Workstations

This stage assumes that the data analysis from production lines is finished, and that a new method is ready to be applied. The goal at this stage is to give visual support to the proposed method, where the main tasks are:

- Make process flowcharts for the redesigned process
- Create visual aids for operators
- Design new templates for the workstation

At this stage, several flow charts were developed regarding the new method in order to visually represent the standardization in the production process. The charts were used to illustrate the precise work sequence of the tasks that must be performed at some time, as it was estimated in the bimanual progress chart. Then, visual aids for each workstation were created, which include photographs taken from tasks to highlight the fundamental points of them, as well as indicate the manual tools needed for each task. It is worth mentioning that the visual aids were developed by considering the creativity and criteria of the authors as analysts, therefore, paying attention to aspects, such as simplicity, clarity, visibility, and straightforwardness to ensure that they have an appropriate support acceptance from operators.

The last step at this stage involved making design templates for the workstations in order to indicate the positions of the manual tools, as well as help the operators place these tools by themselves. The templates were used to ensure that the process at each workstation runs smoothly and without bottlenecks. The templates were designed in real size, using pictures from workstations and bimanual progress chart, which were designed to remain in one side of the corresponding workstation.

2.4. Stage 4. Implementation of Standardized Work in the Production Lines

This stage is aimed to implement a new method as well as standardized work in the production lines. Once the new workstation design and the visual aids were ready, then the following task is done:

- Implement standardization proposal in production lines.

At this stage, the obtained results were compared with the initial goals to determine whether or not they were attained. If the method proves to be effective, the production lines are installed with the new production method, and the redesigned workstations are installed along with their corresponding visual aids and designed templates.

3. Results

3.1. Research Problem

In order to demonstrate the importance of SW, a case study conducted in a publishing company is presented, which employs 150 workers and has an operational infrastructure that comprises both mechanical tasks and manual tasks. The mechanical tasks are pre-press, printing, stapling, binding, and cutting, among others, whereas the manual tasks comprise of folding, collating, and box assembly. The main services that the company offers are the printing and publishing of manuals, box assembling, and packaging, which account for 70% of the company operations. The remaining 30% include the manufacturing of labels, file folders, magazines, books, and catalogues. The company has six major departments: Editing, Pre-Press, Machine Works, Manual Works, and Box Assembly.

It was found that the assembly lines in the Box Assembly department experience at least one of the following undesirable events: bottlenecks, production delays, late product deliveries, payment of extra hours to workers, unnecessary movements when employees perform their tasks, and high costs due to unbalanced production lines. Therefore, the costs per unit increase, and the corporation's image is adversely affected by its inability to fulfill the demand. Box assembly is the last stage of the production process, before the final product is sent to the customers, however, the company is often unable to fulfill the demand on time. The overall goal of this research is to increase the corporation's production rate and improve the employees' performance through the standardization of the production process of box model A in the box assembly department. Similarly, the three specific objectives of the research include increasing production levels by 20%, reducing the standard time by at least 15%, and reducing costs per unit by 40%.

This research is conducted in the box assembly department, but it does not include the product packaging stage, since there are no production problems in different models. The production process comprises four assembly lines, and each line is run by five operators, a quality inspector, and a packing operator as it appears in Figure 1.

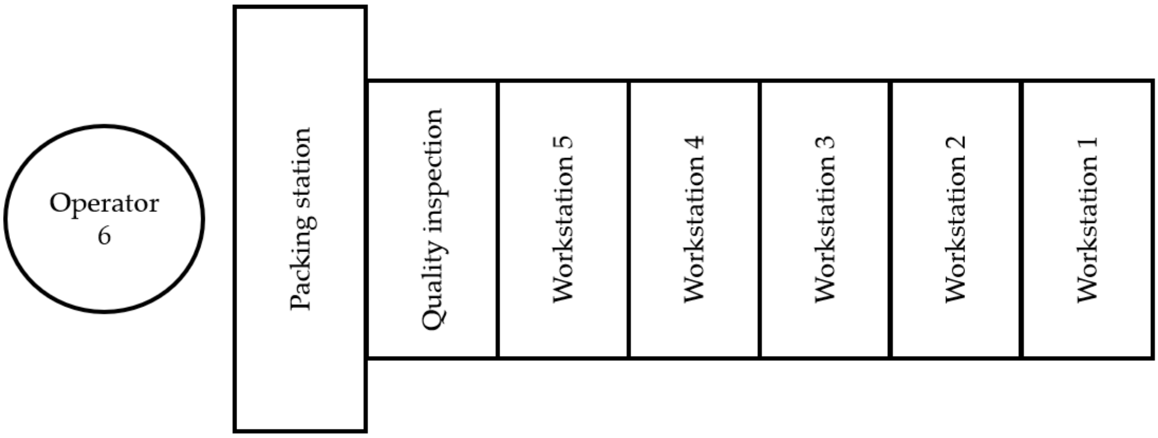

Figure 1. Current layout distribution for an assembly line.

Figure 1. Current layout distribution for an assembly line.

The company offers an array of services to its customers, yet it shows multiple opportunities for improvement, such as increased production, more on-time deliveries, better inventory handling, and the implementation of visual aids, among others. The most common box model that is manufactured is the model A.

Notably, one line produces an average of 3500 units daily, yet the demand is of 3750 units daily, which is equivalent to one day and a half of extra work (see Table 1). Unfortunately, extra hours involve higher production costs and sometimes, employees report fatigue and back pain due to long working hours.

Table 1. Difference in production and equivalence in extra work time.

	Difference in Production	Equivalence in Extra Work Hours	Equivalence in Extra Work Days
Day	300	33.33	3.7
Week	1750	194.44	21.6
Month	7000	777.77	86.41

Table 1. Difference in production and equivalence in extra work time.

3.2. Results at Stage 1. Collect the Analyzed Data

After defining the problem with the information in Table 1, at this stage, a flow chart is developed with the corporation's current production system, as it is displayed in Figure 2, where in order to have a better understanding about the manufacturing process of model A, a brief description of the operations required are given.

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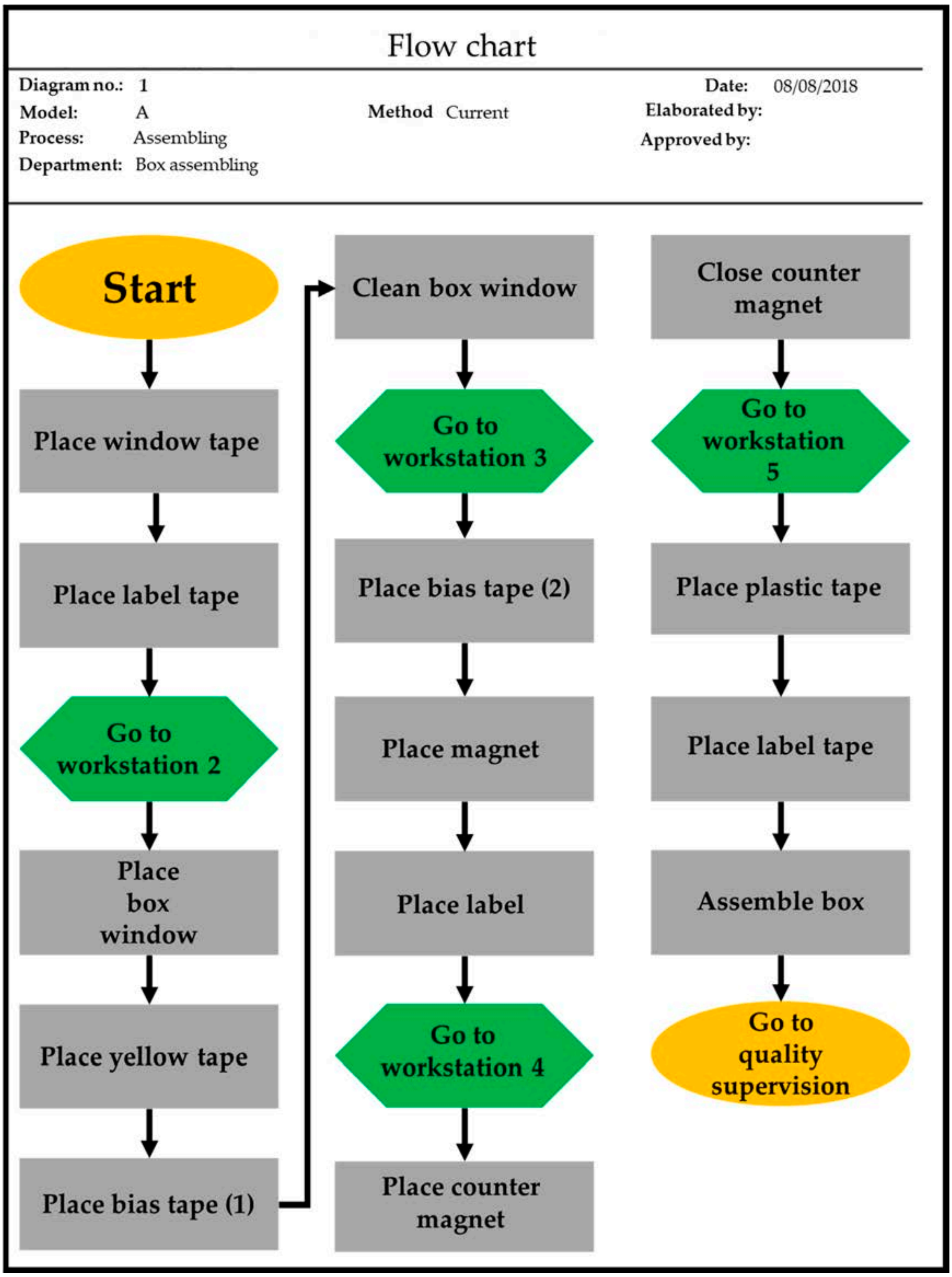

Figure 2. Flow chart of the corporation current production process.

Figure 2. Flow chart of the corporation current production process.

The operators at workstation 1 take the item on their right side and place it in front of them as they place a small strip of double-sided tape on the back of the box, where a label with the client's name is included later. Next, the operator places four double-sided tape strips on the contour of a quadrangular perforation, which are then removed, leaving the rubber on display. Finally, the item is sent to workstation 2.

At workstation 2, the operators place a double-sided tape strip bending to the side of the box. Subsequently, they place a strip of double-sided mustard tape, and a quadrangular plastic in the rubber, exposing the tape strips placed in workstation 1. Finally, the operators clean the plastic with a cotton ball dipped in alcohol to remove fingerprints and pass the piece to workstation 3.

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At workstation 3, the operators take the item and remove the cover of the double-sided label tape placed in the workstation 1. Subsequently, the label is placed with the customer's name. Next, another double-sided fold tape is placed. In addition, they also place two positive magnets in the openings that are in the quadrangular shaped plastic. Next, the magnets are covered with black tape strips and the item is sent to workstation 4.

At station 4, the operators take the item and remove the counter of the mustard tape and the two-bending tape. Next, two counter magnets are placed on the bottom and top of the box. Subsequently, the box is folded to glue the lid, and the item is sent to workstation 5. Finally, the operators at workstation 5 take the item and place a double-sided tape (NITO) in the base of the box. Afterwards, double-sided tape is placed on a tab of the box, and then removed. Then, a tab is glued to the other side of the box to shape it. Then, the item is sent to the quality station.

3.3. Results at Stage 2. Study Time and Motion in Workstations

Table 2 lists the information about the performance factors and allowances assigned to each original workstation. For example, in the case of performance factors, the clearance of the skill factor for workstation 1 (operator 1) was 0.06, which indicates that the operator had good skill and ability. In the case of the effort factor, a clearance of 0.03 was obtained in workstation 1, which indicates that the operator made a good effort to reach the production goals. The same procedure is applied to the other slacks of the other factors for each workstation. In the last row, the slack scores are added for each workstation, and a 1 is added and the total is obtained. The same procedure is applied to obtain the constant and allowance variables.

Table 2. Performance factors and allowances in original workstations.

Performance Factors					
Item	Workstation 1	Workstation 2	Workstation 3	Workstation 4	Workstation 5
Skill	0.06	0.03	0.02	0.03	0.03
Effort	0.03	0.02	0.03	0.02	0.02
Consistency	−0.02	0.01	−0.03	−0.03	−0.02
Conditions	−0.03	−0.03	0	−0.02	−0.03
Total	1.04	1.03	1.02	1.0	1.0
Constant and variable allowances					
Item	Workstation 1	Workstation 2	Workstation 3	Workstation 4	Workstation 5
Personal	0.05	0.05	0.05	0.05	0.05
Basic fatigue	0.04	0.04	0.04	0.04	0.04
Standing allowance	0.02			0.02	
Fine work		0.02			
Total	1.11	1.11	1.09	1.11	1.0

Table 3 shows the estimated observed time (OT), the normal time (NT), and the standard time (ST). ST in workstations 3 and 4 reported a difference of 17 and 35 s, respectively, where the shortest ST was also found (workstation 5). The sum of all STs is equal to 4.07 min for the original production lines. The NT and the ST were obtained using the Equations (1) and (2) [37].

$$\mathrm{NT} = (\sum Performance\ factors + 1) \times \mathrm{OT} \quad (1)$$

$$\text{ST} = \sum (\textit{Constant and variable allowances} + 1) \times \text{TN} \quad (2)$$

Table 3. Time estimated in original workstations.

Time (Seconds)	Time per Workstation				
	Workstation 1	**Workstation 2**	**Workstation 3**	**Workstation 4**	**Workstation 5**
Observed time (OT)	37	36	48	64	36
Normal time (NT)	38	37	49	64	36
Standard time (ST)	43	41	53	71	36

Table 4 summarizes the results of the motion analysis. In fact, 230 inefficient therbligs were identified and 33 were detected in the number 9 task (i.e., placing plastic tape), consequently, it is the task with the greatest number of inefficient motions. On the other hand, Table 5 summarizes the results on the cost per unit, that is, a line balancing analysis of the original assembly line with five operators. As it can be observed, the total production time for a box of Model A is 4.12 min and the control cycle is 1.18 min. Hence, it corresponds to the highest time among the operation times. The time in line is 5.92 min, which represents the product of multiplying the control cycle by the number of operators (5 in this case). The assembly lines are balanced in 70%, and the cost per unit is of $1.39 Mexican pesos (i.e., $0.072 USD). Equations (3)–(9) were applied to complete Table 5 [41].

$$Balancing\ percentage = \frac{Total\ \sum}{Time\ in\ line} \times 100 \quad (3)$$

$$Adjusted\ work\ cycle = \frac{Control\ cycle}{Balancing\ percentage} \times 100 \quad (4)$$

$$Production\ per\ hour = \frac{60\ minutes}{Adjusted\ work\ cycle} \quad (5)$$

$$Production\ per\ shift = \frac{Units}{Hour} \times \frac{Hours}{Shift} \quad (6)$$

$$Production\ per\ department = Production\ per\ shift \times Number\ of\ assembly\ lines \quad (7)$$

$$\frac{Units}{operators} = \frac{Units\ per\ shift}{Total\ operators} \quad (8)$$

$$Cost\ per\ unit = \frac{Total\ operators \times Daily\ salary}{Units\ per\ shift} \quad (9)$$

On the other hand, Table 5 summarizes the results on the cost per unit, that is, a line balancing analysis of the original assembly line with five operators. As it can be observed, the total production time for a box of Model A is 4.12 min and the control cycle is 1.18 min. It corresponds to the highest time among the operations times. The time in line is 5.92 min, which represents the product by multiplying the control cycle by the number of operators (5 in this case). The assembly lines are balanced in 70%, and the cost per unit is of $1.39 Mexican pesos (i.e., $0.072 USD).

Following these results, this study determined that tasks 1, 7, 8, 9, 10, and 11 (see Table 4) could be performed at the same time before the remaining tasks. Similarly, it was further concluded that before task 14 is performed, the first 13 tasks must be completed. These results were used along with the report of each positional weight of the tasks (obtained after estimating the cycle times of tasks) to make a new distribution of the box assembly process across only four workstations, as displayed in Table 6. It means that the length of a production line can be reduced by rebalancing the assembly line, because of the new times in tasks [42]. Moreover, with this new distribution, the greatest difference of time between the two tasks is eight seconds, consequently reducing the gap by 27 s if compared to the original distribution of the process.

Table 4. Inefficient therbligs in original work method.

Task	Description	Left Hand	Right Hand	Total
1	Place window tape	8	9	17
2	Place box window	7	1	8
3	Clean box window	12	6	18
4	Place magnet	0	5	5
5	Place black tape	13	6	19
6	Place opposite magnet	4	4	8
7	Place bias tape	12	12	24
8	Place yellow tape	12	12	24
9	Place plastic tape	10	23	33
10	Place flap tape	10	15	25
11	Place label adhesive	8	5	13
12	Place label	10	4	14
13	Close opposite magnet	4	3	7
14	Assemble box	9	6	15
	Total			230

Table 5. Cost per unit—line balancing analysis results.

Workstation	Description	Time	Min	Operators
			0:01:00	
1	Place double-sided tape	0:00:42	0.7	1
2	Place box window, yellow tape, and bias tape	0:00:41	0.68	1
3	Place magnet, bias tape and label, and clean box window	0:00:53	0.88	1
4	Place opposite magnet and close	0:01:11	1.18	1
5	Place flap tape and plastic tape, assemble box	0:00:40	0.67	1
Total Σ		0:04:07	4.12	5
	Control cycle		1.18	
	Number of operators		5	
	Time in line		5.92	
	Balancing percentage		70%	
	Adjusted work cycle		1.7	
	Production per hour		35	
	Production per-shift		318	
	Production per department		1588	
	Units/Operators		64	
	Cost per unit		$1.39	

Table 6. Redesign of activities for the box assembly process.

Workstation 1		Workstation 2		Workstation 3		Workstation 4	
Place bias tape	(16)	Place windowtape	(43)	Place box window	(31)	Place opposite magnet	(8)
Place yellow tape	(8)	Place plastic tape	(8)	Place magnet	(8)	Close opposite magnet	(35)
Place flap tape	(7)			Place plastic tape	(8)	Assemble box	(16)
Place label adhesive tape	(8)			Clean box window	(4)		
Place label	(14)						
Total	53		51		51	59	

The numbers in the parentheses indicate time in seconds for each operation.

Figure 3 displays the redesigned workstations, where (A) illustrates the overall proposal, whereas (B), (C), (D), and (E) represent the individual redesigns for workstations 1, 2, 3, and 4 with their respective locations of the parts and tools. The findings indicate that ST estimated in the production line was 3.32 min, that is, 45 s shorter than the original ST (i.e., a time reduction of 18%). Table 7 lists the time estimations in each new workstation, and as it can be observed, the difference in time between two workstations is not over six seconds.

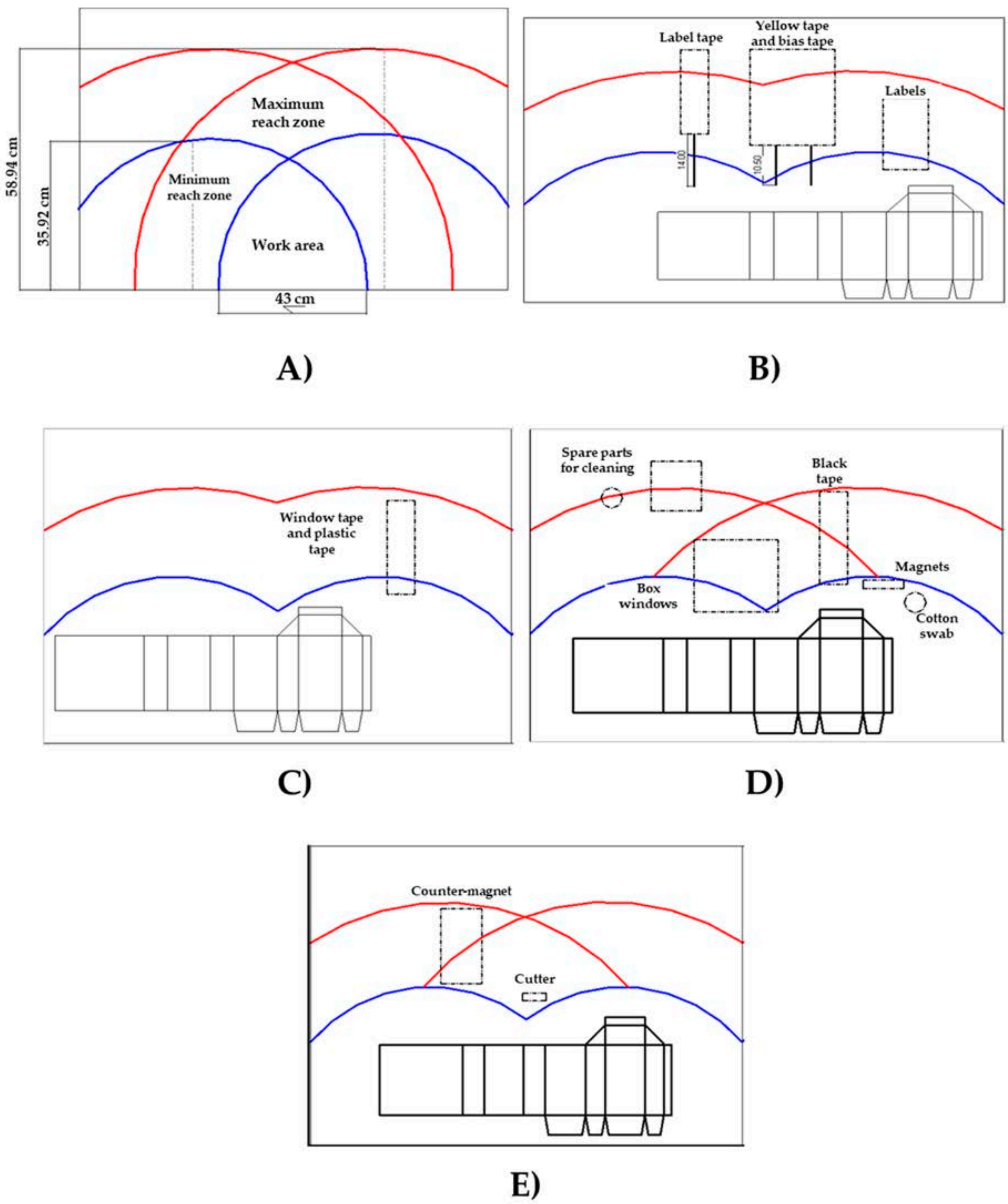

Figure 3. Workstation designs: (**A**) Overall design, (**B**) Workstation 1, (**C**) Workstation 2, (**D**) Workstation 3, (**E**) Workstation 4.

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Table 8. Inefficient therbligs in the redesigned process.

Workstation	Task	Left Hand	Right Hand	Total
1	Place bias tape Place yellow tape Place flap tape Place label adhesive tape Place label	20	9	29
2	Place window tape Place plastic tape	17	7	24

Table 7. Time estimations for the redesigned process.

Time (Seconds)	Time per Workstation (Seconds)			
	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Observed time (OT)	48	43	48	47
Normal time (NT)	47	42	47	47
Standard time (ST)	51	46	51	51

Regarding the time analysis in the redesigned process, only 78 inefficient therbligs are found, thus representing a reduction of 66.1% if compared to the original process. Table 8 summarizes the obtained results, and as it can be observed, the highest rate of inefficient motions was found in task 1.

Table 8. Inefficient therbligs in the redesigned process.

Workstation	Task	Left Hand	Right Hand	Total
1	Place bias tape Place yellow tape Place flap tape Place label adhesive tape Place label	20	9	29
2	Place window tape Place plastic tape	17	7	24
3	Place box window Place magnet Place plastic tape Clean box window	6	9	15
4	Place opposite magnet Close opposite magnet Assemble box	8	2	10
Total		51	27	78

Table 9 summarizes the results of the cost per unit and the line balancing analysis performed to the redesigned process. It is essential to notice that line balancing increased from 70% to 97%, and as a result indicates that production can flow smoothly and without bottlenecks. Similarly, the cost per unit decreased by 58.27%, that is, from $1.39 to $0.58 Mexican pesos (i.e., from $0.072 to $0.030 USD).

Table 9. Results of cost per unit—line balancing analysis in the redesigned process.

Workstation	Description	Time	Min / 00:01:00	Operators
1	Place yellow tape, bias tape, flap tape, and label adhesive, and place label	00:00:51	0.86	1
2	Place window tape and plastic tape	00:00:46	0.76	1
3	Place box window, magnet, and plastic tape and clean window	00:00:51	0.86	1
4	Place and close opposite magnet, assemble box	00:00:51	0.86	1
Total Σ		00:03:19	3.32	4
	Total minutes per operator		3.32	
	Control cycle		0.86	
	Number of operators		4	
	Time in line		3.44	
	Balancing percentage		97	
	Adjusted work cycle		0.89	
	Production per hour		67	
	Production per shift		606	
	Production per department		3030	
	Units/operators		152	
	Cost per unit		0.58	

3.4. Results at Stage 3. Apply Visual Standardization in Workstations

At this stage, visual aids and templates were generated for the redesigned workstations. The headings of the visual aid forms included the following information: department name, production line number, workstation number, task name, box model, sheet number, issue date, and last-reviewed date. Similarly, the right side of the form includes important information on the task to be performed. This information is not part of the directions, yet they remind operators about the importance of the details of each task. Below the details section, all visual aids must list the tools that are necessary in the task. In this sense, the operators must make sure that they have all the materials and tools in place before starting to perform a task. Below the material section, visual aids include information to be completed by those who develop the visual aids. The visual aids also contain a picture of each step for the tasks. Next, the operators are asked to perform the steps, one by one, while a picture is taken. In addition, the photographs must be as neat as possible and must clearly illustrate what the operator must do at a particular step. Further, close attention was paid to writing clear and concise descriptions on how each task step is to be performed. A description is related to each image in the aid, but it is not overloaded with information, since the pictures are the key for the aids. Finally, each step of a task was numbered to establish a precise and logic sequence of work events, and therefore, prevent errors and confusions. In total, six visual aids were developed: workstations 1 and 2 were installed with one visual aid each, whereas workstations 3 and 4 were installed with two aids each. Figures 4 and 5 present two examples of the visual aids that were developed.

Figure 6 illustrates the flowchart process of the redesigned steps. As it can be observed, the methodology proposes a 16-task process with a total time of 144 s. Notice that tasks 4 and 5 are performed before the box assembly process or when there is no demand for box model A. This allows the operators to have several parts (e.g., labels and corresponding adhesive tape) ready before initiating the box assembly process. Further in Figure 6, the green rectangle delineates the tasks of box assembly. The tasks from workstations 1, 2, 3, and 4 are marked in red, blue, black, and yellow rectangles, respectively. A processing time of 197 s was found, yet 15 min from tasks 4 and 5 were deduced, consequently, the estimated OT was 182 s. This is a value that is close enough to what is shown in Table 7 (i.e., 186 s).

	VISUAL AID					**Page:** 1 de 6 **Date:** 16/10/2018 **Review date:**
	Departament	**Line**	**Workstation**	**Task**	**Model**	**Part Number**
	Box Assembly	1	1	Taping and labeling	A	

1. Place label tape
Cut a 5cm strip of tape, place it on box slot, remove protective film with the cutter.

2. Place yellow tape
Cut the neccesary yellow tape and place it on the middle of the box back.

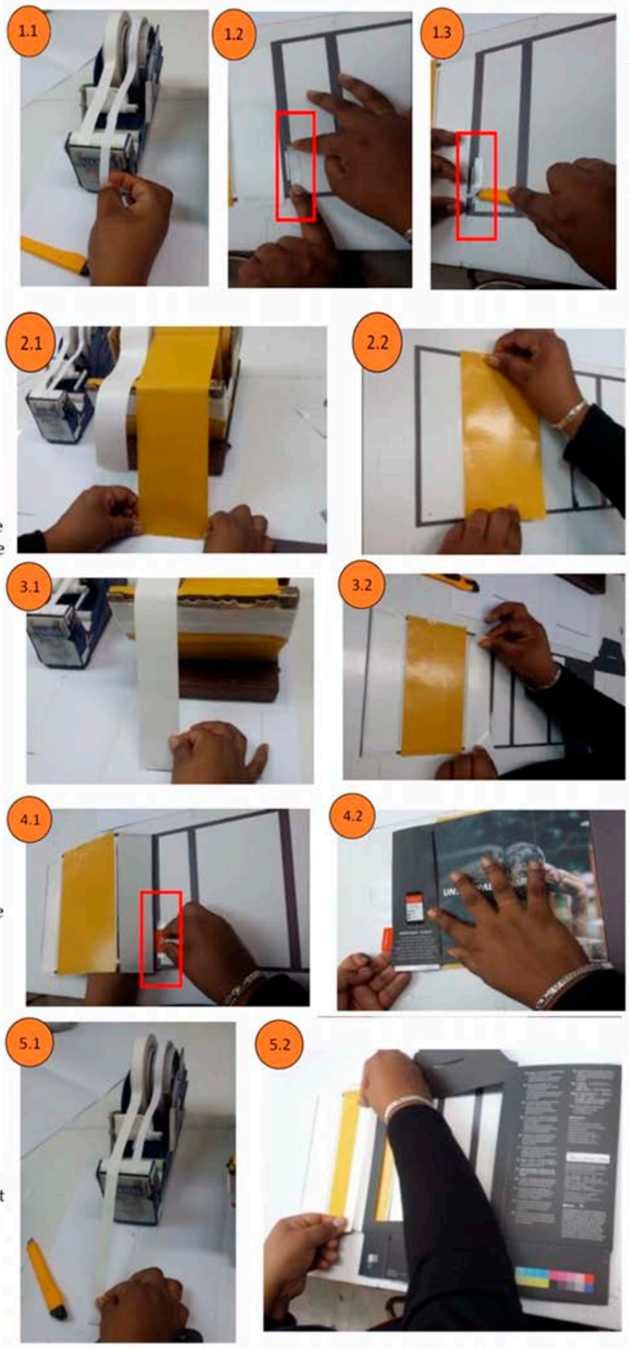
3. Place bias tape

Cut 2 strips of bias tape and place them on both ends of the yellow tape strip.

4. Place label
Lift box bottom, place label from the inside out on label tape.

5. Place flap tape
Fold box inward, cut flap tape strip, place it in the corresponding place.

Once finished, go to workstation 2.



IMPORTANT
1. When cutting tape strips, consider 3-5 mm excess on both sides.
2. Only place label at the end of the task.
3. The label must be properly aligned to the center of the box.

Materials:
Flap tape
Yellow tape
Bias tape
Label tape
Label
Cutter

Elaborated by:

Name and signature

Reviewed by:

Name and signature

Approved by:

Name and signature

Figure 4. Visual aid for the redesigned workstation 1.

Figure 4. Visual aid for the redesigned workstation 1.

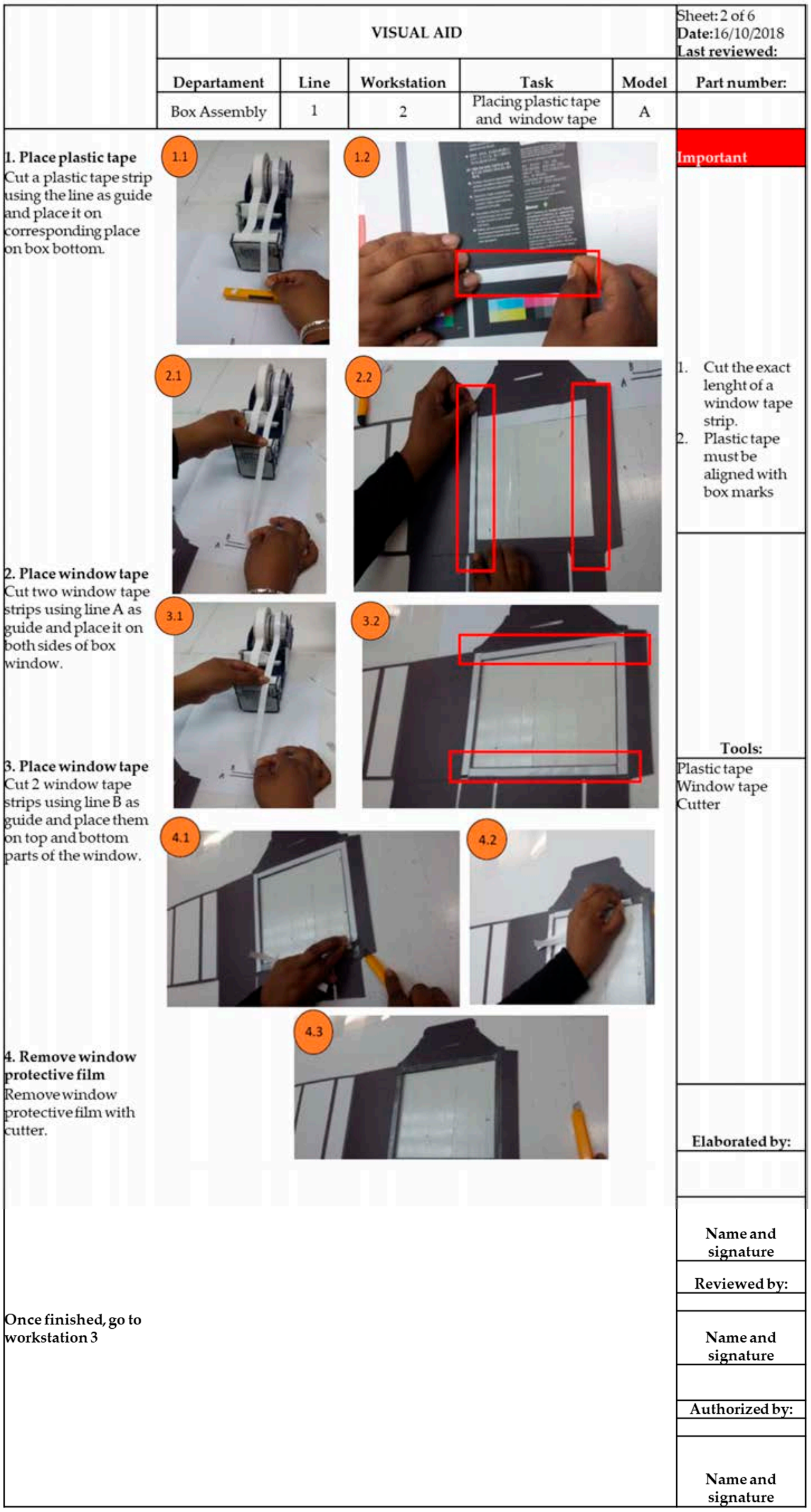


Figure 5. Visual aid for the redesigned workstation 2.
Figure 5. Visual aid for the redesigned workstation 2.

the operators to have several parts (e.g., labels and corresponding adhesive tape) ready before initiating the box assembly process. Further in Figure 6, the green rectangle delineates the tasks of box assembly. The tasks from workstations 1, 2, 3, and 4 are marked in red, blue, black, and yellow rectangles, respectively. A processing time of 197 s was found, yet 15 min from tasks 4 and 5 were deduced, consequently, the estimated OT was 182 s. This is a value that is close enough to what is shown in Table 7 (i.e., 186 s).

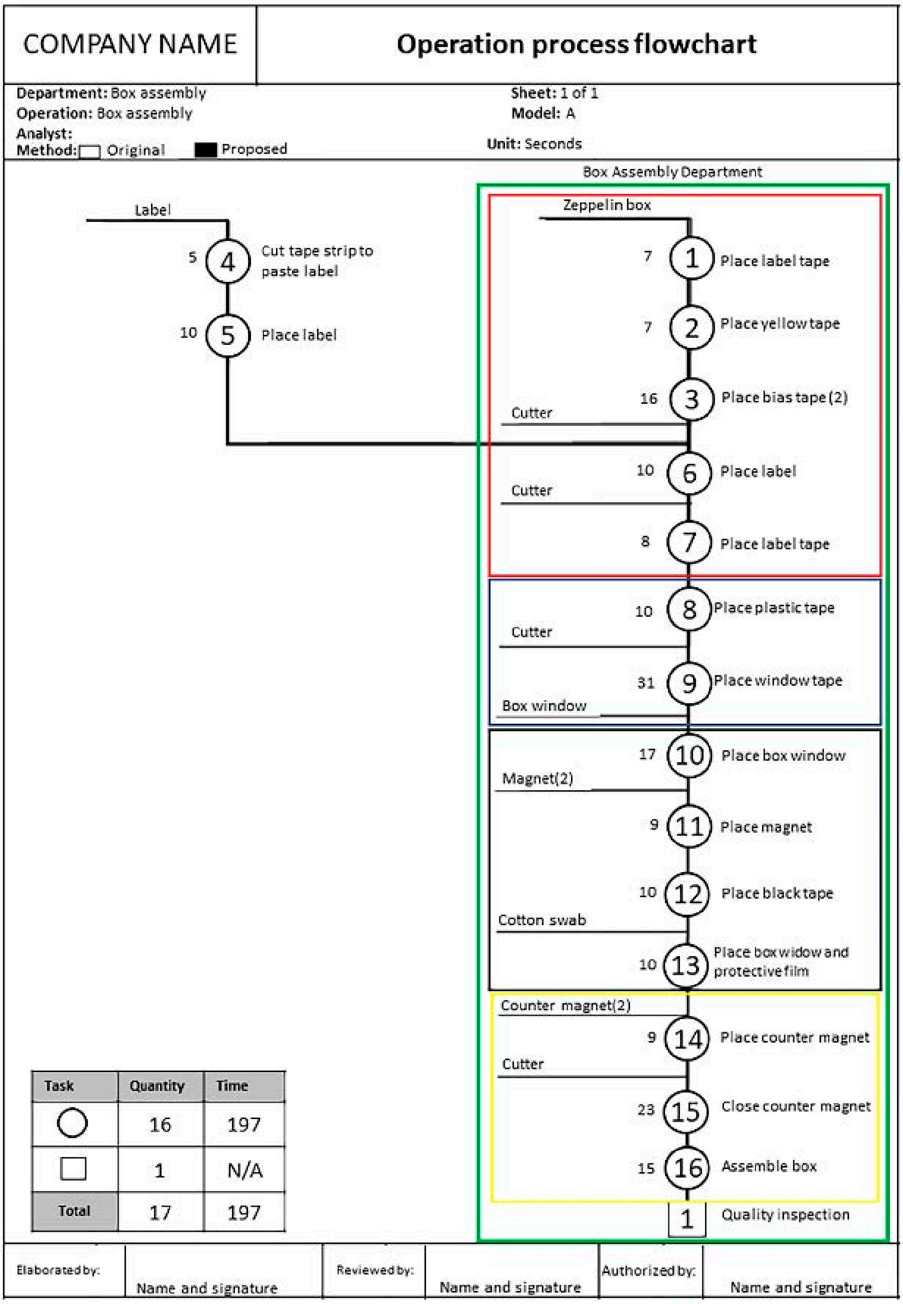


Figure 6. Flowchart process of the redesigned process.

3.5. Overall Results

Once the production process was standardized, four assembly lines with four operators each were monitored for one week to assess the production increment. The first three assembly lines worked under the redesigned process, whereas the fourth line operated under the original methodology. As Table 10 indicates, a significant increase of production in assembly line 3 was identified, where 2971 units were assembled, that is, 1158 units more than in production line 4 (i.e., the old methodology). Figure 7 visually presents such results.

worked under the redesigned process, whereas the fourth line operated under the original methodology. As Table 10 indicates, a significant increase of production in assembly line 3 was identified, where 2971 units were assembled, that is, 1158 units more than in production line 4 (i.e., the old methodology). Figure 7 visually presents such results.

Table 10. Comparison of production increase: Original methodology versus new methodology.

Assembly Line	Operators	Daily Production					Total
		Monday	Tuesday	Wednesday	Thursday	Friday	
1	4	549	570	595	613	615	2942
2	4	555	578	610	609	611	2963
3	4	547	584	614	614	612	2971
4	5	340	359	380	374	360	1813

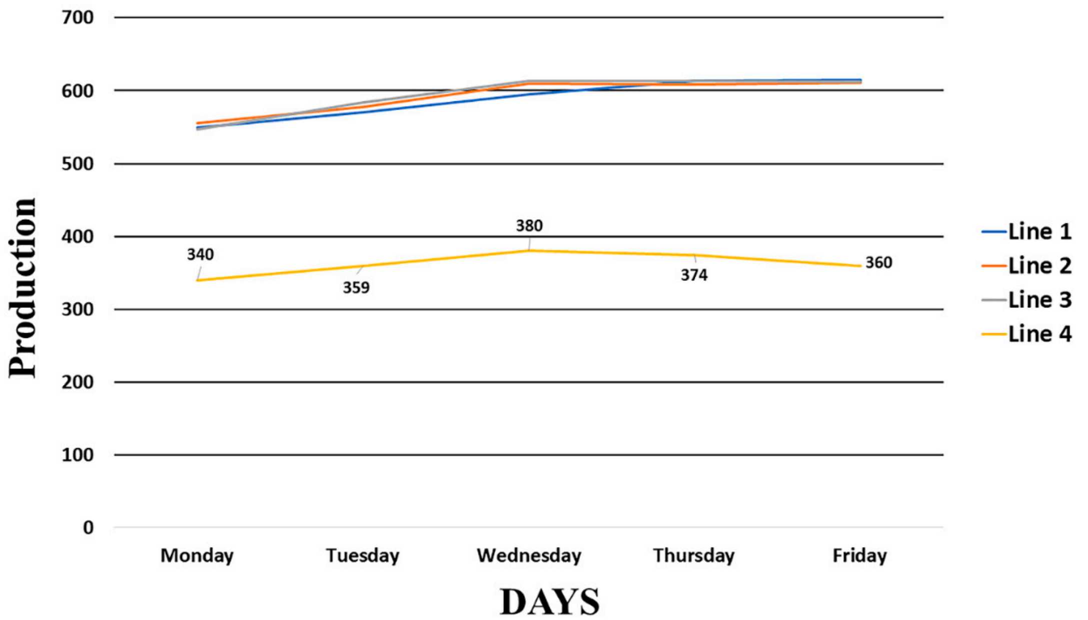


Figure 7. Comparison of production increase: Original methodology vs. new methodology.

As a matter of fact, with the five assembly lines working fully under the redesigned process, the company reported a production increment of 42.62%. Further, by running five assembly lines instead of four, the company increased production by 45.9%. More specifically, the company increased on average their daily production from 1400 to 3050 units, which represents an increment of 1650 units. Table 11 summarizes the results of this analysis.

Table 11. Production increase analysis.

	Original Methodology	New Methodology	Production Increase	Increase Percentage
Production per line	350	610	+260	+42.62%
Total production	1400	3050	+1650	+45.9%

Finally, it is crucial to mention that in the records of the company, there are no injuries and illnesses reported from the operators from the box assembling area, however, they did show pain in the arms, back and legs, in addition to physical fatigue. This is due to the positions they were forced to adopt with the original design of the workstations and the exposure time (working hours plus extra time). The anthropometric redesign of the workstations, as well as the work method, would positively affect the health and safety of the operators. In the specific case of the anthropometric design of workstations, this would prevent the operators from adopting uncomfortable body postures [43]. On the other hand, the redesign of the working method eliminates repetitive movements and according to the literature review, uncomfortable body postures and repetitive movements are the cause of musculoskeletal disorders (MSDs) [44]. Thus, with the new working method, the operators can be prevented from suffering from MSDs or from suffering physical fatigue by eliminating overtime.

4. Conclusions

The basic industrial engineering tools can have a significant impact on the performance of SMEs, since larger firms compete on international markets, which usually rely on expensive AMT. Moreover, basic industrial engineering tools help SMEs save costs, fulfill demand on time, and increase competitiveness. A proper analysis of the production process in aspects, such as timing, motions, workstation design, and task sequence can lead to changes that promote great results. The standardized work (SW) technique, combined with line balancing is an effective tool for minimizing waste, such as delays on deliveries and over-processing. In addition, an analysis of worker motions and anthropometric studies are effective techniques for redesigning workstations, and as a result, reduce the number of inefficient therbligs. In fact, in the present case study, inefficient motions were reduced by 66%, that is, from 230 to 78, while standard time decreased from 244 to 199 s, that is, by 18.44%.

The results also demonstrate that, when work is standardized, fewer operators are required per assembly line. This is an opportunity for companies to optimize human recourses by installing new assembly lines with the other operators, and consequently, increasing production at a much higher rate. In the present case study, the number of operators decreased by 20%, that is, from five to four operators. As a result, the company installed one more assembly line. Finally, the present findings allow the conclusion that both the implementation of SW and line balancing have a positive impact on the balancing percentage, which in turn helps minimize costs per unit and increase demand fulfillment rates. Notably in this case study, the balancing percentage rose from 70% to 97%, whereas production increased by 63.2%, that is, 229 units per assembly line per day. Therefore, the case study shows that SW and line balancing can have a positive impact for many SMEs in the manufacturing sector. Further, the present findings are consistent with those reported by Mor et al. [19], Rahul and Kaler [45], More et al. [21], Bhardwaj et al. [46], Mor et al. [47], and Garg et al. [48], where simple techniques have been implemented among SMEs to promote greater production and efficiency. As a practical value, these results, as well as the method and techniques applied, can be used as an improvement reference by SMEs in massive production processes with multiple operators. However, there is no practical value to those production processes where each produced unit is customized according to the requirements of a specific customer, since there is no specific production process for all units, and therefore, work standardization is not possible.

Finally, it is important to mention that this standardization process was applied to only one production line for assembling a specific box model. However, there are several processes in this company that can be standardized, hence, future research must be focused on other box models and other production areas, such as book production line or stamping lines. Moreover, in this case study, topics such as the production level, product demand, customers' complaints, among others, can be explore further. Further, as mentioned before, this case study is part of a project of the manufacturing processes' improvement. Therefore, more companies (most of them categorized as big) can participate, and more problems can be analyzed, more tools and techniques can be developed, applied and refined. Further, more results can be obtained that support the impact industrial engineering tools have in manufacturing processes.

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Anexo II

Artículo:

Improving a Manufacturing Process Using the 8Ds Method. A Case Study in a Manufacturing Company

applied sciences

MDPI

Article

Improving a Manufacturing Process Using the 8Ds Method. A Case Study in a Manufacturing Company

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Featured Application: The present case study reports the 8D technique applied to a real manufacturing production process. Future applications can be adapted to other manufacturing industries by integrating the most important variables in their own contexts.

Abstract: Customer satisfaction is a key element for survival and competitiveness in industrial companies. This paper describes a case study in a manufacturing company that deals with several customer complaints due to defective custom cable assemblies that are integrated in an engine. The goal of this research is to find a solution to this problem, as well as prevent its recurrence by implementing the eight disciplines (8Ds) method in order to: (1) develop a team, (2) describe the problem, (3) develop an interim containment action, (4) determine and verify root causes, (5) develop permanent corrective actions, (6) define and implement corrective actions, (7) prevent recurrences, and (8) recognize and congratulate teamwork as well as individual contributions. Therefore, a software tool is proposed to conduct a functional test on assembly lines. After the test, the problem was successfully reduced and detected, because from 67 engines that were identified with problems, 51 were redesigned before being sent to customers, consequently decreasing the number of defective products by 75%, whereas the remaining 16 engines were replaced by new engines. In conclusion, the research goal was accomplished, and the 8Ds method proved to be a helpful model with which to increase employees' motivation and involvement during the problem-solving process.

Keywords: 8 disciplines method; custom cable assemblies; defects; functional test; customer satisfaction

1. Introduction

In manufacturing industries, waste refers to the activities that consume resources but that do not directly add value to the product or service for the customer [1]. According to the literature review, there are seven categories of waste in manufacturing that negatively affect the quality of products, delivery times, and unit cost [2,3]. These wastes are overproduction, inventory, over-processing, motion, waiting, transport, and defects [4,5]. Regarding the defects, during the manufacturing processes, companies receive material or components from their suppliers. Then, those materials or components are changed to obtain a final product, which must be delivered to customers on time and without defects [6]. However, defects continue being present in the manufacturing industry nowadays. In fact, several authors mention that defects are the main cause of damages in final products or other components [7–10], which represent a critical situation for the industrial and manufacturing sector [11].

Moreover, customer satisfaction is a requirement that must be considered for any distributor business that is intending to remain globally competitive [12,13]. Nevertheless, if managers want to fulfill customer needs, an appropriate product design process must be included [14]. In this sense, one of main customer needs is a non-defective, quality product [15], since product defects lead to customer dissatisfaction, sales decreases, low financial profits, and greater unit costs [16,17]. In order to improve the effectiveness and efficiency of the production process, offer quality products, and avoid the latest problems, manufacturing companies rely on a wide range of methods and techniques for production improvement [18], including the six sigma management philosophy, DMAIC (i.e., define, measure, analyze, improve, and control) [19], process flow charting (PFC) [20], the Deming or PDCA cycle (i.e., plan, do, check, act) [21,22], and the eight disciplines (8Ds) method [23], among others.

Specifically, the 8Ds are focused on: (D1) develop a team, (D2) describe the problem, (D3) develop an interim containment action, (D4) determine and verify root causes, (D5) Choose/verify permanent corrective actions, (D6) implement and validate corrective actions, (D7) prevent recurrences, and (D8) recognize and congratulate teamwork as well as individual contributions, which is a powerful method because it helps with creating appropriate activities in order to identify the root causes of a problem, and provides permanent solutions to eliminate them. In addition, the 8Ds method is a special tool of ISO/TS 16949:2009 that has been broadly applied in automotive industry for service, including the issues concerning supplier qualification confirmation, process deviations, maintenance, customer complaints, and purchases.

The 8Ds method has been adopted widely in the manufacturing world [24]. For instance, several authors have applied it to solve problems of defects. Some of these authors are: Mitreva et al. [25], who applied it for solving a problem in a LED diode that does not perform its function in a circuit board. Likewise, Titu [26] implemented the 8Ds method to reduce complaints about a defective part; consequently, 60 days after corrective actions were implemented, no other product was identified with this type of defect, and customers decided to withdraw the complaint. Additionally, Kumar and Adaveesh [24] conducted a study in a spring and stamping manufacturing plant for solving a high rejection rate (i.e., 17.07%) of valve springs due to defects. In order to solve this problem, the 8Ds method was applied, and as a result the rejection rate decreased significantly in 6 months, by 4.91%.

Research Problem

A maquiladora is a factory that operates under preferential tariff programs established in Mexico that has headquarters in other countries and performs assembly operations with high hand labor required. Materials, assembly components, and production equipment used in maquiladoras are allowed to enter Mexico duty-free. Currently, in Mexico there are 5144 maquiladoras giving 2,678,633 direct jobs. However, Baja California state has 914 (17.76% from national) maquiladoras giving 333,392 direct jobs [27].

Those companies are using several techniques and methodologies for solving manufacturing problems in production lines. This paper reports a case study applied in a manufacturing company located in Tijuana, Mexico, dealing with the manufacturing of electric custom cables. Each cable is tested for quality through a series of computer-assisted programs for a complete inspection. This strategy allows the company to build and maintain long-term relationships with its customers, thereby helping the company reach its goals and be successful. However, the company has lately experienced problematic defects; as a result, customers are complaining due to 67 returned assemblies.

The problem concerns a stepper motor (see Figure 1), one of the main assembly components, which has a part number that will be called part number A. Customers provide the motors to the company, which introduces them into the production process; next, the motor cables are cut at a specific experienced problematic defects; as a result, customers are complaining due to 67 returned assemblies.

The problem concerns a stepper motor (see Figure 1), one of the main assembly components, which has a part number that will be called part number A. Customers provide the motors to the company, which introduces them into the production process; next, the motor cables are cut at a specific length, and the plate and terminals are riveted; then, the terminals are inserted into connector units in which a functional test is performed; finally, some defects that are found in this assembly process include cable inversion, incorrect cable length, and lack of an ID tag. In order to solve these problems, the 8Ds method is implemented to decrease the rate of defective products, and to increase customer satisfaction. Therefore, the objective of this paper is to prove the efficiency of the 8Ds method through a case study.

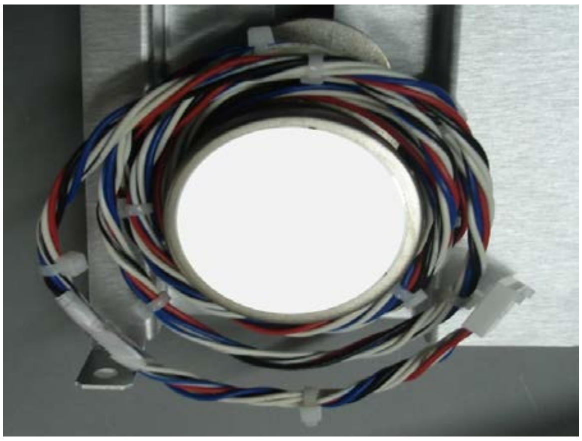

Figure 1. Stepper motor.

A case study is conducted because according to Easton [28], the critical realism approach (CRA) states that a single case study research method is enough to generalize theoretical and empirical findings, giving a new, rigorous, and coherent philosophical position that helps the development of theoretical and research processes. Similarly, Tsang [29] states that CRA highlights the impacts of case study on theoretical processes, empirical generalization, and theoretical evidence. Additionally, Tsang presents the fallibility of knowledge, which establishes that all developed theory requires being subjected to empirical evidence and evaluation; in that sense, case studies are appropriate research strategies to illustrate and analyze proposed theories. Therefore, only one case study is enough to generalize results [30]. Recently, several case studies in the manufacturing sector have been published in journals with a high impact factor. These case studies include the application of methodologies such as value-stream mapping [31,32], the plan-do-check-act (PDCA) cycle [22], lean six sigma [19], and standardized work [33], to mention few.

Specifically, this research implements the single case study approach, since the main contribution is that it allows generalizing the positive impact of the 8Ds methodology on defect reduction in the manufacturing processes with a single case study, which is supported by the CRA. Therefore, this paper contributes to illustrating how a single case study technique can be applied for improving the production system in the maquiladora industry.

The rest of the paper is organized into five sections: Section 2 reports the literature review about the 8Ds method and its successful implementations from case studies; Section 3 addresses a description of materials and methods that are implemented in the case study; Section 4 shows the findings obtained; and finally, Section 5 presents the conclusions and industrial implications regarding the 8Ds implementation.

2. Literature Review

The 8Ds is a teamwork-oriented problem-solving method that aims at identifying the root cause of a problem to solve it through a corrective action-guided procedure [23]. From a business perspective, the 8Ds method seeks to find the main problems' root causes, identify their possible solutions, and assess their impacts on companies [34]. Originally, the 8Ds method was developed at Ford Motor Company; it was introduced in 1987 to a manual entitled "Team Oriented Problem Solving" (TOPS) [35]. Since then, the method has been applied mainly in automotive industries to solve product and service-related problems, such as defects, customer complaints, manufacturing process deviations, returned purchases, poor machinery maintenance, and supplier qualification issues, among others [34,35].

According to Chelsom et al. [36] and Vargas [37], the 8Ds method can be applied to any type of problem or activity in order to provide assistance to achieving effective communication among departments that share a common objective. However, the 8Ds method is popularly applied to solve quality problems; it is typically required when at least one of the following events are presented [38]:

- The company receives customer complaints.
- Safety or regulatory issues have been discovered.
- Internal rejects, waste, scrap, underperformance, or test failures occur at abnormal levels.
- Warranty concerns indicate greater-than-expected failure rates.

The literature review mentions several successful case studies wherein the 8Ds method was applied. For instance, Mitreva et al. [25] implemented the 8Ds method to solve the problem of an LED diode that did not perform its function in a circuit board; they reported a decrease of operational defects after its implementation, and an increase the efficiency of software packages in the application of statistical methods and techniques. In the same way, Bremmer [39] applied the 8Ds method and other techniques to analyze Scania's global supply chain; how the company could guarantee the quality of products was demonstrated. As a result, this author found the problem and its root causes.

Similarly, Pacheco-Pacheco [40] sought to optimize delivery times of alteration clothing (Alto de basta and Alto de camisa) products in a tailor shop by implementing the 8Ds method. It was found that production times decreased by 2.46% in two mix products. In both products, delivery delay times decreased by 33.33%. Finally, Zasadzień [41] employed the 8Ds method to reduce machine downtimes that were caused by bottlenecks. In summary, Table 1 presents the successful case studies wherein the 8Ds method was implemented.

Table 1. Recent case studies applying the 8Ds method.

Author	Implementation of 8Ds	Results
Mitreva et al. [25]	The study applies the 8Ds method to solve the problem of a LED diode that does not perform its function in the circuit board.	Employees' responsibility was improved towards carrying out business processes. Fewer operational defects were shown. Software packages efficiency increase in the application of statistical methods and techniques. Employees' participation increased. Employees' commitment towards quality improvement. Full managerial commitment. Ability to solve problems at all levels increased. Slightly, but significant improvements in the production processes and products. Business processes were optimized. Low organizational job levels were incorporated to the decision-making process.
Bremmer [39]	The research analyzes the Scania's global supply chain and determines how the corporation can guarantee the quality of products by applying 8Ds and other methodologies.	The current production process at Scania is working, but it is requiring some improvements, especially due to the expected growth of the North Bound Flow (NBF).

Table 1. *Cont.*

Author	Implementation of 8Ds	Results
Kumar and Singh [42]	The study explores the hospitality industry of Delhi and Rajasthan, in India. Specifically, the research addresses the issue of employee turnover in the housekeeping department by identifying both causes and solutions with the help of an 8Ds model for problem solving.	In the hospitality industry, the 8Ds method can be positively adopted to solve problems, especially in terms of employee turnover in the housekeeping department.
Zasadzień [43]	The research seeks to solve problems that are identified in the process of railway carriage renovation by implementing the 8Ds method.	The 8Ds method enabled to identify causes of problems in the railway repair process, as well as allowed the author to develop improvement actions, which considerably streamlined the analyzed process.
Mitreva et al. [44]	This work analyzes the quality assurance system of an automotive company to determine its efficiency. Specifically, the authors studied the company's business process management strategies (identification, documentation, and control), as well as verified whether the system's efficiency documentation had been properly developed or not.	The quality and a better productivity at the lowest costs in operation were defined.
Titu [26]	This study relies on the 8Ds method to solve the complaint about a defective part. The study takes place in SC COMPA S.A., a company based in Sibiu, Romania.	60 days after corrective actions were implemented, there were no other pieces identified with this type of defect. Thus, the customer decided to withdraw complaints.
Fuli et al. [45]	The research develops a quality improvement procedure for automotive companies based on quality management practices. The 8Ds method and the Six Sigma pilot programs were implemented.	The results indicated that the proposed procedure is effective among the studied in Chinese and South African automotive industries.
Nicolae et al. [46]	This work proposes a solution to decrease the response time for the 8Ds method by: (a) warning workstations and warehouses about the appearance of a customer complaint, as well as (b) using a software program for the computerized management of some documents that are needed for the 8Ds analysis.	There are some of the main results: a decreased in the communication time between the quality teamwork and the staff in the manufacturing process, since when a customer complaint is received, it is solved. A faster process of collecting information on manufacturing processes during the 8Ds analysis. A better quality of information that can lead to the resolution of non-compliance was obtained. Less 8Ds analysis time, especially in the first phase of the method. A brand-new customer interface that informs customers about the problem-solving steps that are being taken. The platform is more consistent with the common guidelines for reporting 8Ds analyses.
Kumar and Adaveesh [24]	The six-month study was conducted in a spring and stamping company. The research found a high rejection rate (i.e., 17.07%) of valve springs due to defects. Thus, the 8Ds method was implemented to reduce the rate in 4.91%.	The product rejection rate decreased significantly in 6 months: from 17.07%, in January 2014, to 4.91%, in July 2014.

Table 1. *Cont.*

Author	Implementation of 8Ds	Results
Roque and Berenice [47]	This work relies on the 8Ds method to design and implement new processes for manufacturing dental units with current technology for a company named Briggith. The goal was to ensure the company's subsistence in the current market.	The standardization of raw materials and variables that intervene in the process was possible. Design of new, lighter, and modern structures. Design of an overall electronic control method for the variables identified in the production process. Compliance with quality standards established in the project.
Škůrková [48]	The research focuses on reducing scrap costs in an industrial company. The author implemented a series of methodologies, including the 8Ds method.	Causes of scrap costs were identified, and corrective actions were taken to reduce such costs.
Wichawong and Chongstitvatana [49]	The research introduces a knowledge management system for failure analysis of hard disks that applies a case-based reasoning. The 8Ds method was implemented for problem solving to design a document template.	The document template was successfully designed. The system reported a high customer satisfaction rate, as well as searching effectiveness was acceptable. In summary, the system was successful.
Vargas [37]	This work implements the 8Ds method to solve the problem of sudden stoppages in a continuous vacuum batch cooker that is used in a Brazilian sugar and alcohol company.	An effective method combined with quality tools for detecting and solving the problem and eliminating its recurrence was implemented. The application of the 8Ds method increased the company's performance, as well as and contributed to the continuous improvement of its production process. However, the method could also be applied in other type of processes to increase the company's competitiveness in terms of quality and safety.
Zasadzień [41]	The study implements a quality engineering method to improve the company's maintenance processes in a Silesian production plant. Specifically, the research implements the 8Ds method to reduce machine downtimes caused by bottlenecks.	Machine downtimes caused by bottlenecks were significantly reduced.
Pachecho-Pacheco [40]	The research seeks to optimize delivery times of alteration clothing (Alto de basta and Alto de camisa) products in a tailor shop by implementing the 8Ds method.	Production times decreased by 2.46%, for Alto de basta products (i.e., from 13.30 min to 12.98 min), and by 21.16% for Alto de camisa products (i.e., from 8.49 min to 6.69 min). In both products, delivery delay times decreased by 33.33%: from 3 days to 2 days.

Although the 8Ds method is flexible—it can be adapted to different situations—and has several successful applications, it has some disadvantages, such as [50]:

- It can be time consuming and difficult to develop.
- Employees that are involved in its implementation should receive appropriate training about it.
- Constant communication among the participants and the application of a continuous improvement program are required.

3. Materials and Methods

In order to conduct the present case study, the following materials were used: Microsoft Excel® spreadsheets [51], AutoCAD® [52], Visual Basic® [53] software programs, a PDCA form, and a visual aid form. As for the methodology, the 8Ds method was applied and its steps are presented in Figure 2.

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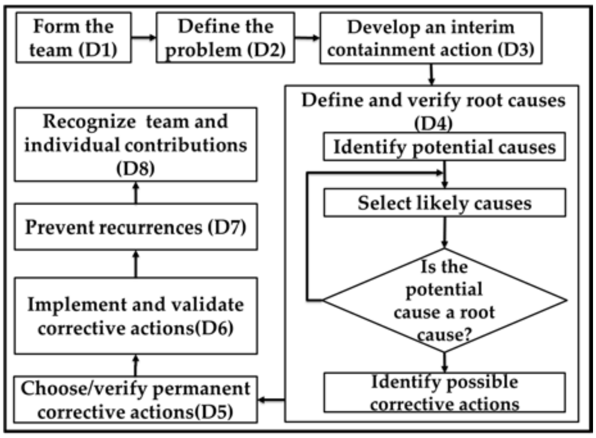

Figure 2. Steps for the 8Ds problem-solving process. Adapted from Joshuva and Pinto [35].

Some similar case studies to this research have used the Kano model as a tool to classify and prioritize customer needs based on how they affect customer satisfaction [54]. However, according to experts, the Kano model has several deficiencies, which discouraged its use in this case study. For instance, it is known that, to conveniently quantify the Kano model, customer satisfaction or dissatisfaction levels toward a product or service must be measured by using the customer satisfaction scale (see Table 2) of positive or negative comments with product or service attributes [55,56]. However, some experts claim that the satisfaction scale is asymmetric, since a positive answer is stronger than a negative answer, which reduces the impact of a negative assessment [54,55].

Table 2. Satisfaction scale of positive and negative comments.

		I Don't Like It	I Can Live with It	I Am Neutral	It Must Be This Way	I Like It Very Much
Product or service attribute	Without the attribute	1	0.5	0	−0.25	−0.5
	With the attribute	−0.5	−0.25	0	0.5	1

Another inconvenience with the Kano model is that it does not consider customer perceptions towards a product or service attributes. Particularly, it provides limited decision support for designers [57], and it is administered through a reduplicative survey, which is time-consuming. In addition, the classification obtained after analyzing the survey results is based merely on subjective assessments; therefore, it may be biased. Finally, it has been claimed that Kano's different classification schemes may influence resource allocation and product design strategy, not only customer satisfaction, and it inherently emphasizes customer and market perspectives, but does not consider the capacity of the company [54,57].

An alternative to the Kano model is the 8Ds method, which relies on facts rather than opinions [37,58]. Specifically, the 8Ds method adopts an objective approach, whereas the Kano model is based on a subjective approach. In this case study, the 8Ds method is applied to solve the identified problem.

3.1. Develop a Teamwork (D1)

Proper planning will always guarantee a better start; therefore, the following criteria should be applied before integrating 8Ds teamwork [38]:

- Collect information regarding symptoms, such as the ID number and description of the claimed part, failure date, customer and supplier numbers, and a short, descriptive analysis of the problem [39,59,60].

- Use a symptoms checklist to ask the correct questions.
- Identify the need for an emergency response action (ERA), which protects customers from further exposure to undesired symptoms.

Moreover, the 8Ds method involves organizing a cross functional teamwork that must have enough knowledge about the product/process to successfully deal with customer complaints or quality deviations in the problem-solving phase [23,35]. Additionally, the teamwork must be interdisciplinary—integrated by operators from several departments (i.e., manufacturing, engineering, and marketing) and different knowledge fields to create a solid task force [61], because the experience of the members is a key element to implementing any problem-solving method [62].

In addition, a teamwork leader is assigned, who ensures that all activities are being carried out and the 8Ds report is regularly updated. Additionally, there should be a champion; this is a person in a management position with enough authority to assist and lead the teamwork when it encounters difficulties or in case additional resources are required [59]. Similarly, any permanent solution may require subsequent teamwork involvement [36]. Based on these facts, manufacturing companies employ hundreds, or even thousands of people with different types of skill sets, ideas, and values, who must be useful for the company.

3.2. Describe the Problem (D2)

This step involves explaining the problem that affects quality or does not meet customer satisfaction [23]. The problem should be explained in detail, identifying in quantifiable terms the who, what, when, where, why, how, and how many problems are involved in the problem (i.e., 5W+2H) [35].

3.3. Develop an Interim Containment Action (D3)

Since 8Ds teamwork members have enough knowledge on the product/process, possible corrective actions must be undertaken in order to control the problem and avoid its expansion. Teamwork members should define and implement those intermediate actions that will protect the customer from the problem until permanent corrective actions are implemented. Additionally, interim containment actions should follow the ISO/TS 16949:2009 quality system and rely on the current approach to appropriately determine and verify the effectiveness of these actions. (ISO/TS 16949:2009 is a technical specification which defines the quality management system requirements for the design, development, production, relevant installation, and service of automotive-related products [23]). In addition, this step is aimed to preserve evidence and stop the outcome from being irremediably enlarged before the problem can be solved and the goal achieved. Some tasks must be monitored to ensure compliance with the requirements, such as documenting, control planning, scheduling, and assigning the specific needs according to the problem that is being solved [23].

3.4. Define and Verify Root Causes (D4)

This step refers to identification of all the applicable causes that could explain why the problem occurred, as well as the reasons why the problem was not perceived the first time it occurred. All causes shall be verified or proved, and not determined by assumptions. Experts recommend using the Ishikawa's five-whys diagrams to map causes against the identified effect [35]. The 5W2H method is used to make diagrams about customer requirements, review the problem-solving process, and analyze the problem [23].

3.5. Develop Permanent Corrective Actions (D5)

Depending on the different causes of the problem, several suitable strategies ought to be proposed. Therefore, either results must be reviewed and the required adjustments have to be made, or some permanent corrective actions must be taken [23]. Finally, a quantitative method ought to be performed through pre-production programs to confirm that the selected corrections will solve the problem [35].

3.6. Implement and Validate Corrective Actions (D6)

In this step, the best corrective actions are defined and implemented to ensure that the target is reached and the problem is solved. In addition, it is necessary to control or monitor any potential effects [23,34,35].

3.7. Prevent Recurrences (D7)

In this step, management systems, operation systems, practices, and procedures should be modified and controlled to prevent their recurrence or any other similar problems, avoiding customer complaints [35].

3.8. Recognize and Congratulate Teamwork as Well as Individual Contributions (D8)

Finally, in this step, the problem is solved; therefore, the knowledge and results are shared. Additionally, the collective efforts from team members are recognized, providing positive feedback and being formally recognized. Training and education records are established and the plan-do-check-act (PDCA) cycle is followed to attain higher customer satisfaction [23,34,35].

The 8Ds method has been successfully implemented in a wide range of case studies across multiple settings. Table 1 presents a recent literature review conducted on the practical applications of the 8Ds method.

3.9. Supplementary Tools in 8D Method

3.9.1. Ishikawa Diagram

The Ishikawa diagram is also known as a cause–effect diagram, fishbone diagram, or root cause analysis diagram, and was developed by Kaoru Ishikawa in the 1960s [63,64]. It helps to visualize a problem and categorize its root causes; it is considered as one of the seven basic quality management tools. The head of the diagram lists the problem to be studied, whereas the fish bones are arrows connected to the spine that list the causes that contribute to the problem. The arrows are interpreted as causal relationships.

According to Da Fonseca et al. [65], the diagram ramifications represent the possible sources of the problem that are related to some factors, such as materials work methods, workforce, measurements, machinery/equipment, and environment. The Ishikawa diagram offers multiple advantages, among which the following can be highlighted [66]. It:

- Classifies all causes that are related to a problem.
- Shortens a relatively large problem.
- Encourages the participation of all the teamwork members in the analysis and creation of project management dynamics.
- Increases the role of teamwork in the problem-solving process.
- Identifies the areas that require more in-depth research when some information is missing.
- Provides elements to develop an adequate solution to a problem.
- Offers a concise view of cause-and-effect relationships.

In this case study, an Ishikawa diagram is designed to find the root causes of the problem. For instance, it is supposed that there is an absenteeism problem in a manufacturing company; therefore, managers want to know the different causes of this problem that are related to the factors previously mentioned. Once the causes of the problem are identified, they are categorized by their factors, as shown in Figure 3.

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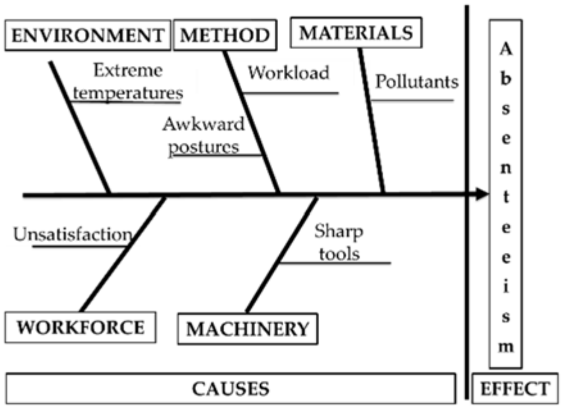

Figure 3. Ishikawa diagram to illustrate the causes of an absenteeism problem.

3.9.2. Pareto Chart

The Pareto chart is a special type of bar graph in which each bar represents a different category or part of a problem [67]. It was developed by the Italian scientist Wilfredo Pareto, who found that 80% of the wealth was held by 20% of the people in Italy [68]. The Pareto chart illustrates the frequency distribution of descriptive data that are classified into categories. The categories are placed on the horizontal axis, whereas the frequencies are placed on the vertical axis [67,68]. The categories are arranged in a descending order, from left to right, while a line represents the frequencies in cumulative percentage. The highest bars of the chart represent the categories that contribute the most to the problem.

Furthermore, Pareto charts help identify how certain factors influence on a problem along with other factors; in other words, Pareto charts help identify the best opportunities for improvement [69]. Experts recommend using Pareto charts for two particular purposes: to decompose a problem into categories or factors and to identify the key categories that contribute the most to a specific problem [67]. For instance, continuing with the example of absenteeism in a manufacturing company, the six causes shown in Figure 3 were ordered according to their frequencies, as shown in Figure 4. Based on this order, managers should try to eliminate the first three causes (extreme temperature, sharp tools, and workload), since they represent the 80.47% of all causes of absenteeism.

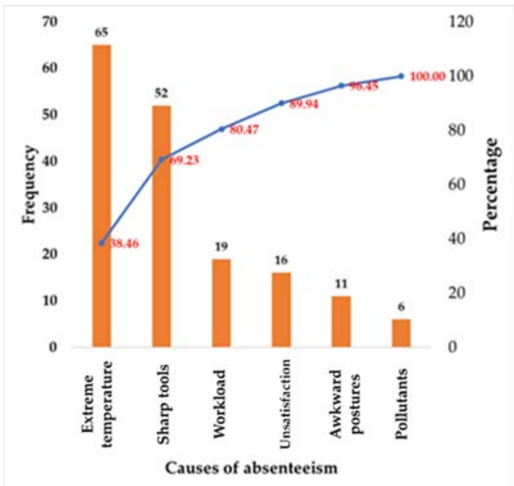

Figure 4. Example of a Pareto chart application for causes of absenteeism.

In the present case study, a Pareto chart is created for a better understanding of the key causes that contribute to the problem of non-working custom cable assemblies.

4. Results

The results obtained for each stage of the 8Ds methodology are shown as follows:

4.1. Develop the Teamwork (D1)

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The teamwork included a maintenance engineer, a processes engineer, an intern engineer, a production line manager, and two quality inspectors. The principal teamwork goals were to determine an adequate manufacturing process for part number A and to define the root causes of the defects. In order to achieve these goals, a task was assigned to each teamwork member, as summarized in Table 3. Note that each PDCA cycle step comprised at least one discipline, since the 8Ds method follows the logic of this cycle [50,70]. Additionally, disciplines are assigned to different teamwork members; i.e., no more than one discipline was assigned to more than one member.

Table 3. Task assignment.

The 8Ds Methodology	PDCA Cycle	Teamwork Member
Develop the teamwork (D1)	Plan	Maintenance engineer
Describe the problem (D2)		
Develop an interim containment action (D3)	Do	
Define and verify root causes (D4)		Production line manager
Develop permanent corrective actions (D5)		Intern engineer
Implement and validate corrective actions (D6):	Check	Quality inspector 1
Prevent recurrences (D7):	Act	Quality inspector 2
Recognize and congratulate the teamwork as well as individual contributions (D8):		All involved employees

Once the tasks have been assigned to the teamwork members, they have to implement an efficient communication system to keep each other informed, and as a result, guarantee the involvement of all the members in the problem-solving process. Similarly, a PDCA form was designed on Microsoft Excel® for each teamwork member to report their corresponding tasks from the PDCA cycle.

4.2. Describe the Problem (D2)

As previously mentioned, 67 cable assemblies were returned to the company by customers, who complained about either the product's poor performance or regarding unacceptable features. The main problem was that the assembly did not work; however, that can be due to several types of defects. Table 4 lists the six different types of defects that were found in the cable assemblies.

Table 4. Defects found in the rejected cable assemblies.

Defect	Frequency	Percentage	Cumulative Percentage
Inverted cables	35	52%	52%
Disfigured motor	10	15%	67%
Noisy motor	9	13%	81%
Motor does not work	7	10%	91%
Lack of ID tag	4	6%	97%
Wrong cable length	2	3%	100%
Total	67	100%	

Disfigured motor	10	15%	67%
Noisy motor	9	13%	81%
Motor does not work	7	10%	91%
Lack of ID tag	4	6%	97%
Wrong cable length	2	3%	100%
Total	67	100%	

Specifically, the data in Table 4 were used to create a Pareto diagram, as shown in Figure 5. The diagram helped define which problems or defects had to be prioritized, according to their frequencies. In this sense, the most frequent defect was inverted cables, followed by a disfigured motor. Even though both wrong cable length and the lack of an ID tag were less frequent problems, they had to be solved from the root cause as well.

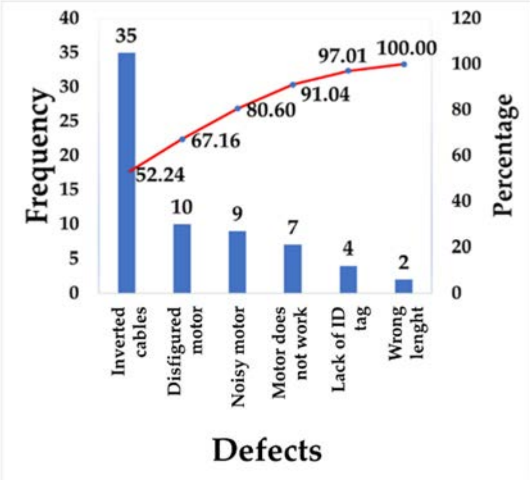

Figure 5. Pareto diagram of cable assembly defects.

4.3. *Develop an Interim Containment Action (D3)*

Both interim and rapid interventions were implemented to solve most of the six problems, including those concerning inverted cables, disfigured motors, lack of ID tag, and wrong cable length. A series of interim visual aids were developed to help employees assemble the components. Regarding inverted cables and disfigured motors, a document is created to report the conditions of both the stepper motor and the cables before and after being handled by the employee. Additionally, as Figure 6 presents, a provisional sign is created for helping employees to insert the assembly cables not only in the correct positions, but also in the right entry holes by using the colors of the cables as references. Similarly, the sign is intended to help employees guarantee that each cable's final end is the one that is required by customers.

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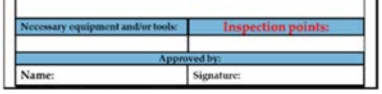
Figure 6. Provisional aid for cable insertion.

Finally, AutoCAD® was used to design a customizable 1:1 scale 2D template of a drawing provided by customers for the assemblies to verify that customers' demands would be accomplished, as shown in Figure 7. Perhaps the greatest advantage of this electronic template is that it can be stored in a database and updated for new specifications (i.e., new cable length) if required. The updates can be performed quickly and effectively without compromising the template function. After implementing this system of solutions (i.e., the spreadsheet, the sign, and the 2D template), it was noticed that the most insignificant errors were immediately fixed; consequently, four of the six



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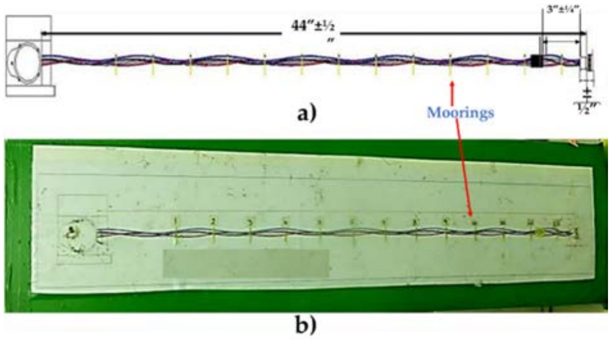

Figure 7. Template of the drawing provided by the customer: (**a**) picture of the template made in AutoCAD; (**b**) picture of the printed template.

4.4. Determine and Verify Root Causes (D4)

This discipline aims to find the root causes of problems. According to Škůrková (2017), cause–effect diagrams can be used to map causes with their corresponding effects or problems. The general problem in this case study is that the assembly does not work; hence, a fishbone diagram is developed—also known as Ishikawa diagram—as depicted in Figure 8 to identify the root cause. As can be observed, several causes were identified across five aspects: materials, methods, environment, workforce, and machinery.

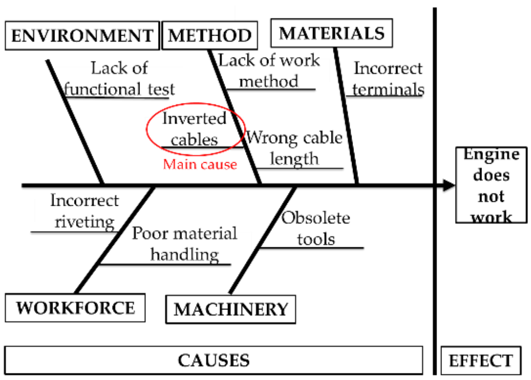

Figure 8. Cause-effect diagram to find out the root cause of the problem.

Regarding the environment, the reason why the returned assemblies were defective is because the company lacked a functional test to confirm that they worked. However, to perform this evaluation, the cables first had to be correctly assembled—and even then it would have been impossible to know if the assemblies worked properly. As for the materials, it was found that the cable end terminals were incorrect, since the warehouse employees mistakenly provided the wrong types to the operators. Additionally, two more problem causes were associated with the work method. Usually, the motors supplied to the company come with already-integrated cables, and the employees only need to cut these cables as specified by the customers, and then rivet the excess. However, sometimes the cables are not always cut at the right length or inverted.

In terms of machinery, it was found that the tools of the company were obsolete and needed required to be replaced. Finally, regarding the workforce aspect, the diagram indicates that the assembly cables were not always riveted properly, yet correct riveting makes it possible for the motor to be connected to the cables, which in turn enables the functional test to be successfully performed. Similarly, it was found that the employees may poorly handle the motors, and in the case of the evaluation, the cables first had to be correctly assembled—and even then, it would have been impossible to know if the assemblies worked properly. As for the materials, it was found that the cable end terminals were incorrect, since the warehouse employees mistakenly provided the wrong types to the operators. Additionally, two more problem causes were associated with the work method. Usually, the motors supplied to the company come with already-integrated cables, and the employees only need to cut these cables as specified by the customers, and then rivet the excess. However, sometimes the cables are not always cut at the right length or inverted.

In terms of machinery, it was found that the tools of the company were obsolete and needed required to be replaced. Finally, regarding the workforce aspect, the diagram indicates that the assembly cables were not always riveted properly, yet correct riveting makes it possible for the motor to be connected to the cables, which in turn enables the functional test to be successfully performed. Similarly, it was found that the employees may poorly handle the motors, and in the case of the rejected assemblies, this could have an impact on their performance. Another possible cause of having defective assemblies is that the motors might have been damaged during their delivery.

Moreover, since most of the assemblies were returned because of inverted cables, this issue is considered as the main root cause of the problem (see Figure 3). In most of the assemblies, the black, white, and blue cables had been inverted. At first, this can be a problem related to the company work method; however, a functional test could have also solved the problem. In addition, with a functional test, the company could have prevented non-working motors and abnormal noise problems. During functional tests, motors usually display a "not working" message, in which case the position of the cables must be thoroughly reviewed. Finally, to prevent the problem from re-occurring, a program in Visual Basic® was developed to conduct motor functional tests (see Appendix A). The test uses binary values (0 and 1) that allow employees to confirm an assembly's functionality before it is delivered to the customer. Figure 9 introduces the truth table for the motor, with values 1 = true (ON) and 0 = false (OFF).

4 White	3 Black	2 Blue	1 Red
1	0	1	0
1	0	0	1
0	1	0	1
0	1	1	0

CCW ROTATION

1= ON, 0 = OFF

Figure 9. Truth values for the motor.

The binary values are translated into decimal values to be used in the program; first a formula table is built, as depicted in Figure 10, wherein each row corresponds to one cable. Then, in each row, the first ten powers of 2 are displayed, i.e., $2^0 = 1$, $2^1 = 2$, …, $2^9 = 512$, from right to left, and it is assigned one binary value from Figure 9 corresponding to a power of two, starting at $2^0 = 1$. Finally, each binary value in each row is multiplied by its corresponding power of 2, and the sum of the products is the resulting decimal value that is reported on the right side of each row. Once the four decimal values were obtained, they were used in the program commands to be executed, consequently beginning a new project according to customer specifications.

Row 1

512	256	128	64	32	16	8	4	2	1	
						1	0	1	0	= 10

Row 2

512	256	128	64	32	16	8	4	2	1	
						1	0	0	1	= 9

Row 3

512	256	128	64	32	16	8	4	2	1	
						0	1	0	1	= 5

Row 4

512	256	128	64	32	16	8	4	2	1	
						0	1	1	0	= 6

Figure 10. Translation of binary values to decimal values.

Once the Visual Basic® program was designed, the Parmon's parallel port monitor application was used to verify that the decimal values were correct when the program was executed, as shown in Figure 10. The Dec column contains the decimal values corresponding to the binary values from the binary column. In all the decimal values shown in Figure 11, the motor being tested was turned on. Once the motor finished its cycle, the program indicates that the motor is turning in the opposite

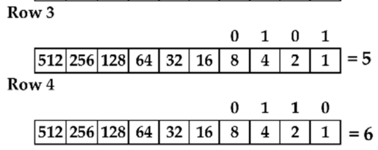

Figure 10. Translation of binary values to decimal values.

Once the Visual Basic® program was designed, the Parmon's parallel port monitor application was used to verify that the decimal values were correct when the program was executed, as shown in Figure 10. The Dec column contains the decimal values corresponding to the binary values from the binary column. In all the decimal values shown in Figure 11, the motor being tested was turned on. Once the motor finished its cycle, the program indicates that the motor is turning in the opposite direction regarding the position it had started in. The goal of this test is to confirm that the motor works properly without abnormal noise.

Figure 11. Parmon's parallel port monitor application and motor functioning: (**a**) decimal value 10 enabled, the motor starts turning; (**b**) decimal value 9 enabled, the motor continues its cycle; (**c**) decimal value 5 enabled, the motor continues its cycle; (**d**) decimal value 6 enabled, the motor finishes its cycle.

4.5. Develop Permanent Corrective Actions (D5)

In this discipline, the following corrective actions are implemented:

- Connector insertion method: This action was implemented because inverted cables were the root cause of the problem.
- Functional test: This action was implemented, since the lack of a functional test was one of the reasons why the assemblies had inverted cables. Functional tests can help solve the problems of noisy motors and dysfunctional motors.
- Template: This action was demanded by customers, because the template guarantees that the assembly component features match the customer specifications.

The three corrective actions significantly improved the production system, since they helped solve problems of inverted cables, noisy motors, dysfunctional motors, and wrong component features. Additionally, the brand-new insertion method was added in the datasheet of part number A, and it was stored in an electronic file to be updated when necessary. However, one important factor to consider is that, regardless of whether the motor was properly assembled or not, it was still likely to fail or generate abnormal noise.

4.6. Implement and Validate Corrective Actions (D6)

An operation method for the functional test was developed (see Appendix B). Specifically, each connector being tested only had to be connected to the box containing the driver. The process time established by the customer was 7.28 min, but it is managed to decrease in 4.61 min (i.e., 36.68% less time) after the process was documented and a functional test was conducted. In the end, the operation method helped employees avoid mistakes when assembling the cable. The corrective actions were validated by comparing the analysis results from the defective assemblies before and after implementing these actions. Actually, the defective products decreased by 76%, which validates the implemented corrective actions [24].

4.7. Prevent Recurrences (D7)

The manufacturing process of part number A comprises eight tasks: manual cable cutting, semi-automatic cable riveting, cable end terminal insertion, cable labeling, performing electrical and functional tests, conducting final inspection, packaging, and shipping. Once these tasks were identified, a series of checklists was designed to monitor their successful completion and ensure continuity in the manufacturing process. At the shipping stage, all this documentation was assigned a customer revision number, which would allow the resulting datasheet to be immediately updated as customer specifications change, thereby informing the production, quality, and cutting departments of such updates.

Finally, in this discipline, an executable version of the Visual Basic® program was developed. The program forbid employees from changing any of its settings, since it only allows them to open it and perform the test in a pre-configured mode to prevent misconfiguration problems.

4.8. Recognize Teamwork and Individual Contributions (D8)

In this stage, all the teamwork members were acknowledged for their individual and group performances. Although each member had his/her own ideas, and different suggestions were proposed during the problem-solving process, the teamwork remained united and worked towards a common goal.

5. Conclusions and Industrial Implications

The principal goal of this work was successfully accomplished. The 8Ds method implemented in the manufacturing company managed to decrease the number of assembly defects in part number A from 67 to 16, which represents a decrease of 76.12%. Figure 12 shows a comparison about the frequency of each defect before and after implementing the 8Ds method. Note that the frequency of all defects decreased. For example, the frequency of inverted cables, the most common defect, decreased from 35 to 2. Similarly, the frequency of motor disfigured decreased from 10 to 3, and the noisy motor decreased from 9 to 3, to just mention the higher frequency defects.

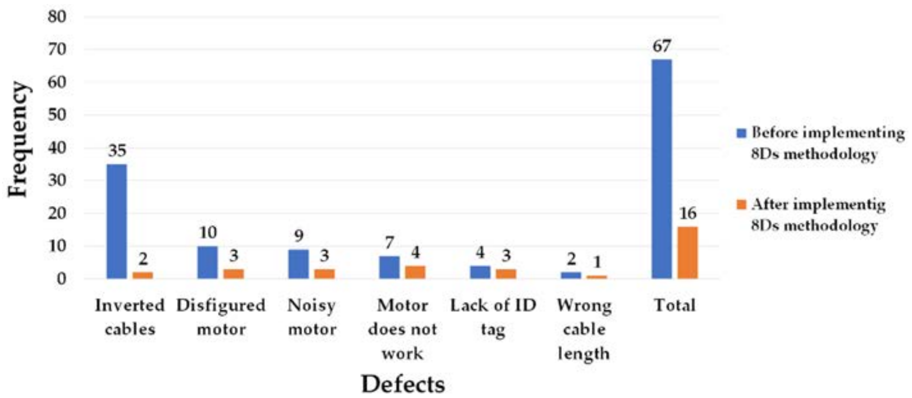

Figure 12. Comparison of the frequency of defects before and after applying the 8Ds method.
Figure 12. Comparison of the frequency of defects before and after applying the 8Ds method.

Simultaneously, the 8Ds method implementation allowed increasing customer satisfaction. In the 16 case studies reported in Section 3, the 8Ds method was applied to help corporations to comply with delivery times, reduce scrap and defect costs, implement new processes or develop new products, improve quality assurance systems, minimize supply chain and customer complaints, and improve services. However, solving these types of problems involves having a solid and effective communication system among the affected departments, which should also share a common goal.

In addition, by implementing the 8Ds method, the company managed to decrease production time, machine downtimes, scrap costs, operational defects, the rate of late deliveries, and customer complaints. Regarding the manufacturing system, the 8Ds method increased efficiency and productivity in the application of statistical methods and techniques at low operational costs. Table 5 shows a comparison of the main indicators before and after implementing the 8Ds method. It is important to note that the total defects were reduced by 76.12%, while the customer complaints were reduced by 100%. Similarly, production, inspection, and packing times for the part number A were complaints. Regarding the manufacturing system, the 8Ds method increased efficiency and productivity in the application of statistical methods and techniques at low operational costs. Table 5 shows a comparison of the main indicators before and after implementing the 8Ds method. It is important to note that the total defects were reduced by 76.12%, while the customer complaints were reduced by 100%. Similarly, production, inspection, and packing times for the part number A were reduced by over 30%; and machines stoppages were reduced by over 77%. This reduction of time cycles allowed for increasing the production level by 34.22%.

Table 5. Comparison of the main indicators before and after applying the 8Ds method.

Indicator	Before Implementing the 8Ds Methodology	After Implementing the 8Ds Methodology	Difference
Total defects	67	16	−76.12%
Time for the production process of part number A	7.28 min	4.61 min	−36.68%
Time for the inspection and packing of part number A	6.5 min	4.28 min	−34.22%
Customer complaints	67	0	−100%
Machines stoppages	155 min/day	35 min/day	−77.42%
Production	850 products/day	1141 product/day	+34.22%

Moreover, the implementation of the 8Ds method had a positive impact on the company's competitiveness in terms of quality and safety. Furthermore, the 8Ds method had a significantly positive effect on employees and managerial responsibility, participation, and commitment, which streamlined and improved the company problem-solving process, especially by helping delegate equal responsibilities to the lowest organizational levels. Finally, the 8Ds method implementation allows collecting information concerning a problem in a quick manner, and reduces the communication time between the quality teamwork and operators.

When problems arise, a method, technique, or abstract tool ought to be implemented to find the best solution. On some occasions, the implementation process may require making small modifications in the organization, whereas in other cases, engineers must be more careful to spare the company losses. Additionally, in the implementation of any method, communication is a key element of success. A solid, rapid, and effective communication system encourages employees to be creative and be engaged in the problem-solving process and motivates employees to be prepared for any further change. In other words, the 8Ds method has a two-fold goal: to solve problems and to increase active employee participation in the problem-solving process. In order to achieve these goals, experts recommend the following strategies:

- Implement the 8Ds method to solve problems with other part numbers, and/or in other areas (purchase or sales, for instance).
- Always consider each employee's opinion, since it will make their work motivating.
- Engage customers' opinions and ideas to improve both the production processes and their satisfaction.

As future work and based on the findings obtained in the present case study, the authors of this research plan to implement the 8Ds method in some companies from the 914 manufacturing industries located in Baja California state to solve problems related to defective products and/or production process efficiency. Additionally, the authors plan to extend the 8Ds method implementation, as well as other industrial engineering tools (PDCA cycle, standardized work, poka-yoke, DMAIC, to mention few) not only to companies in the manufacturing sector, but also in another sectors, such as construction, education, agriculture, and food services.

Finally, the authors encourage researchers from the industrial engineering field to publish their case studies on the applications of different techniques, methods, or tools, supported by the CRA.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

Appendix A. Code for the Program on Visual Basic

The next step involved introducing the following command:

Command for the input variable:

```
Private Declare Function Inp Lib "inpout32.dll" _
Alias "Inp32" (ByVal PortAddress As Integer) As Integer
```

Command for the output variable:

```
Private Declare Sub Out Lib "inpout32.dll" _
Alias "Out32" (ByVal PortAddress As Integer, ByVal Value As Integer)
```

Command to tell the program that a delay function exists in milliseconds:

```
Private Declare Sub Sleep Lib "kernel32" (ByVal dwMilliseconds As Long)
```

The following instructions are given to the MOTOR TURNS TO THE LEFT button.

```
Private Sub Command2_Click()
MsgBox ("BE SURE THAT THE MOTOR IS TURNING COUNTER CLOCKWISE. PRESS OK TO START")
Dim x As Integer
For x = 10 To 500
Sleep 200
Out &H378, 6
Sleep 200
Out &H378, 5
Sleep 200
Out &H378, 9
Sleep 200
Out &H378, 10
Sleep 200
Next x
MsgBox ("END OF TEST TO THE LEFT")
End Sub
```

Now, instructions are given to the MOTOR TURNS TO THE RIGHT button.

```
Private Sub Command4_Click()
MsgBox ("BE SURE THAT THE MOTOR IS TURNING CLOCKWISE. PRESS OK TO START")
Dim x As Integer
For x = 10 To 500
Sleep 200
Out &H378, 10
Sleep 200
Out &H378, 9
Sleep 200
```

```
Out &H378, 5
Sleep 200
Out &H378, 6
Sleep 200
Next x
MsgBox ("END OF TEST TO THE RIGHT")
End Sub
```

Finally, instructions are given for the EXIT TEST button.

```
Private Sub Command3_Click()
MsgBox ("ARE YOU SURE YOU WANT TO EXIT?")
End
End Sub
```


Appendix B

Appendix B.

Page: 1 of 4

Operation method

Operation: Functional test	Part number A	Date:

1. IDENTIFY MOTOR PART NUMBER. IN THIS CASE: PART NUMBER A

2. ENSURE THAT THE TERMINALS HAVE BEEN INSERTED IN THE CORRECT POSITION

Necessary equipment and/or tools:	Inspection points:

Approved by:

Name:	Signature:	

Figure A1. First Visual Aid to Conducting the Functional Test.

Figure 1. First Visual Aid to Conducting the Functional Test.

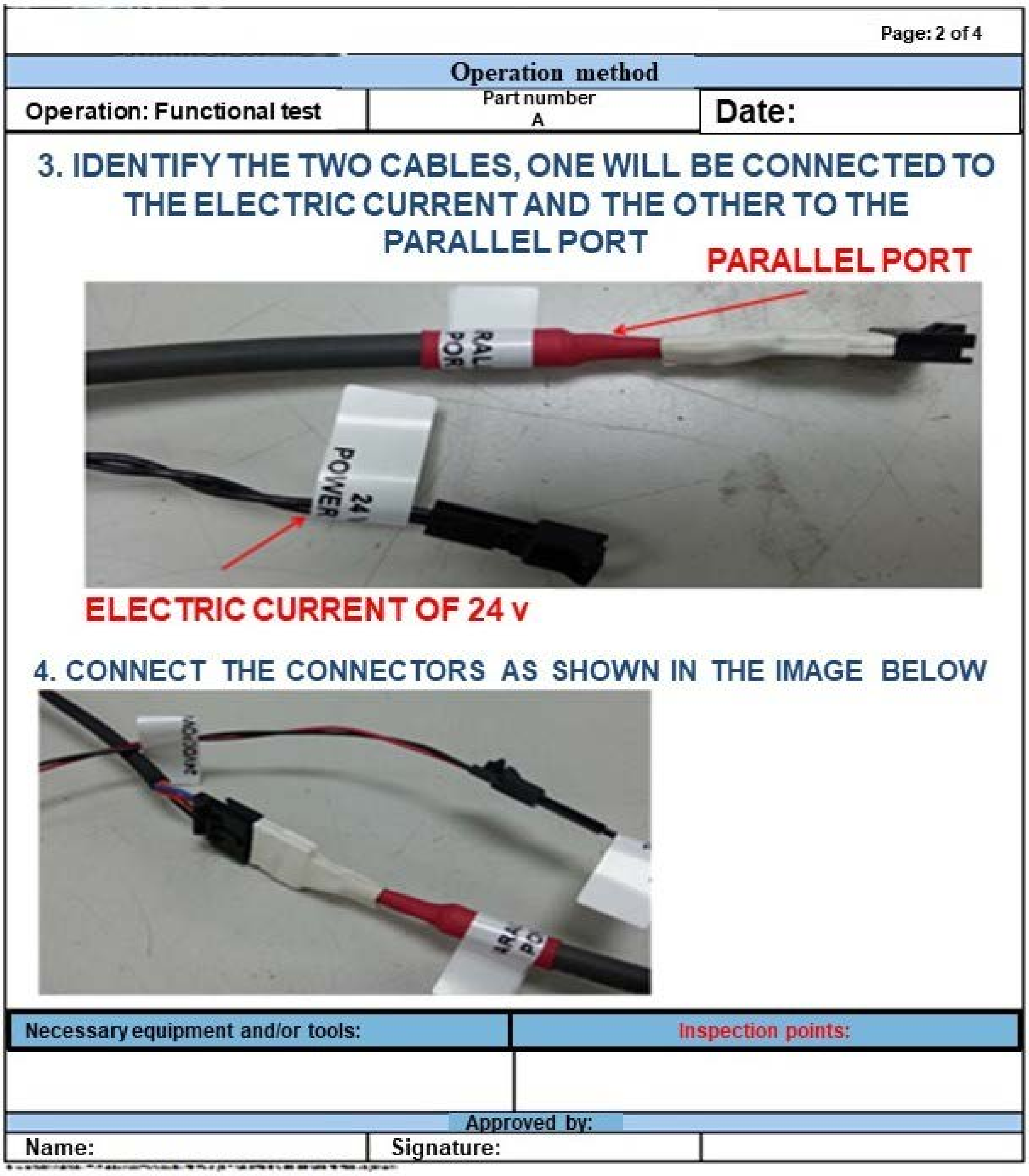
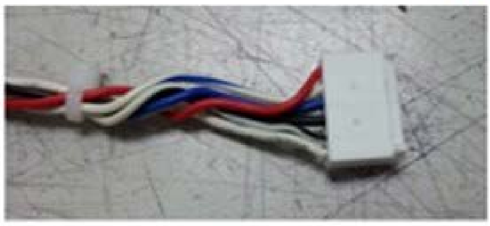


Figure A2. Second Visual Aid to Conducting the Functional Test.

		Page: 3 of 4
Operation method		
Operation: Functional test	Part number A	Date:

5. INSERT CONNECTOR IN THE CORRECT POSITION AS SHOWN BELOW



NOTE THE CONNECTOR'S ORIENTATION, THAT IS THE CORRECT WAY TO INSERT

CORRECT

INCORRECT

Necessary equipment and/or tools:	Inspection points:

Approved by:		
Name:	Signature:	

Figure A3. Third Visual Aid to Conducting the Functional Test.

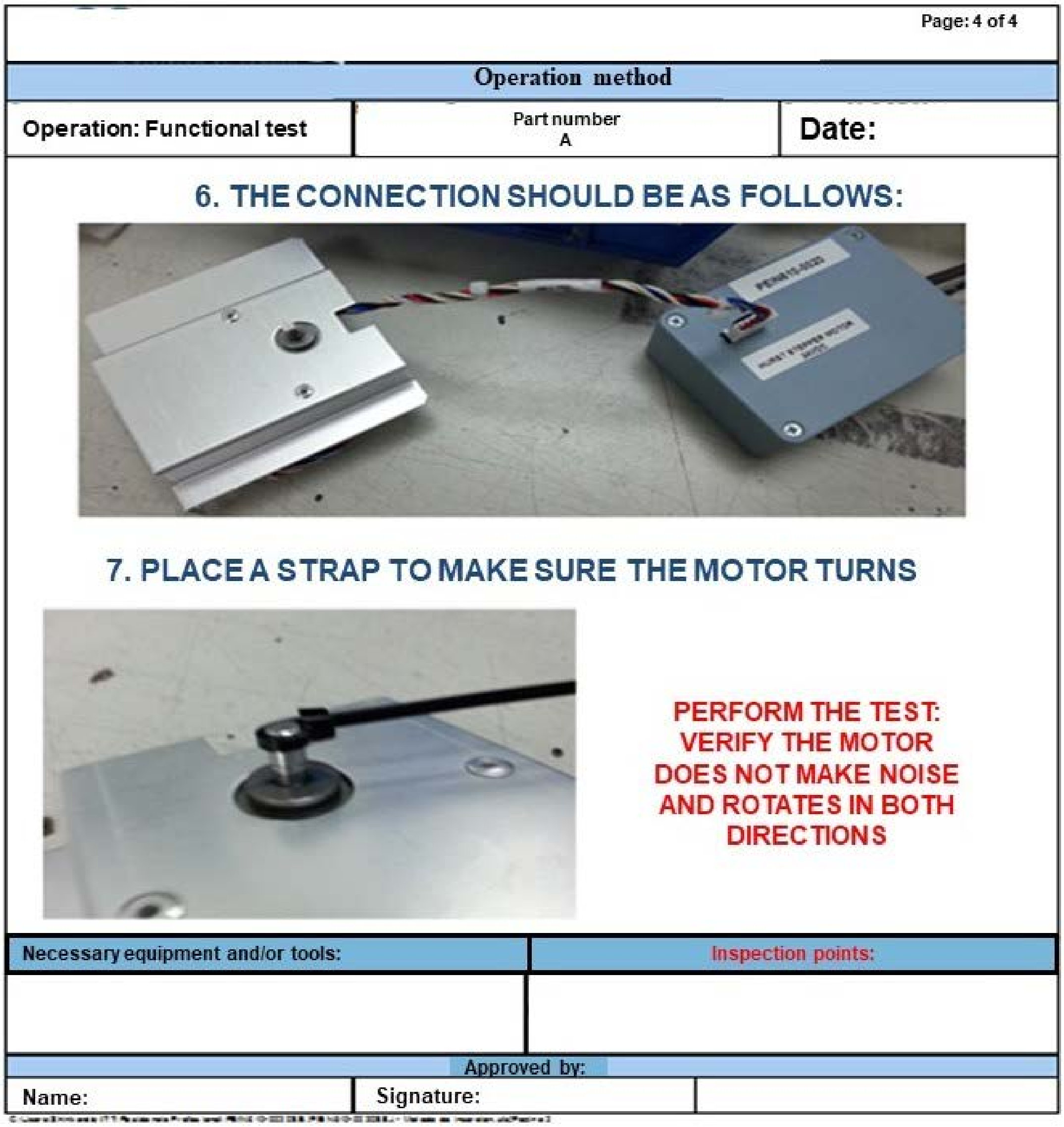


Figure A4. Fourth Visual Aid to Conducting the Functional Test.

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Anexo III

Artículo:

Work Standardization and Anthropometric Workstation Design as an Integrated Approach to Sustainable Workplaces in the Manufacturing Industry

sustainability

MDPI

Article

Work Standardization and Anthropometric Workstation Design as an Integrated Approach to Sustainable Workplaces in the Manufacturing Industry

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Abstract: Poor workstation designs represent a risk factor for operators in assembly production lines. Anthropometric design of workstations facilitates the sustainable development of the workplace. This paper proposes a novel integrated approach about work standardization and anthropometric workstation design as a strategy to increase human factor performance as well as the productivity index in manufacturing companies. The integrating approach is presented through a case study in a publishing press company with operators who perform manual and mechanical tasks in production lines in the box assembly department. Currently, the company's production capacity is below demand, and in order to satisfy customers' requirements, the company pays a lot of overtime to operators. In order to solve this problem, the integrated approach was applied. The findings indicated that inefficient movements and body postures in operators decreased from 230 to 78, and the standard time was reduced from 244 to 199 s for each assembled box. In addition, the production rate increased by 229 units per assembly line per day, and overtime was eliminated. Therefore, the novel integrated approach allows the increase of sustainability in the company and the operators' well-being by making a better use of the human factor, eliminating overtime, and increasing production capacity.

Keywords: work standardization; human factor; anthropometric workstation design; optimization of productivity; inefficient movements; line balancing; sustainable workplaces

1. Introduction

Nowadays, the level of competition in the global marketplace requires that manufacturing companies efficiently adopt a sustainable workplace. However, there is a variety of production-related problems, such as late deliveries, line stoppages, bottlenecks, unbalanced production lines, hours of production, overtime, inefficient material handling equipment, risky body postures for employees, and high production costs, among others.

1.1. Problems for Sustainable Workplaces

In the case of late deliveries, Peng and Lu [1] report an analysis regarding the impact of delivery performance on customer transactions, which affects the customers' transaction amounts and the price units. On the other hand, Fazlollahtabar [2] reports a case study applied to an assembly line in which late deliveries of products were the source of poor performance in the manufacturing system, and he proposed a parallel line of autonomous assembly of guided vehicles. Late deliveries reflect a low-quality logistics infrastructure, which represents a barrier for sustainability [3].

In the case of unbalanced production lines and bottlenecks, different authors have confirmed that they decrease the manufacturing systems' productivity and diminish the capacity in the production system [4,5] because bottlenecks can cause line stoppages [6,7], which in turn adversely affect performance. For example, Ren et al. [4] and Zupan and Herakovic [8] present case studies in which unbalanced bottlenecks and production lines cause a low level of productivity in an assembly area, which was solved by balancing the production lines and redesigning their distribution. In addition, Gu et al. [6] claim that maintenance problems cause bottlenecks in complex manufacturing systems, which result in the loss of production. In other words, unbalanced production lines create organizational problems, decrease the supply chain performance, and increase production costs. Therefore, the appropriate balance in a production line is a traditional production strategy that helps reduce bottlenecks in manufacturing systems.

Furthermore, regarding production line stoppages, these are responsible for production losses [9] and for production cost increases [10,11], especially when they occur unexpectedly; consequently, they affect subsequent manufacturing operations [12]. According to Hossen et al. [13], losses due to inactivity and equipment downtime and failures represent 89.3% of total losses due to downtime in a production system. Nevertheless, Peng and Zhou [10] mention that mixed-model assembly lines are currently widely adopted in the automotive industry to achieve an ongoing customization, since it is not allowed to have a material shortage because it is extremely expensive to afford due to the stoppages from the resulting production lines.

Similarly, Sonmez et al. [9] state that production line stoppages due to broken machinery cause production loss in manufacturing systems, and Zhao et al. [14] present a preventive maintenance (PM) modeling based on delay times for manufacturing systems in a steel industry. Specifically, line stoppages are a consequence of raw material shortage. Finally, Peng and Zhou [11] investigate a problem of programming multiple servers in an automotive assembly line, where the supply of parts just in time (JIT) is a critical and costly problem.

Regarding overtime, Hansson et al. [15] report a study to determine if the batch preparation process affects work efficiency when it is compared with only preparing one batch, and found that the kitting process is associated with overtime as a result of the material batching and feeding process. In addition, they conducted two experiments and discovered that the preparation of a single batch took longer than the batch preparation, which represented a higher production cost. Similarly, several studies argue that overtime is a specific aspect of certain tasks or departments associated with manufacturing systems. For example, Wang et al. [16] indicate that poor process planning make operators work longer, which translates into higher production costs.

Moreover, El-Namrouty and Abushaaban [17] mention that the material handling process and inefficient body movements or postures do not add value to a product, generate a long production cycle time, or make inefficient the implementation of human resources. Regarding body movements and postures, they imply an inadequate implementation of ergonomics in the production system, since operators will perform hazardous tasks, such as stretching, bending, or lifting, when it is not required. For example, Kamat et al. [18] and Gómez-Galán et al. [19] mention that uncomfortable body postures, as well as repetitive movements, represent a risk factor for employees, since they can cause musculoskeletal disorders and negatively affect employees' health and performance, altering their well-being. In the same way, Yeow et al. [20] showed that repetitive movements may cause fatigue and loss of concentration while performing a task, which increases the probability of making mistakes, negatively affecting their performance. These problems may be generated by a poor design of workstations, which generates uncomfortable postures, causes musculoskeletal disorders, and consequently, affects work performance and well-being [21], as well as causing high production costs [17].

In conclusion, all of these problems cause high costs, a lack of competitive advantage, and a weak market position, which, along with the times of work shifts, lack of human resource performance, and well-being, represent a barrier for sustainable workplaces [3,22].

1.2. Sustainability Strategies

According to the literature, there are eight sustainability strategies. These strategies are classified into two perspectives: Strategies adopted by project organizations, and strategies adopted by project hosts [23]. One of these strategies is setting strategic and tactical sustainability goals. This strategy is focused explicitly on sustainability issues when developing project strategies, paying special attention to instances where sustainability issues align with other aspects [24]. Another strategy is influencing the sustainability of project practices, which consists in supporting the incorporation of sustainability into project practices and technical systems through, e.g., construction tools, prefabrication, and waste management systems [25]. Table 1 summarizes the eight sustainability strategies provided by the literature.

As can be observed in Table 1, none of these strategies are focused on achieving sustainable workplaces by integrating standardized work and anthropometry. That is why this research proposes an integrative approach of standardized work and anthropometry as a strategy to achieve sustainable workplaces and well-being for operators.

In order to solve the previous issues, multiple strategies are implemented in manufacturing systems. For example, in the supplier selection process, companies are focused on attributes related to delivery time and performance [1], since they avoid having technical stoppages due to a lack of raw material [1]. For example, a business-to-business (B2B) study indicates that those that have an appropriate delivery performance can have higher prices on their products, as well as gaining more customers due to their price flexibility [32]. Another example of a competitiveness strategy is the Fulfillment by Amazon (FBA) service, which provides a greater flexibility in their sales practices and manages the full compliance of a product from external suppliers after it has been purchased. In addition, a recent survey reported that 73% of FBA users have obtained increases in unit sales over 20% [33]. On the contrary, the low performance of deliveries causes a decrease in sales and even sale losses.

In addition, standardized work (SW) is a fundamental tool for solving manufacturing problems because it offers almost immediate results for the organizational performance, since it increases productivity and reduces delivery times [34]. Similarly, SW is a set of specific instructions that are required for assembling a product in the most efficient way, since it allows definition of the best methods and sequenced tasks needed for each production process and employee; consequently, it helps to reduce waste [34–36] and increase the well-being and performance of the human factor. In addition, SW is probably the most reliable method for performing any manufacturing task, since it is one of the safest and most efficient tools for meeting timely, orderly, and quality deliveries [37].

Table 1. Sustainability strategies according to the literature. Adapted from Aarseth et al. [23].

Sustainability strategies adopted by project organizations		
Strategy	**Description**	**Reference**
Developing sustainable supplier practices	Supporting suppliers in implementing sustainable practices such as, e.g., use of ecological materials and prefabrication.	Shi et al. [26]
Setting strategic and tactical sustainability goals	Focusing explicitly on sustainability issues when developing project strategies, paying special attention to instances where sustainability issues align with other concerns.	Martens and Carvalho [24]
Emphasizing sustainability in project design	Incorporating sustainability issues in early phases of projects and explicit project design documents. The methods are based on development of performance indicators (which may be used throughout the project life cycle) and appraisal techniques, such as lifecycle assessments and value management.	Zhong and Wu [27]
Sustainability strategies adopted by project hosts		
Strategy	**Description**	**Reference**
Influencing sustainability of project practices	Supporting the incorporation of sustainability into project practices and technical systems through, e.g., construction tools, prefabrication, and waste management systems.	Jaillon and Chi-Sun [25]
Setting sustainability policies	Defining sustainable project policies that include the development of laws and regulations, norms, plans, and guidelines to support sustainability on the project level, as well as executing governmental and regulatory tasks in a manner that emphasizes and promotes sustainability in projects carried out in the host region.	Block and Paredis [28]

Mutual sustainability strategies			
Strategy	**Description (project perspective)**	**Description (host perspective)**	**Reference**
Sustainability emphasis in project portfolio management	This relies on either using a framework for project selection or actively including sustainability as a dimension in early-phase appraisals.	Emphasizing sustainability issues when deciding which projects to fund and approve.	Sánchez [29]
Inclusion of sustainability-promoting actors in project organization	Selection and inclusion of actors that bring sustainability-promoting skills, capabilities, and roles to the project.	Inclusion of different authorities and NGO representatives to act as legitimacy actors in project organization, supporting multidisciplinarity in project organization.	Genus and Theobald [30]
Developing sustainability competencies	Expanding competencies and skill sets of project managers, e.g., by investing in formal training programs.	Facilitation of local decision-making and engagement of local stakeholders in the project's decision-making through, e.g., guidelines, norms, or financial incentives	Yunus and Yang [31]

Likewise, SW defines how each operator must perform each task or job in the production system; as a result, random tasks that reduce life cycle times are avoided [34,38]; in fact, SW uses takt-time to meet the customer demand [39]. Specifically, the main objective of SW involves eliminating Mura [40]; this is a general term for unevenness or irregularity in physical materials or in human condition, which is a key concept for performance improvement systems, since it is one of the three forms of waste that can be found in manufacturing systems (Muda, Mura, and Muri) [41]. Hence, SW does not mean that a work routine will be changed; instead, it implies that "it is the best method to know how to perform a task better" [38,42]. In addition, SW consists of three elements [34]: Uptime, work sequence, and standard inventory.

SW applications in productive systems are found in the work of Nallusamy [43], who applied line balancing and SW in the Computer Numerical Control (CNC) industry to reduce activities that did not add value to a product by 17%, while its production increased by five units per day with two employees, and up to seven units by day with a single employee. Similarly, Nallusamy and Saravanan [44] implemented these two tools in a manufacturing company to reduce cycle time and increase productivity. In addition, Mor et al. [34] implemented SW, obtaining a 31.6 s reduction in cycle times and 6.5% increase in production. Finally, Ordieres-Mere and Villalba-Diez [45] implemented SW in the inter-communication processes in the automotive industry to increase the optimization of the total performance by 4%.

In summary, SW helps to increase the competitiveness of companies because it is not only focused on controlling production processes, but it also minimizes costs and maximizes efficiency [46]. Specifically, in small and medium enterprises (SMEs), SW represents a tool that compensates for the lack of advanced manufacturing technology (AMT) in production processes; however, SW is often poorly implemented or misunderstood [34].

Lee et al. [47] define anthropometry as a measurement of the human body, which is necessary for the design of workstations, and multiple cases are reported; for example, Colim et al. [48] studied a furniture assembly workstation where most employees were continually exposed to risk factors for musculoskeletal disorders; they redesigned workstations by considering anthropometric data from employees and, as a result, body posture was improved and the risk of suffering skeletal muscle disorders was eliminated. Likewise, Kibria and Rafiquzzaman [49] indicate that working for long periods in a sitting position in front of a computer causes several types of pain, discomfort, and health problems in university teachers; therefore, workstation designs with an anthropometric approach were proposed. Finally, Lee and Cha [50] report that console operators in nuclear power plants face human–computer interaction problems due to inappropriate console design; consequently, they redesigned the consoles by considering anthropometry. In conclusion, based on the previous examples, the correct use of anthropometry in workstation redesign improves the well-being, health, comfort, and safety of operators [51].

Workstation design influences the postures and movements that operators perform during task execution [52]. The most basic movements are named Therbligs, which were introduced by Frank B. Gilbreth, who, in his early work in the study of movement, developed certain subdivisions or events that he considered common to all kinds of manual work. The term refers to 17 elemental subdivisions or basic movements. According to Palit and Setiawan [53], Therbligs can be effective or ineffective. On the one hand, effective Therbligs directly advance work progress and can often be shortened, but generally cannot be removed entirely. On the other hand, ineffective Therbligs do not advance the progress of the job and should be removed if possible. Some of the 17 Therbligs, along with their symbols, are Reach (RE), Move (M), Grasp (G), Assemble (A), and Disassemble (DA), to mention few. A complete view of the 17 Therbligs (effective or ineffective), their definitions, and their symbols can be seen in Palit and Setiawan [53] and Freivalds and Niebel [54]. According to Jia et al. [55], the Therblig is one of the basic concepts in the study of movement, and is defined as a basic energy demand unit. The basic idea of the study of movement is to divide the worker's operation into simple motion elements, which are Therbligs [55].

Concerning the relationship between anthropometry and sustainability, the literature mentions that a poor workplace design is a major risk factor responsible for the uncomfortable conditions that operators on assembly lines are exposed to, especially when operators are working multiple hours a day, decreasing their well-being [56]. As mentioned above, this poor design generates uncomfortable postures, causing musculoskeletal disorders. The anthropometric design of the workstations facilitates the sustainable development of the workplace and, therefore, of the operators [56].

Different authors, such as Kim et al. [57] and Nadadur and Parkinson [58], mention that anthropometry is essential to improve the sustainability and physical suitability of a workplace design. In addition, these authors suggest that anthropometry positively impacts sustainability by reducing the consumption of raw materials, increasing the useful life of products (including workstations), and considering the variability among the user population. Therefore, anthropometric design allows improvement of global sustainability by efficiently using available resources, prolonging the time of use of products, and increasing their versatility by satisfying different user populations.

The uniqueness of this research is that it proposes and integrates an approach by combining SW and the anthropometric design of workstations in the production processes in order to improve sustainability in manufacturing companies and well-being in operators. The integrated approach is illustrated in a real case study as a response to an industrial problem.

2. Methodology

The methodology presented in this research has a similar structure to that of Realyvásquez-Vargas et al. [59]; it includes the four stages presented in Figure 1.

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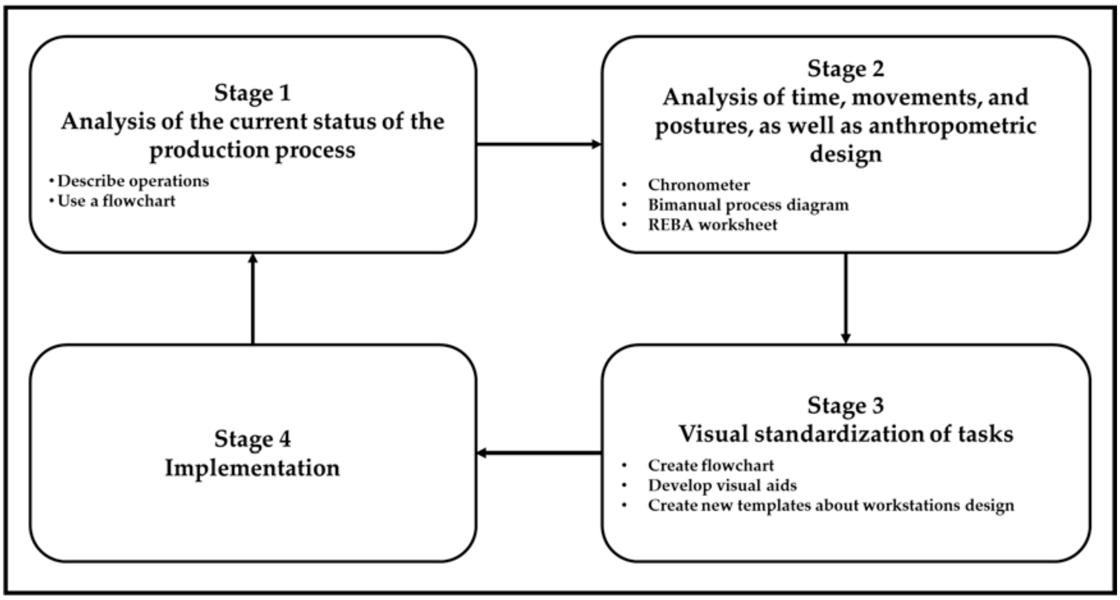

Figure 1. The integrated approach of standardized work (SW) and anthropometric workstation design.

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In the next sections, each stage is explained in detail.

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2.1. Stage 1. Analysis of the Current Status of the Production Process

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This stage consists of obtaining information on the current status of the production process, as well as performing a preliminary analysis. The following activities are performed: Describing workstations, creating diagrams about the current production process in the company, checking and analyzing the production process, identifying critical production process indicators, and providing an improvement production project for managers.

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In general terms, the deficiencies of the current production process are summarized; the proposal based on SW and on the anthropometric design is described, highlighting the benefits of a standardized process, where workstations are focused on the capabilities and limitations of operators. Specifically, the production process is analyzed along with the operators' assistance, because they have a better knowledge about the production process and they check the production tasks constantly to identify potential opportunities for improvement. Next, a production process flow chart is designed to visually represent the precise sequence of required tasks that operators must perform, which are described in detail at each workstation.

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2.2. Stage 2. Analysis of Times, Movements, and Postures, as well as Anthropometric Design

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In this stage, a management permission is granted to apply SW in anthropometric design and in the production process in workstations. The activities are focused on analyzing the production process by carrying out studies of times, movements, and postures adopted by the operators in the workstations. The activities are as follows: Study of times, study of movements, ergonomic evaluation of postures, balancing of production lines, and anthropometric redesign of workstations.

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These tasks seek to discover and eliminate the inefficiencies of time and movement when performing an activity, and thus to measure operators' performance [60] and improve their safety and well-being, as well as the interaction of the operator–workstation system [61]. In the time analysis, the number of cycles to be observed [54], the average time observed (OT) for each work cycle, and the normal time (NT) for each task are obtained; these are defined according to four

These tasks seek to discover and eliminate the inefficiencies of time and movement when performing an activity, and thus to measure operators' performance [60] and improve their safety and well-being, as well as the interaction of the operator–workstation system [61]. In the time analysis, the number of cycles to be observed [54], the average time observed (OT) for each work cycle, and the normal time (NT) for each task are obtained; these are defined according to four performance factors of the System of Westinghouse rating [54,62]. The standard time (ST) is obtained by assigning constant clearances and variables that the International Labor Organization (ILO) established. In addition, normal time and standard time are taken by applying Equations (1) and (2) [54].

$$NT = \left(\sum Performance\ factors\ +\ 1\right) \times OT \tag{1}$$

$$ST = \sum \left(Constant\ and\ variable\ allowances\ +\ 1\right) \times TN \tag{2}$$

In the movement analysis, effective and ineffective Therbligs are identified and analyzed, and the bimanual process diagram is constructed, eliminating ineffective Therbligs and the uncomfortable postures that may cause bottlenecks. According to Fieivalds and Niebel [54], this diagram shows all movements and delays made by the right and left hands, as well as the relationships among them. These authors mention that the main purpose of this diagram is to identify inefficient movement patterns and observe violations of the principles of motion economy. The bimanual process diagram has the advantage that it facilitates changing work methods; consequently, there is a balanced two-handed operation and a smoother and more rhythmic cycle that keeps both delays and operator fatigue to a minimum, which can be achieved [54].

Specifically, the movement analysis helps to determine which types of hand tools employees use the most in order to place these tools closer to redesigning the workstation [54]. In the posture analysis, the Rapid Entire Body Assessment (REBA) is applied [63,64], since it determines which level of risk operators are exposed to. [65].

The balancing of production lines refers to the balanced assignment of activities in an assembly line to meet the required production demand [66], where a unit cost analysis is performed to achieve it: First, the tasks from each work cycle are described and the cycle time is converted into a decimal format; second, the number of employees required in each workstation is defined and the total number of employees who are required per line is estimated. In addition, the time on the line, the percentage of equilibrium for each production line, the adjusted work cycle, and the production per hour, shift, and department are estimated. Third, the number of items that are manufactured by each operator and the production costs per unit are estimated. Subsequently, a possible work sequence is defined for the tasks that can be performed to maintain similar cycle times in each workstation, which allows the determination of the efficiency and the time of activities in each line. Then, the number of employees needed in each production line to meet the customer demand is estimated as well. Finally, Equations (3)–(9) are applied to perform this analysis [67].

$$Balancing\ percentage = \frac{Total\ operator\ time}{Time\ in\ line} \times 100 \tag{3}$$

$$Adjusted\ work\ cycle = \frac{Control\ cycle}{Balancing\ percentage} \times 100 \tag{4}$$

$$Production\ per\ hour = \frac{60\ minutes}{Adjusted\ work\ cycle} \tag{5}$$

$$Production\ per\ shift = \frac{Units}{Hour} \times \frac{Hours}{Shift} \tag{6}$$

$$Production\ per\ department = Production\ per\ shift \times Number\ of\ assembly\ lines \tag{7}$$

$$\frac{Units}{operators} = \frac{Units\ per\ shift}{Total\ operators} \quad (8)$$

$$Cost\ per\ unit = \frac{Total\ operators \times Daily\ salary}{Units\ per\ shift} \quad (9)$$

Similarly, the workstations are redesigned using the bimanual process diagram developed in Stage 1. Therefore, an anthropometric study is carried out among the operators to define the minimum and maximum range areas, where the 5th percentile of the forearm, the 5th percentile of the extended arm, and the 95th percentile of the shoulder width are required [68]. In addition, workstations are adjusted considering the minimum and maximum range areas, and the locations of hand tools are determined according to their frequencies of use. The final measurements of the workstations were obtained by applying Equation (10) [68].

$$P_k = \overline{X} + \sigma Z \quad (10)$$

In Equation (10), P_k represents the length obtained for the percentile k, $\overline{X}$ is the average of the data of the measurements for a certain part of the body, σ represents the standard deviation of the data, and Z represents the value of the normal distribution for the percentile k. Finally, experimental runs are performed on production lines with the original and proposed methods to compare the times, movements, and postures that are used, as well as the cost of production per unit.

2.3. Stage 3. Visual Standardization of Tasks

The objective of this stage is to provide a visual support for the proposed method; therefore, the principal tasks to carry out are: Creating flowcharts about the adjusting process, developing visual aids for employees, and creating new templates about the design of workstations.

Specifically, flowcharts help to illustrate the sequence of tasks that must be performed, since they are established in a bimanual process diagram. Therefore, the required visual aids are prepared for each workstation with photographs taken of the tasks in order to highlight the most important points and indicate the necessary hand tools. Visual aids are developed seeking clarity, visibility, and simplicity. Finally, the templates are designed in real size using workstation images and a bimanual process diagram, to remain fixed in the corresponding workstation. These images should display the locations of hand tool and help employees to locate them quickly.

2.4. Stage 4. Implementation

In this stage, the new methods and standardized work are implemented in the production lines. In addition, the results obtained are compared with the objectives initially set to determine if they are achieved. In the case that the new methods are effective, production lines are adjusted with the new production methods, and the adjusted workstations are established, including the designed visual aids and templates.

3. Results

3.1. Context of the Case Study and Research Objective

A publishing press with 150 employees has mechanical and manual tasks in its production process. The mechanical tasks are prepress, printing, spine gluing, bending, printing, gluing, and cutting, while manual tasks include bending, collating, crimping, and box-build assembly. The principal offered services are box packaging and assembly, as well as printing and publication of manuals, which represent 70% of its operations. The 30% left includes the manufacture of file folders, labels, books, magazines, and catalogs. The company is organized in six departments: Prepress, Printing, Machine Assembly, Manual Assembly, Edition, and Box Assembly.

The present research is particularly carried out in the Box Assembly Department, where the product packaging is not included. The production process is integrated by four assembly lines: Five operators, one quality inspector, and one packing operator oversee each production line, which is shown in Figure 2.

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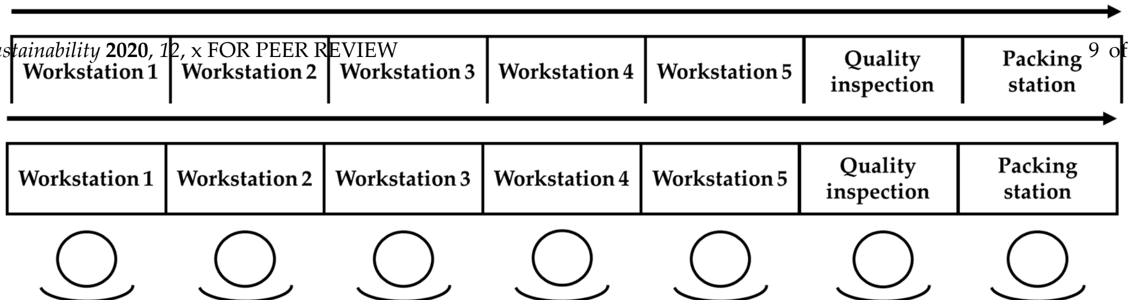

Figure 2. Current layout distribution of production lines in the Box Assembly department.

Currently, the daily demand is 650 units for the X model, but the assembly line produces only 350 units; therefore, extra time must be used (see Table 2), which implies a higher production process cost, and employees are sometimes fatigued or get back pain or a type of pain in their arms or feet due to the long working hours, where body postures are adopted from the workstations (during the June–August 2019 period, at least 20 cases were reported). Figure 3 shows the positions adopted by operators.

Table 2. Difference in production as well as equivalence in overtime from one production line.

	Production	Demand	Difference in production	Equivalence in extra work hours	Equivalence in extra workdays
Day	350	650	300	33.33	3.7
Week	1750	3250	1500	194.44	21.6
Month	7000	13000	6000	777.77	86.41

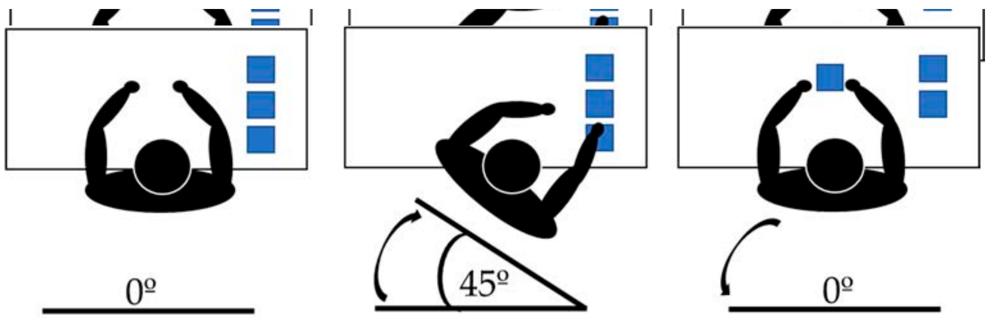

Figure 3. Postures adopted by operators.

In a preliminary analysis, it was determined that one or more of the following undesirable processes is experienced in the Box Assembly department: Bottlenecks, production delays, late deliveries, overtime, unnecessary body movements, uncomfortable body posture costs, and high costs due to unbalanced production lines. Due to this situation, production costs increase; consequently, the corporate reputation is negatively affected because the customer demand is not achieved. In addition, there are risks of absenteeism or resignation by operators if the workstation design is not improved to eliminate unsatisfactory body postures.

As a matter of fact, the general objective of this research is to increase the production rate of the assembly line of box X through the standardization of the production process and to anthropometrically redesign the workstation; to achieve the previous objective, it is sought to increase production levels by 20%, reduce standard time by 15%, and reduce unit cost by 40%.

This case study is designed from the perspective of critical realism, generalizing empirical and theoretical findings [...] [69] indicates, since [...] theory is developed, it needs to be tested empirically, and case studies are an appropriate way to accomplish this. Similarly, Easton [70] proposes critical realism as a [...]

double-sided adhesive tape is placed on the back of the box; a label with the customer's name will be included as well. Then, operators place four strips of double-sided adhesive tape on the contour of a quadrangular aperture, which are subsequently removed from the box, leaving the rubber on display. Finally, it is sent to station 2.

At station 2, operators place next to the box a strip of double-sided adhesive tape that bends. Subsequently, a strip of a double-sided mustard adhesive tape and a quadrangular piece of clear plastic are placed on the rubber, which must expose the adhesive tape strips that were placed at station 1. Then, operators must clean the clear plastic using an alcohol-dipped ball of cotton to erase any fingerprints, and the box is sent to station 3.

At station 3, operators take the box and remove the face of the double-sided label adhesive tape that was placed at station 1; then, the customer's name tag is placed, as well as another double-sided folding tape. In addition, two magnets are placed in the space that is in the quadrangular plastic; then, the magnets are coated with black adhesive tape strips, and the box is sent to station 4.

At station 4, operators take the box and remove the remaining mustard adhesive tape, as well as the double-flex adhesive tape, and countermeasures are inserted—one at the bottom and one at the top of the box. Then, the box is assembled by pasting the lid of the box, and it is sent to station 5. Finally, operators at station 5 take the box and place double-sided adhesive tape in the base of the box, and then place double-sided adhesive tape on one of the box tabs and remove it. Then, a box tab is stuck to the other side of the box to shape it. In the end, the box is transferred to the quality supervision station.

redesign the workstations in it. In order to achieve the previous objective, it is sought to increase production levels by 20%, reduce standard time by 15%, and reduce unit cost by 40%.

This case study is used because, from the perspective of critical realism, generalizing empirical and theoretical findings is not enough, as Tsang [69] indicates, since fallibilism implies that once a theory is developed, it needs to be tested empirically, and case studies are an appropriate way to accomplish this. Similarly, Easton [70] proposes critical realism as a coherent, rigorous, and novel philosophical position, which supports the research of a single case as an investigative approach, but provides useful implications for a theoretical framework.

3.2. Results at Stage 1

A flowchart was created using the company's current manufacturing system for the box model X, which is shown in Figure 4. In addition, a description was made about the operations that are required in order to have an appropriate understanding about the production process.

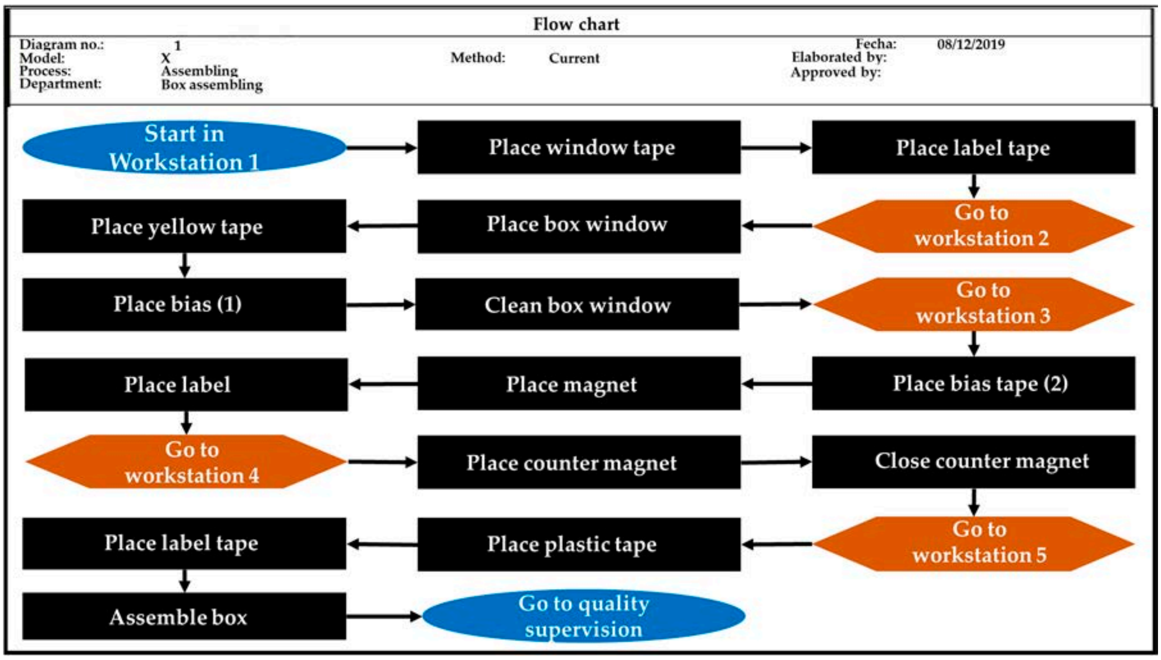

Figure 4. Flowchart for the current production process of the box model X.

Figure 4. Flowchart for the current production process of the box model X.

3.3. Results at Stage 2

Table 3 shows information on the allowances and performance factors that are assigned to each operator at station 1. For instance, in the performance factor case, the effort rating factor for station 1 (operator 1) was 0.03; this indicates that the operator had an appropriate effort. Regarding the consistency factor, a value of 0.02 was obtained; this indicates that the operator had an acceptable

At station 1, operators pick the box from the right side and place it in front, where a strip of double-sided adhesive tape is placed on the back of the box; a label with the customer's name will be included as well. Then, operators place four strips of double-sided adhesive tape on the contour of a quadrangular aperture, which are subsequently removed from the box, leaving the rubber on display. Finally, it is sent to station 2.

At station 2, operators place next to the box a strip of double-sided adhesive tape that bends. Subsequently, a strip of a double-sided mustard adhesive tape and a quadrangular piece of clear plastic are placed on the rubber, which must expose the adhesive tape strips that were placed at station 1. Then, operators must clean the clear plastic using an alcohol-dipped ball of cotton to erase any fingerprints, and the box is sent to station 3.

At station 3, operators take the box and remove the face of the double-sided label adhesive tape that was placed at station 1; then, the customer's name tag is placed, as well as another double-sided folding tape. In addition, two magnets are placed in the space that is in the quadrangular plastic; then, the magnets are coated with black adhesive tape strips, and the box is sent to station 4.

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of the box. Then, the box is assembled by pasting the lid of the box, and it is sent to station 5. Finally, operators at station 5 take the box and place double-sided adhesive tape in the base of the box, and then place double-sided adhesive tape on one of the box tabs and remove it. Then, a box tab is stuck to the other side of the box to shape it. In the end, the box is transferred to the quality supervision station.

3.3. Results at Stage 2

Table 3 shows information on the allowances and performance factors that are assigned to each original station. For instance, in the performance factor case, the effort clearance factor for station 1 (operator 1) was 0.03; this indicates that the operator had an appropriate effort. Regarding the consistency factor, a clearance of −0.02 was obtained; this indicates that the operator had an acceptable consistency. The same happened with the other slacks from the other factors for each station. Finally, slack scores were added to each station, one was added, and the total was obtained. In fact, the same procedure was applied to obtain the constant and variable allowances.

Table 3. Constant and variable allowances and performance factors in original stations.

	Constant and variable allowances				
	Personal	**Basic fatigue**	**Standing allowance**	**Fine work**	**Total**
Station 1	0.05	0.04	0.02		1.11
Station 2	0.05	0.04		0.02	1.11
Station 3	0.05	0.04			1.09
Station 4	0.05	0.04	0.02		1.11
Station 5	0.05	0.04			1.09
	Performance Factors				
	Skill	**Effort**	**Consistency**	**Conditions**	**Total**
Station 1	0.06	0.03	−0.02	−0.03	1.04
Station 2	0.03	0.02	0.01	−0.03	1.03
Station 3	0.02	0.03	−0.03	0	1.02
Station 4	0.03	0.02	−0.03	−0.02	1.0
Station 5	0.03	0.02	−0.02	−0.03	1.0

Table 4 shows the estimated OT, NT, and ST. The STs in stations 3 and 4 presented a difference of 17 and 35 s with respect to the shortest ST (station 5). The total ST was 4.07 min for the original production lines.

Table 4. Time estimated in original stations.

Station	**Time in Each Station (sec)**		
	Observed Time (OT)	**Normal Time (NT)**	**Standard Time (ST)**
Station 1	37	38	43
Station 2	36	37	41
Station 3	48	49	53
Station 4	64	64	71
Station 5	36	36	36

Furthermore, Table 5 shows the results from the movement analysis for each of the operations included in the flowchart (Figure 4). In fact, 230 inefficient Therbligs were obtained, of which 33 were detected in task 9 (that is, placing the plastic adhesive tape); thus, this was the task with the most inefficient Therbligs. In addition, for the evaluation of postural load, a score of 8 was obtained with the REBA method; therefore, the risk of suffering from musculoskeletal disorders turned out to be high, and changes in the design of workstations are required [71]. In addition, Table 6 shows the anthropometric measurements obtained from the operators for the redesign of workstations.

Table 5. Ineffective Therbligs from the original production method for the box assembly process.

No of Task	Operation Name	Use of the Left Hand	Use of the Right Hand	Therbligs
1	Placing the double-sided adhesive tape	8	9	17
2	Placing the window of the box	7	1	8
3	Cleaning the window of the box	12	6	18
4	Placing a countermagnet in the upper side of the box	0	5	5
5	Placing the black adhesive tape	13	6	19
6	Placing another countermagnet in the bottom side of the box	4	4	8
7	Placing the bias adhesive tape	12	12	24
8	Placing the mustard adhesive tape	12	12	24
9	Placing the clear plastic adhesive tape	10	23	33
10	Removing the flap adhesive tape	10	15	25
11	Placing the label adhesive tape	8	5	13
12	Placing the label of the customer	10	4	14
13	Securing the magnetic closure in the box	4	3	7
14	Assembling the box	9	6	15
	Total			230

Table 6. Anthropometric measurements to redesign the production process in workstations.

Operator	Fore Arm (cm)	Extended Arm (cm)	Back (cm)
1	50	74	40
2	42	64	43
3	47	71	39
4	44	74	41
5	45	70	42
6	37	60	40
7	40	64	38
8	40	66	35
9	49	71	39
10	44	66	40
11	41	66	40
12	43	72	40
13	41	60	34
14	49	76	38
15	39	66	38
16	41	64	43
17	42	65	35
18	42	65	36
19	38	61	38
20	40	62	39
Average (cm)	43	67	39

Table 7 presents the results from the production line balance as well as the unit cost analysis, which is related to the original method that is performed by five operators in the production line. It is observed that the total cycle time of the model X is 4.12 min. In the same way, the control cycle of the model X corresponds to the highest time between operating times, which is 1.18 min. The average time in the production line is 5.92 min, which represents the outcome of multiplying the control cycle in the production process by the number of operators who are assigned to the production line, which is five employees in this case. Therefore, the assembly lines are balanced by about 70%, and the unit cost is 1.39 Mexican pesos (that is, 0.072 USD).

Table 7. Unit cost–production line balance analysis from the original production method for the box assembly process.

Station	Operation Name	Average Cycle Time	Min 0:01:00	Operators
1	Placing the double-sided adhesive tape	0:00:42	0.7	1
2	Placing the box window, the mustard adhesive tape, and the bias adhesive tape	0:00:41	0.68	1
3	Placing a countermagnet in the upper side of the box, the bias adhesive tape and label, and cleaning the box window	0:00:53	0.88	1
4	Placing another countermagnet in the bottom side of the box to close the box	0:01:11	1.18	1
5	Placing the flap adhesive tape and the clear plastic adhesive tape to assemble the box	0:00:40	0.67	1
	Total operator time	0:04:07	4.12	5
	Total of the control cycle		1.18	
	Operators		5	
	Average time in the production line		5.92	
	Percentage balanced in the assembly line		70%	
	Adjusting of the cycle time		1.7	
	Total of production per hour		35	
	Total of production per shift		318	
	Total of production per department		1588	
	Total of units/operators required		64	
	Unit cost (Mexican peso)		$1.39	

Based on this analysis, it is established that the 1st, 7th, 8th, 9th, 10th, and 11th tasks from Table 5 can be performed at the same time before the other tasks. In the same way, it is shown that all 13 tasks must be performed before the 14th task is completed. The present results are used, along with the report regarding the positional weight rank for each task, in order to create a new distribution of the box assembly process in only four workstations, as is shown in Table 8. Specifically, this means that the production line length is reduced when the assembly line is balanced due to the cycle time of new operations [67]. In addition, with this type of distribution in the box assembly process, the largest cycle time difference between two operations is 8 s, which has a difference of 27 s when it is compared with the original distribution of the production process.

Figure 5 shows the redesigned workstations from an anthropometric approach: The image in A) illustrates the general proposed model, while the images in B), C), D), and E) represent the individual redesigns for the stations 1, 2, 3, and 4, as well as their assigned locations to place the required items and hand tools. After an anthropometric redesign of the workstations, the postural load score with the REBA method was 3; therefore, the risk of suffering musculoskeletal disorders was low [71].

The results show the estimated standard time (ST) in the production line, which is 3.32 min; that is, 45 s less when it is compared with the original standard time in the production line (18% less). Table 9 presents the cycle time from each redesigned station, for which it is determined that the estimation time difference between two stations is not over 6 s.

Regarding the analysis of the time in the redesigned process, only 78 inefficient Therbligs were detected, which represents a reduction of 66.1% when compared with the original production process. In addition, Table 10 displays the results that were obtained from this analysis; the most inefficient movements were retrieved from Operation 1.

Furthermore, Table 11 presents the results of the unit cost as well as the analysis of the production line balance in the adjusted production process. Specifically, the production line balance increased from 70% to 97%, indicating the smooth flow of the production process where any bottleneck was presented. In addition, the unit cost decreased by 58.27%, from 1.39 to 0.58 Mexican pesos (0.072 to 0.030 USD). In addition, it can be observed that the number of operators per assembly line decreased from five to four.

Table 8. Redesign of the box assembly process operations.

Station 1		Station 2		Station 3		Station 4	
Placing the double-sided adhesive tape	(16)	Placing the window adhesive tape	(43)	Placing the window of the box	(31)	Placing another countermagnet in the bottom of the box	(8)
Placing the mustard adhesive tape	(8)	Placing the plastic adhesive tape	(8)	Placing a countermagnet in the upper side of the box	(8)	Securing the magnetic closure of the box	(35)
Placing the flap adhesive tape	(7)			Placing the clear plastic adhesive tape	(8)	Assembling the box	(16)
Placing the label adhesive tape	(8)			Cleaning the window of the box	(4)		
Placing the label of	(14)						
			51		51		59

each parenthesis indicates the cycle time (sec) from each operation.

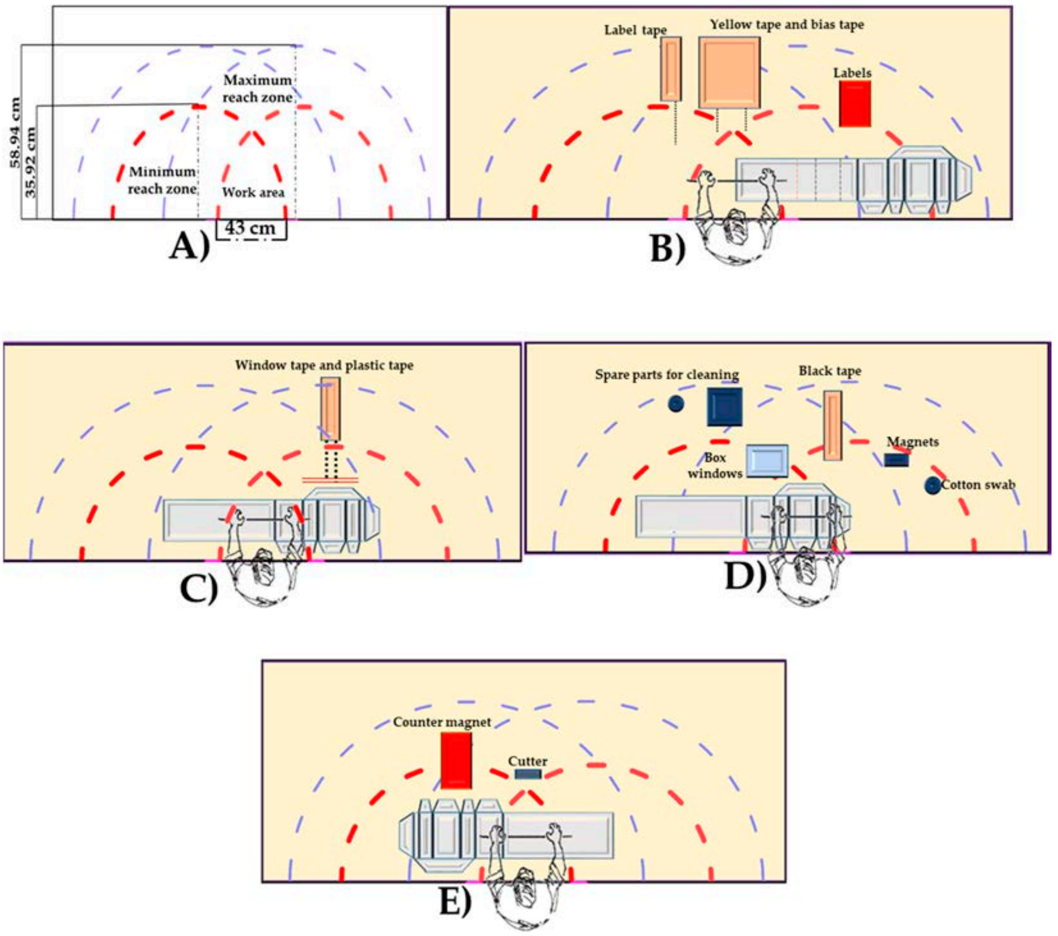


Figure 5. Workstations' anthropometric redesigns: (**A**) Overall design of workstations, (**B**) station 1, (**C**) station 2, (**D**) station 3, and (**E**) station 4.

Figure 5. Workstations' anthropometric redesigns: A) Overall design of workstations, B) station 1, C) station 2, D) station 3, and E) station 4.

Table 10. Ineffective Therbligs from the redesigned production method for the box assembly process.

Station	Operation name	Use of the left hand	Use of the right hand	Therbligs
1	Placing the double-sided adhesive tape Placing the mustard adhesive tape Placing the flap adhesive tape Placing the label adhesive tape Place the label of the customer	20	9	29
2	Placing the window tape Placing the clear plastic adhesive tape	17	7	24
	Placing the window of the box Placing a countermagnet in the upper side of the			

Table 9. Estimations of time from the redesigned production method for the box assembly process.

Workstation	Time Per Workstation (sec)		
	Observed Time (OT)	Normal Time (NT)	Standard Time (ST)
Station 1	48	47	51
Station 2	43	42	46
Station 3	48	47	51
Station 4	47	47	51
Total	186	183	199

Table 10. Ineffective Therbligs from the redesigned production method for the box assembly process.

Station	Operation Name	Use of the Left Hand	Use of the Right Hand	Therbligs
1	Placing the double-sided adhesive tape Placing the mustard adhesive tape Placing the flap adhesive tape Placing the label adhesive tape Place the label of the customer	20	9	29
2	Placing the window tape Placing the clear plastic adhesive tape	17	7	24
3	Placing the window of the box Placing a countermagnet in the upper side of the box Placing the clear plastic adhesive tape Cleaning the window of the box	6	9	15
4	Placing another countermagnet in the bottom side of the box Securing the magnet closure Assembling the box	8	2	10
	Total	51	27	78

Table 11. Unit cost–production line balance analysis of the redesigned production method for the box assembly process.

Station	Operation name	Average cycle time	Min 00:01:00	Operators
1	Placing the mustard adhesive tape, the double-sided adhesive tape, the flap adhesive tape, the label adhesive tape, and the label of the customer	00:00:51	0.86	1
2	Placing the window adhesive tape as well as the clear plastic adhesive tape	00:00:46	0.76	1
3	Placing the window of the box, one countermagnet in the upper side of the box, and the clear plastic adhesive tape, as well as cleaning the window of the box	00:00:51	0.86	1
4	Placing and securing the magnet closure with the second countermagnet, as well as assembling the box	00:00:51	0.86	1
	Total operator time	00:03:19	3.32	4
	Total time per operator		3.32	
	Total of the control cycle		0.86	
	Operators		4	
	Average time in the production line		3.44	
	Percentage balanced in the assembly line		97%	
	Adjusting of the cycle time		0.89	
	Total of production per hour		67	
	Total of production per shift		606	
	Total of production per department		3030	
	Total of units/operators required		152	
	Unit cost (Mexican peso)		$0.58	

3.4. Results at Stage 3

In this stage, the visual aids and templates for redesigning workstations were developed; headings of visual aids include the following aspects: Name of the department, number of the production line, number of the station, name of the task, model of the box, number of the page, and date of issue and of the latest revision. Particularly, the right side of the visual aid addresses aspects concerning a specific task, which reminds operators about the importance of each detail in every task. In the instruction section, a list of the hand tools that are necessary is presented; therefore, operators should ensure that the materials and tools required are arranged before starting to work. Finally, in the materials section, some aspects are included that must be reported by the personnel who produce the visual aids.

In fact, six visual aids were created; one for the workstations 1 and 2, as well as two for workstations 3 and 4. Figures 6 and 7 portray some examples about the visual aids that were created. Specifically, visual aids include an image and a brief description about the steps to follow in each task. In addition, each step is numbered to provide an accurate and logical sequence for the tasks in order to avoid errors or confusion.

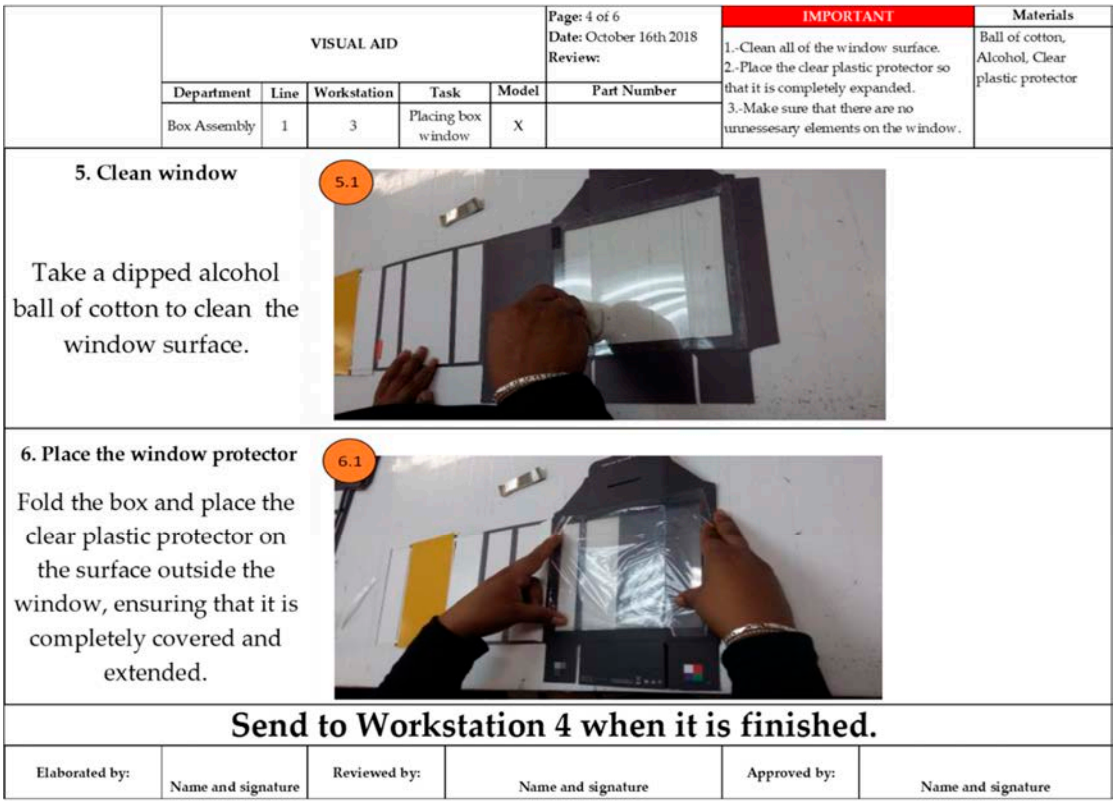
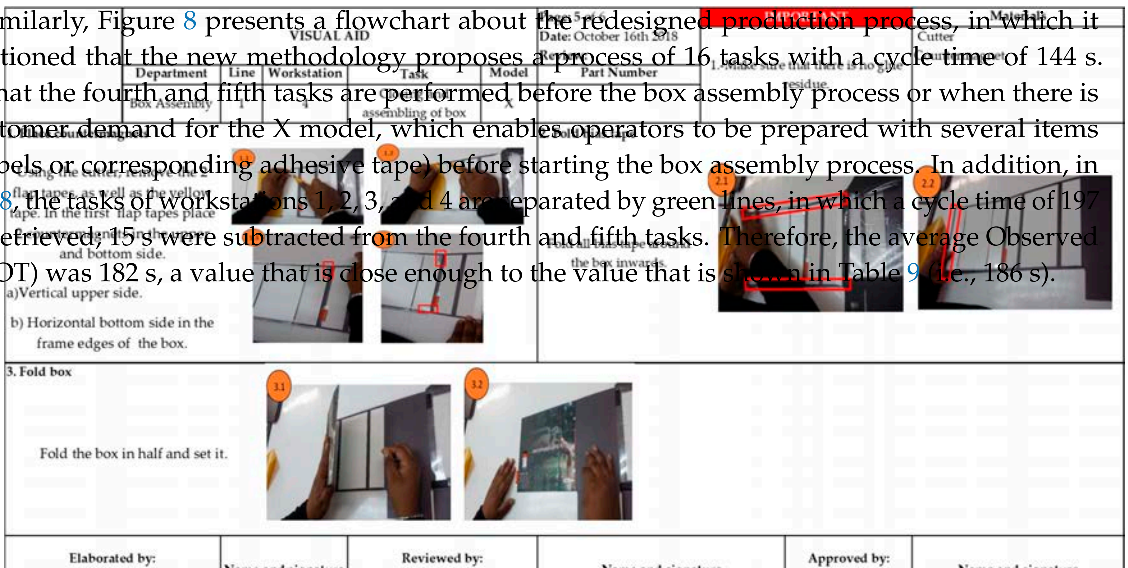


Figure 6. Visual aid for the redesigned station 3.

Similarly, Figure 8 presents a flowchart about the redesigned production process, in which it is mentioned that the new methodology proposes a process of 16 tasks with a cycle time of 144 s. Note that the fourth and fifth tasks are performed before the box assembly process or when there is no customer demand for the X model, which enables operators to be prepared with several items (i.e., labels or corresponding adhesive tape) before starting the box assembly process. In addition, in Figure 8, the tasks of workstations 1, 2, 3, and 4 are separated by green lines, in which a cycle time of 197 s was retrieved; 15 s were subtracted from the fourth and fifth tasks. Therefore, the average Observed Time (OT) was 182 s, a value that is close enough to the value that is shown in Table 9 (i.e., 186 s).



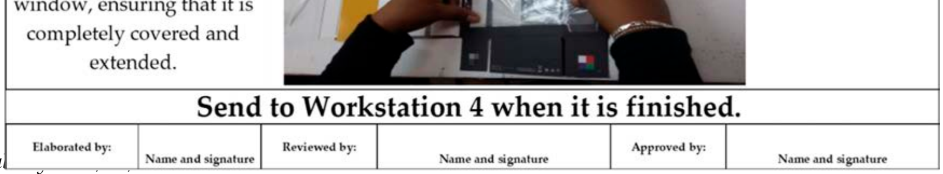
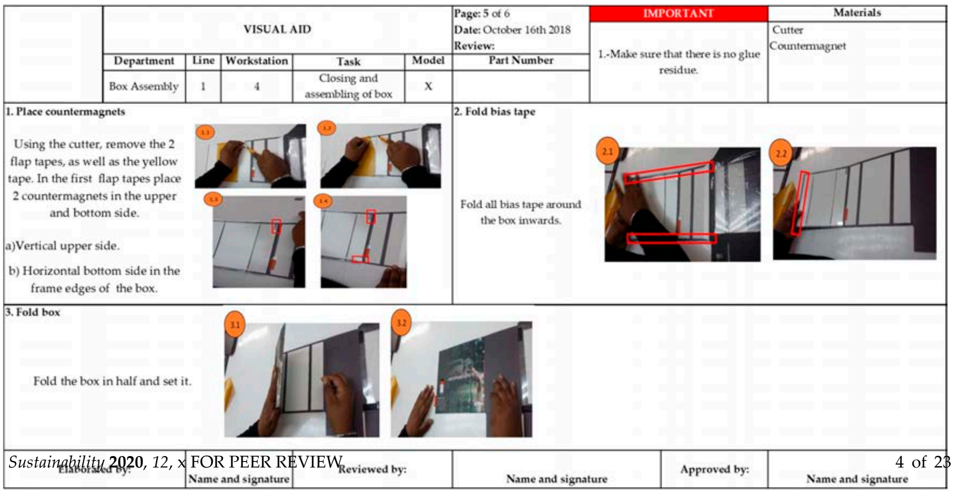


Figure 6. Visual aid for the redesigned station 3.



197 s was retrieved; 15 s were subtracted from the fourth and fifth tasks. Therefore, the average Observed Time (OT) was 182 s, a value that is close enough to the value that is shown in Table 9 (i.e., 186 s).

Figure 7. Visual aid for the redesigned station 4.

Similarly, Figure 8 presents a flowchart about the redesigned production process, in which it is mentioned t... te that the fou... no customer de... e., labels or co... in Figure 8, the... of

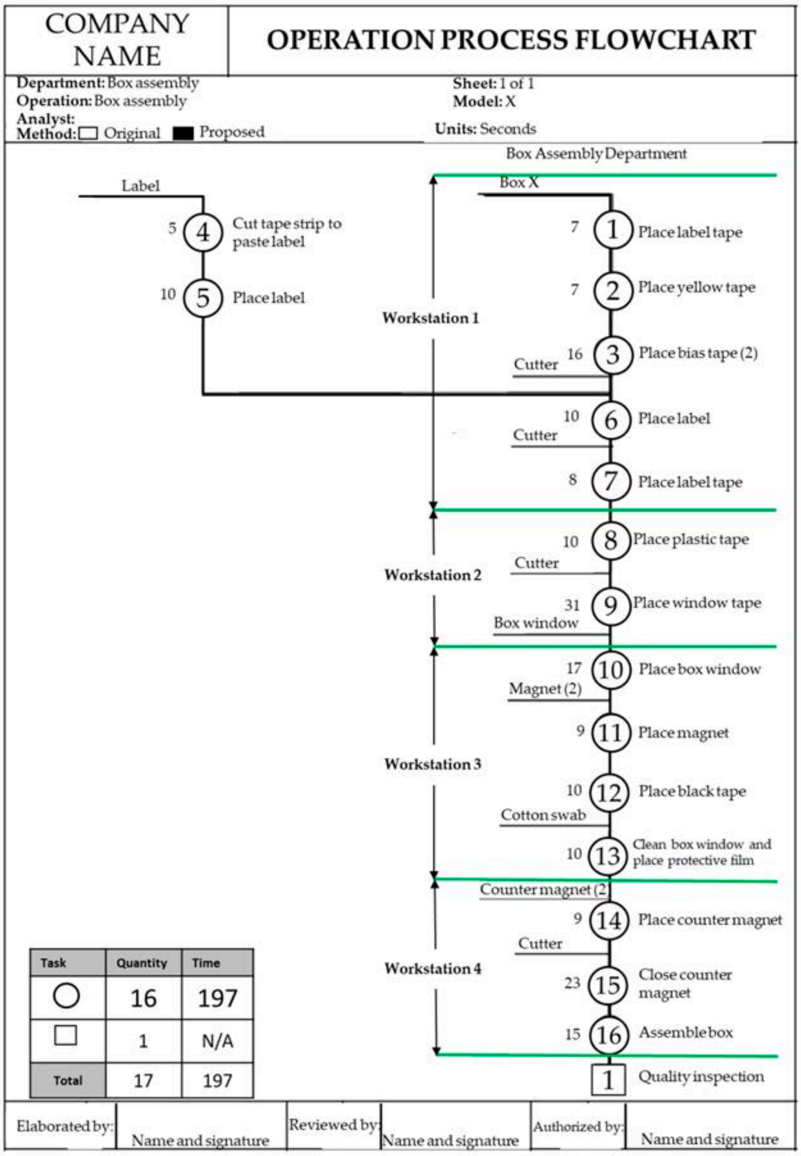


Figure 8. Process flowchart of the redesigned process.

Figure 8. Process flowchart of the redesigned process.

3.5. Stage 4. Implementation

After the production process was standardized, three production lines were monitored by four operators in each production line, together with a fourth line with five operators that was supervised for a week, in order to estimate the increase in the production process. The three production lines worked by applying the redesigned production process, while the fourth line worked by applying

3.5. Stage 4. Implementation

After the production process was standardized, three production lines were monitored by four operators in each production line, together with a fourth line with five operators that was supervised for a week, in order to estimate the increase in the production process. The three production lines worked by applying the redesigned production process, while the fourth line worked by applying the original production method. A significant increase in production was detected in the three production lines, where 2942, 2963, and 2971 units were produced, respectively. On the other hand, in the fourth production line, only 1813 units were produced with the original process method.

Since the five production lines worked completely under the redesigned process, the company reported a 42.62% increase in production. In addition, by having five production lines instead of four, the company increased its production process by 45.9%. In addition, the company average increased the daily production from 1400 to 3050 units, representing an increase of 1650 units; the results of this analysis are presented in Table 12.

Table 12. Analysis of the production process increase.

	Original Process Method	Redesigned Production Process	Production Increase	Increase Percentage
Production line	350	610	+260	+42.62%
Total production	1400	3050	+1650	+45.9%

Finally, it is worth mentioning that after five months of monitoring the proposed method, there were no injuries or any type of discomfort reported by operators from the Box Assembly department. In addition, the anthropometric redesign of workstations and the redesign of the production process had a positive impact on the operators' health and safety. On the one hand, the anthropometric design of the workstations prevented operators from adopting uncomfortable body postures [72]; on the other hand, the redesigning of the production process method eliminated unnecessary movements, since uncomfortable body postures and repetitive movements are the cause of musculoskeletal disorders (MSD) [72]. Therefore, implementing the redesigned process method will prevent operators from suffering MSD or any type of physical fatigue because overtime is not required.

4. Conclusions

This paper has shown the development of a new and reliable strategy to achieve sustainable workplaces in manufacturing industries. The strategy is an integrated approach consisting of work standardization (as a lean manufacturing tool), basic industrial engineering tools (time and movement studies), and human factor tools (anthropometric design). This integrated approach can have a significant impact, first, on the sustainability of operators and manufacturing companies, and then on their performance. This impact is manifested by removing barriers to sustainability, such as high costs, as well as with the improvement in the use of resources by the company. Moreover, the integrated approach helps increase productivity, punctually meet demand, increase competitiveness, minimize waste (such as over-processing), and decrease the number of ineffective Therbligs in the production process. Thus, the integrated approach helps improve sustainability.

In the present case study, ineffective Therbligs decreased by 66% (from 230 to 78), and the Standard Time (ST) decreased from 244 to 199 s; in other words, it was reduced by 18.44%. In addition, the results demonstrate that when a specific task is standardized, fewer employees are required in production lines; as a result, an opportunity for companies to optimize the human factor by installing redesigned production lines with other types of operators is presented; consequently, the production of the company will increase. In this case study, the number of operators was reduced from five to four in each production line, which is 20%; therefore, the company installed a redesigned production line. Similarly, the results show that the integrated approach of standardization of work and the anthropometric design of workstations has a positive impact on the percentage of the production line balance, which helps reduce the unit cost of production as well as the compliance rate of demand increases. In the present case study, the percentage of the production line balance increased from 70% to 97%, while the production process increased by 63.2%, which represents 229 daily units per assembly line.

All of the specific results obtained in the present case study are indicators that the manufacturing company improved the management of its resources (raw materials, time, and human resources); consequently, it improved its sustainability. Similarly, within the company, operators improved their quality of life and well-being, since they did not have to adopt undesired postures or perform uncomfortable hand movements. Outside the company, operators improved their quality of life and well-being, since the overtime was eliminated, they did not arrive at home tired, and they spent more time with their families.

The integrated approach applied and the results obtained have the practical value of being used as an improvement reference by manufacturing companies in mass production in which there is a single production process for specific products that are offered; consequently, the work can be standardized. The present case study has the limitations that it was applied in a small company and only in four production lines. Then, the sample of participants for obtaining anthropometric data was relatively small. In big manufacturing companies, collecting anthropometric data can be time-consuming, which can represent a disadvantage of the integrated approach.

As the integrated approach was implemented only in the production process of the box model X, future practical work should be directed at applying this approach in other box models, types of products (books and stamping, to mention few), and departments within the company. Similarly, there is an opportunity to apply this approach in other companies, whether they belong to the manufacturing sector or to another sector, regardless of their size. Future theoretical work should be directed at proposing and experimenting with the integration of more and different types of tools that are applied in manufacturing systems, as well as their impact on sustainability.

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