UNIVERSIDAD TÉCNICA DE AMBATO

FACULTAD DE INGENIERÍA EN SISTEMAS, ELECTRÓNICA E INDUSTRIAL

MAESTRIA EN PRODUCCIÓN Y OPERACIONES INDUSTRIALES

Tema: REVISIÓN SISTEMÁTICA DE LA UTILIZACIÓN DE LOT STREAMING EN DIFERENTES TIPOS DE PROCESOS DE FABRICACIÓN CON EL OBJETIVO DE REDUCIR EL MAKESPAN.

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A Dios y a María Santísima por otorgarme el milagro de la vida y guiar mis pasos en cada despertar, permitiéndome formularme planes y metas que poco a poco se han ido cumpliendo.

A mi padre que desde el cielo me sigue dando su bendición y quien ha sido durante mi vida el motor de desarrollo y superación con su ejemplo de valía y honestidad, gracias especiales por formarme en la fe y en la superación, a mi madre y mi hermano que continúan junto a mi haciéndome compañía y siendo la razón para que cada día luche por seguir adelante.

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DEDICATORIA

A mi ángel de la guarda, mi padre, Octavio Rodrigo Salazar Chico, que aunque ya no esté físicamente junto a mí, en el transcurso de los años que me pudo acompañar, supo guiarme y mostrarme que aunque el camino de mi vida no ha sido fácil, siempre valía la pena vivirlo, salir adelante e ir mejorando cada día más.

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A todas y cada una de las personas que acompañaron de una u otra persona mis días de motivación, pero principalmente esos días de desasosiego y de frustración.

CAPÍTULO I

EL PROBLEMA DE INVESTIGACIÓN

1.1 Introducción

La Administración de Operaciones enfocada a la Manufactura se refiere al uso de estrategias para combinar los recursos de una organización con el fin de elaborar productos de consumo [1]. Dentro de su estudio se ha diferenciado algunas dimensiones para establecer una posición competitiva de la empresa, entre estas dimensiones existen dos de gran valía, el costo de producción que en consecuencia recae en el precio final de un producto, el que se espera que sea cada vez más bajo a fin de ganar un nicho de mercado; la otra dimensión es la velocidad de entrega que debe ser disminuida con el objetivo de ser una mejor opción con respecto a los demás competidores [2]. Los esfuerzos que las industrias han realizado en los de mejorar estas dos dimensiones se consideran fundamentales dentro de cualquier Plan de Mejora Institucional.

La producción por lotes y el dimensionamiento de los mismos (Lot Streaming) se relaciona directamente con la velocidad a la que se entrega el producto final (Makespan), por ende con el tiempo de operación o fabricación, en diferentes entornos de producción y respondiendo a diferentes dispositivos y sistemas avanzados, a lo largo del mundo, haciendo un uso cada vez más exponencial de las herramientas tecnológicas y de procesamiento de datos existentes.

Si bien los estudios de ventaja competitiva y control de la producción vienen desde el principio de los tiempos, no se pueden considerar como que la materia haya quedado en desuso o se haya extinguido, debido a que las industrias existen y se van mejorando día a día, las estrategias que se adopten para generar mayor satisfacción en los clientes son de estudio actual, reciente y de alto impacto, considerándose además en un tema de significancia universal.

Este estudio pretende realizar un análisis de los artículos científicos publicados en revistas indexadas en lo que se refiere a la aplicación del Lot Streaming en diferentes entornos de los procesos productivos, orientados principalmente a la reducción del Makespan, en un enfoque lo más amplio posible, es decir, sin seguir un filtro de región o país de publicación, pero sí segregando la información según el año de publicación, que será desde el año 2010 al año 2020, con preponderancia o casi exclusividad del idioma de publicación inglés. Este análisis se esquematiza en una revisión sistemática, que tiene su base en la Herramienta Prisma, que es una propuesta de normas que seguir para mejorar este tipo de revisiones, de manera que el trabajo final evite la redundancia de información y la aparición de sesgos, es decir, logrando un trabajo limpio de favoritismos previos en cuanto a los conocimientos ya adquiridos [3].

La estructura que tiene el presente trabajo se detalla a continuación: en el capítulo 2 se incluye los antecedentes investigativos y la fundamentación teórica usada como punto de partida de esta investigación. El marco metodológico que se sigue, es decir, la ubicación, los equipos y materiales, el tipo de investigación, la hipótesis a demostrar, el cálculo de la población y muestra, la recolección de información, procesamiento y análisis de datos se indican en el Capítulo 3. En el Capítulo 4 se realizará un análisis crítico de los resultados obtenidos en la investigación propuesta. Finalmente, las conclusiones, recomendaciones e información adicional se muestran en el Capítulo 5.

1.2 Justificación

En virtud de conseguir la optimización de procesos industriales, el objeto del presente análisis genera un fundamento de cómo se puede reducir el tiempo de procesamiento productivo industrial a través de una herramienta de propuesta y utilización de modelamientos y algoritmos matemáticos, que con el pasar de los tiempos van evolucionando a nuevos esquemas de cálculo que se apeguen a cada una de las diferentes características puntuales de las industrias de vanguardia.

Revisando los artículos publicados, se puede afirmar que existen estudios tanto cualitativos como cuantitativos de la forma en que se ha manejado el dimensionamiento de lotes y su contribución a la disminución del tiempo de procesamiento de la producción en diferentes esquemas de procesos de fabricación de manera individual, sin embargo, no se han encontrado mayores registros de comparaciones entre los diferentes tipos de procesos de fabricación que han hecho uso de estas herramientas a fin de validar si es que se pueden aplicar a todos los entornos productivos.

Basados en la revisión de la literatura existente, se justifica la escritura este trabajo ya que es de una gran importancia principalmente por que se proporciona un fuerte apoyo a la gestión empresarial, pues analiza las investigaciones realizadas a través del tiempo y el mundo en cuanto a la reducción de los tiempos en la entrega de los productos programados en una planta de producción una vez aplicados criterios para el particionamiento de lotes según las restricciones y características propias de cada sector e industria.

1.3 Objetivos

1.3.1 General

Escribir una revisión sistemática de literatura de la utilización de Lot Streaming para la reducción de Makespan mediante la revisión bibliográfica para proveer una nueva fuente de investigación en temas relacionados a la programación de producción.

1.3.2 Específicos

- Realizar una revisión sistemática de literatura mediante la utilización de la metodología PRISMA para la escritura de artículos científicos.
- Investigar los diferentes modelos de procesos de fabricación en los que se ha aplicado acertadamente el Lot Streaming mediante la lectura analítica de las publicaciones relacionadas para realizar un estudio comparativo de los diferentes sistemas de producción en que se ha aplicado.
- Evaluar las diferentes soluciones que se han dado a los problemas de programación reduciendo el Makespan con la gestión de lotes mediante la exploración de fuentes científicas para determinar la incidencia de estas soluciones.

CAPÍTULO II

ANTECEDENTES INVESTIGATIVOS

En lo que a industrias se refiere, existe una gran variedad, sectores y tipos de ellas, y un sinfín de esquemas para clasificarlas, por ejemplo, el del nivel tecnológico, que si bien es cierto, mientras mejor sea, podrá generar mejores oportunidades de desarrollo, como lo manifiestan Carroll *et al.* [4], pero no es el único gestor del éxito, pues en diferentes sectores hay igualmente un sinfín de condiciones para alcanzar mejores condiciones, pero la clave siempre será el desarrollo de las capacidades y el aprendizaje continuo emplazado en la innovación, según lo comprobaron Marlerba y Nelson en su estudio de los sistemas sectoriales [5].

Con respecto a la innovación industrial, no se relaciona explícitamente al diseño de productos, sino más bien a la optimización de procesos, es decir la conjunción de variables o restricciones aplicables a fin del mejoramiento u optimización de la producción, según lo indica Thomas Davenport [6], que podría enmarcarse en la cada vez más común aplicación de la mejora continua, o la gestión de herramientas y técnicas para alcanzar un balance operativo de las actividades industriales, apoyados en lo descrito por Kato y Smalley a partir del sistema de producción Toyota [7].

Para la correcta aplicación de los conceptos de mejoramiento y optimización de procesos industriales se debe modelizar de manera coherente e integral la realidad operativa de la industria, para ello, de arranque se debe conocer a qué tipo de proceso productivo pertenece cada proceso a mejorar, en relación al número de trabajos, número de máquinas y las características de similitud o diferencia de éstas, además de la ubicación de las mismas, esto, según indica Pinedo en su libro [8] se refiere a los procesos tipo *Flow Shop, Flexible Flow Shop, Job Shop, Flexible Job Shop,* o los *Open Shop*, además de otras características especiales, como tardanzas, tiempos de configuración y mantenimiento, entre otros.

Asimismo, hay que tomar en cuenta que uno de los factores de éxito en una compañía es el grado de control que puedan tener sobre los recursos que manejan, sabiendo que esto conlleva a un control en los costos de operación según lo dicho en su estudio por Gottmann *et al*. [9], entonces, se vuelve imprescindible manejar un correcto control de la producción y de los inventarios generados como lo manifiestan Wang y Chan en su análisis [10], amparada en una Programación de la Producción que integre eficientemente el llamado “triángulo de la producción”, es decir la disponibilidad para la entrega (de acuerdo a los requerimientos del cliente), niveles de inventarios (no excesivos) y la utilización de la capacidad (la justa y necesaria para producir), demostrado en el artículo publicado por Bikfalvi *et al*. [11] .

Por lo que, al momento de realizar una correcta Programación de la Producción se debe cuidar el Makespan, que se define como el tiempo total que se tarda en realizar todas las actividades necesarias para cumplir la necesidad de producción [12], por lo que se colige que, para realizar una eficiente gestión estratégica empresarial, es importante disminuir este tiempo, como método de minimización o eliminación de las demoras en los trabajos, el trabajo en proceso (*WIP* por sus siglas en inglés) y el desorden en la planta por causa de los trabajos no realizados, según lo indican López, *et al.* en su estudio [13].

Dentro de las técnicas para conseguir estos objetivos de optimización de la Programación de Producción, se tiene el Lot Streaming, que se considera que es una técnica que acelera la gestión del flujo de un producto a lo largo del proceso productivo, mediante la partición del lote completo de producción en lotes menores y procesándolos de manera simultánea en las máquinas requeridas, con diferentes métodos de cálculo, según lo citan en su revisión sobre el tema Cheng *at al*. [14], Novas [15], Defersha y Chen [16], o Gong *et al*. [17], por citar pocos autores que han estudiado el tema a lo largo del tiempo, en diferentes entornos productivos y alrededor del mundo.

CAPÍTULO III

MARCO METODOLÓGICO

3.1 Ubicación

El documento de revisión referido se basa en la lectura y análisis de otros aportes científicos publicados en diferentes bibliotecas digitales a nivel mundial referentes a Revistas Científicas. El acceso a dichas bibliotecas se realiza desde la ciudad de Ambato, provincia de Tungurahua – Ecuador, lugar de residencia del autor.

3.2 Equipos y materiales

- Equipo de cómputo con:
  - Conexión abierta a internet
  - Procesador de texto
  - Paquete estadístico u hoja de cálculo
- Materiales de escritorio

3.3 Tipo de investigación

El trabajo propuesto sigue un Enfoque Correlacional de la Investigación, ya que analiza la relación existente entre el Makespan y el Lot Streaming, pero enfocado a la aplicación de esta relación en diferentes entornos industriales controlados. Se basa el estudio en una investigación Documental Bibliográfica ya que se realiza mediante la recopilación de información publicada en bases de datos científicas después de realizar una lectura concienzuda, seleccionando los documentos más favorables para la generación del documento propuesto, según los preceptos que rigen la iniciativa Prisma para Revisiones Sistemáticas.

3.4 Hipótesis - pregunta científica – idea a defender

Dado que la investigación a la que se relaciona este trabajo es una revisión documental – bibliográfica, la hipótesis que se plantea demostrar es:

H_1: La utilización de Lot Streaming influye en la disminución del Makespan en diferentes tipos de procesos de fabricación.

3.5 Población o muestra:

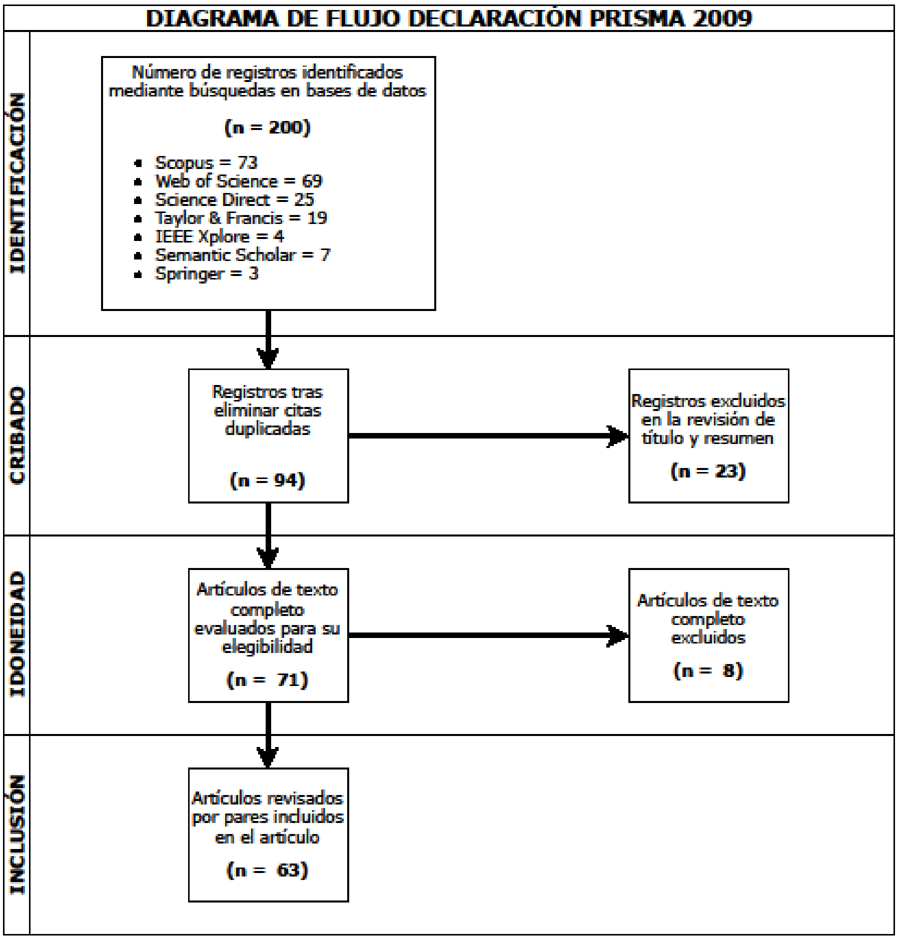

Figura 3-1. Diagrama de flujo PRISMA

Dado que para la gestión del Artículo se hará uso la declaración PRISMA *(Preferred Reporting Items for Systematic Reviews and Meta-Analyses)*, que es una guía para la elaboración de artículos científicos que se fundamenta en la inicialmente llamada declaración QUORUM *(QUality Of Reporting Of Meta-analyses Statement)* [18], para determinar la muestra de artículos científicos que formarán parte del presente estudio se siguen los pasos señalados en el diagrama de flujo de la metodología Prisma, que, partiendo de 200 artículos revisados en las diferentes bases de datos, según la aplicación del protocolo respectivo (planteamiento de reglas y filtros para seleccionar los mejores artículos en virtud de los objetivos planteados), finalmente determinan el uso de 63 artículos válidos. El protocolo seguido puede ser consultado en el Anexo 1 y el diagrama de flujo referido se muestra en la Figura 3-1.

3.6 Recolección de información:

Para recolectar la información de la que se nutre el presente trabajo se examinan publicaciones realizadas en diferentes Bases de Datos Científicas de renombre, tales como Web of Science, Scopus, y Taylor & Francis Online, recomendados por la Universidad Técnica de Ambato, además de Proquest, Scielo, Redalyc, IEEE, entre otras, los artículos científicos se buscaron con un límite de antigüedad de 10 años, la búsqueda priorizó el idioma inglés y posteriormente en idioma castellano.

3.7 Procesamiento de la información y análisis estadístico:

Una vez validados los campos que forman parte de la investigación los que obedecen principalmente a las preguntas de investigación, se establece si existen relaciones entre las variables analizadas, o, si por lo contrario se hace un análisis individual, realizándose un estudio descriptivo de cada campo, que permite realizar un estudio porcentual, tomando en cuenta el número de publicaciones encontradas que presentan información en torno a cada uno de los campos analizados.

Los campos a analizar se describen en la Tabla 3-1, agrupados según el peso que tienen en la investigación, mientras que en la Tabla 3-2 se señalan las preguntas de investigación, identificando la motivación de generarla, proyectándose en el impacto de la misma en el desarrollo de la investigación.

Tabla 3-1. CAMPOS A ANALIZAR

DATOS INICIALES	DATOS DE FONDO	DATOS FINALES
a. Base b. Año c. País del estudio d. Páginas	a. Problema / tipo de proceso productivo estudiado b. Características y tiempos adicionales c. Configuración / número de trabajo - máquinas d. Tipos de sublotes e. Inactividad f. Buffer g. Setup Time h. Objetivos i. Cálculo de la solución del problema j. Software para la solución del problema k. Comparado con l. Métricas a evaluar	a. Conclusión b. A futuro

Tabla 3-2. PREGUNTAS DE INVESTIGACIÓN

N°	PREGUNTA DE INVESTIGACIÓN	MOTIVACION
PR1	¿En qué tipos de procesos productivos se ha aplicado LS?	Identificar los procesos productivos en que se puede aplicar LS
PR2	¿En qué tipos de sublotes se ha aplicado el LS?	Identificar los diferentes sublotes a considerar en LS
PR3	¿Qué algoritmos de optimización se han utilizado para el cálculo de LS?	Identificar el uso de algoritmos de optimización
PR4	¿El LS es útil para disminuir el Makespan?	Identificar el objetivo del LS con relación al Makespan

3.8 Variables respuesta o resultados esperados

- **Variable Independiente:** Lot Streaming

Tabla 3-3. OPERACIONALIZACIÓN VARIABLE INDEPENDIENTE

<table>
<tr><th>CONCEPTUALIZACIÓN</th><th>DIMENSIONES</th><th>INDICADORES</th><th>ÍTEMS</th></tr>
<tr><td rowspan="2">Proceso de dividir los lotes de producción en lotes más pequeños para procesarlos de manera superpuesta en las líneas de producción inmersos en diversos sistemas y en diferentes tipos de industrias.</td><td>Sistemas de producción</td><td>Tipos de sistemas de producción que han empleado Lot Streaming</td><td>¿En qué sistemas de producción se ha utilizado el Lot Streaming?</td></tr>
<tr><td>Tamaño del lote</td><td>Cálculo del tamaño del lote</td><td>¿Qué herramientas se han utilizado para calcular el tamaño del lote?</td></tr>
</table>

- **Variable Dependiente:** Makespan

Tabla 3-4. OPERACIONALIZACIÓN VARIABLE DEPENDIENTE

CONCEPTUALIZACIÓN	DIMENSIONES	INDICADORES	ÍTEMS
Tiempo máximo de **terminación** de una **secuencia de trabajos** o tares, es decir la diferencia entre el tiempo de inicio y final de las actividades.	Tiempo de finalización de las operaciones productivas	Disminución del tiempo de finalización de las tareas	¿Ha habido una disminución en el makespan?

CAPÍTULO IV

RESULTADOS Y DISCUSIÓN

4.1 ¿En qué tipos de procesos productivos se ha aplicado LS?

Éste se considera el dato central a analizar para reconocer la aplicabilidad de la oportunidad de mejora del LS en relación a los diversos entornos industriales, es importante definir si los procesos que tenga la industria que se desee analizar se enmarcan en los encontrados en los diferentes papers estudiados. El resumen de resultados en cuanto a este ítem se muestra en la Tabla 4-1 y en la Figura 4-2.

Tabla 4-1. ESTADÍSTICA DESCRIPTIVA TIPOS DE PROCESOS PRODUCTIVOS

PROCESO PRODUCTIVO	CONTEO TOTAL	PORCENTAJE	PORCENTAJE ACUMULADO
Flexible Job Shop	5	7.94	7.94
Flow Shop	37	58.73	66.67
Hybrid or Flexible Flow Shop	13	20.63	87.3
Job Shop	5	7.94	95.24
Other	3	4.76	100

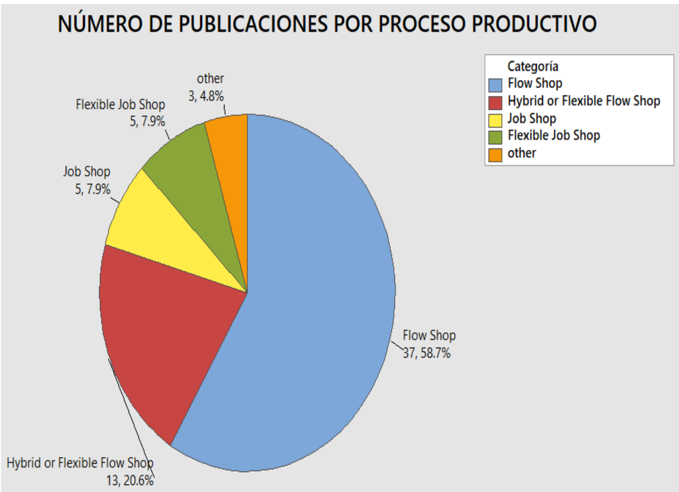

Figura 4-1. Publicaciones por tipo de proceso productivo

Según se puede ver, en los artículos revisados los dos principales tipos de procesos reportados son, el Flow Shop en su forma pura o híbrido, ya que el 79% (50 de 63 papers) analiza este tipo de proceso productivo, lo que indicaría que es el tipo de proceso que más se encuentra en la industria. Su contraparte, el Job Shop (igualmente puro e híbrido) solamente tiene el 16% (10) de las publicaciones.

En cualquiera de los tipos se pueden incluir diferentes restricciones o características particulares, de manera que el modelo diseñado se apegue más al día a día que viven industrias, señalando como principales restricciones el transporte, el bloqueo, el mantenimiento o el efecto que tiene la denominada curva de aprendizaje.

Entonces, se puede deducir que el LS se puede externalizar a cualquier proceso productivo, una vez reconocido cuál es su tipo y poder así generar un modelamiento acorde a la realidad de la industria que se está buscando optimizar.

4.2 ¿En qué tipos de sublotes se ha aplicado el LS?

En este análisis, la mayor parte de artículos proporcionan soluciones para esquemas con sublotes iguales, esto es, más de la mitad de artículos (55%), mientras que el 28% genera soluciones para sublotes consistentes y el 17% para sublotes variables, según se evidencia en la Tabla 4-2 4-2 y la Figura 4-2.

Tabla 4-2. ESTADÍSTICA DESCRIPTIVA TIPOS DE SUBLOTES

TIPO DE SUBLOTE	CONTEO TOTAL	PORCENTAJE	PORCENTAJE ACUMULADO
Consistentes	18	27.69	27.69
Iguales	36	55.38	83.08
Variables	11	16.92	100

Nota: La suma de los archivos revisados es superior a los 63 investigados puesto que un artículo menciona los 3 tipos de sublotes.

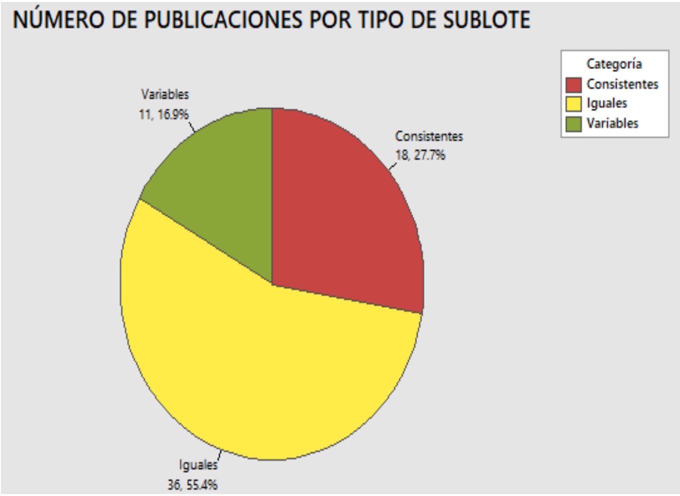

Figura 4-2. Publicaciones por tipo de sublote

Además, en varios de los artículos revisados, se mencionan diferentes consideraciones especiales, como es la de los tiempos ociosos o la inactividad, aunque solamente el 41% mencionan su existencia, o el caso de búferes, en el que sólo el 17% hablan de la presencia de inventarios de seguridad entre procesos, siendo el aspecto más mencionado los tiempos de preparación, que 86% de los artículos lo toma en cuenta.

4.3 ¿Qué algoritmos de optimización se han utilizado para el cálculo de LS?

Para calcular el esquema de optimización del problema planteado, se hace uso de un algoritmo de optimización específico (mencionado ampliamente en la literatura) en 47 de las publicaciones revisadas, en donde se indican todos los supuestos y los pasos a seguir para encontrar la solución. Se destacan los algoritmos HA: Heuristic algorithm, HGA: Hybrid genetic algorithm y SA: Simulated annealing que son aquellos que se han utilizado en mayor número de publicaciones. Los algoritmos que han servido para calcular el LS se indican en la Tabla 4-3.

Por su parte, 16 publicaciones no señalan que se haya utilizado un algoritmo como tal, sino más bien hacen uso de otros esquemas de solución, como puede ser el caso de una formulación matemática con alguna variante para conseguir un acople con el bosquejo levantado inicialmente. Dichos esquemas se señalan en la Tabla 4-4.

Tabla 4-3. ALGORITMOS DEMOSTRADOS UTILIZADOS EN LS

ALGORITMO	CANTIDAD DE PAPERS	%
HA: Heuristic algorithm	3	6%
HGA: Hybrid genetic algorithm	3	6%
SA: Simulated annealing	3	6%
DABC: Discrete artificial bee colony	2	4%
DPA: Dynamic programming algorithms	2	4%
DSOMA: Discrete self organising migrating algorithm	2	4%
GA: Genetic algorithm	2	4%
IMMBO: Improved migrating birds optimization	2	4%
- DEA: Differential Evolution Algorithm - PSO: Particle Swarm Optimization	1	2%
- Glass - Potts - Johnson’s algorithm	1	2%
ABC: Artificial bee colony	1	2%
DACS: Distributed ant colony system	1	2%
DIWO: Discrete invasive weed optimization	1	2%
DLHS: Local-best harmony search with dynamic sub-harmony memories	1	2%
DPSO: Discrete particle swarm optimization	1	2%
EDA: Estimation of distribution algorithm	1	2%
EMMBO: Effective modified migrating birds optimization (EMBO)	1	2%
GAJS: Genetic algorithm-based job splitting approach	1	2%
GEA: Greedy constructive algorithm	1	2%
HDABC: Hybrid discrete artificial bee colony	1	2%
HDHS: Hybrid discrete harmony search	1	2%
ILS: Iterated local search	1	2%
INSGA-II: Improved Non-dominated Sorting Genetic Algorithm II	1	2%
MA: Memetic algorithm	1	2%
MABC: Modified artificial bee colony	1	2%
MHA: Metaheuristic algorithm	1	2%
MOMBO: Multi-Objective Migrating Birds Optimization	1	2%
NEMO: Novel evolutionary multi-objective optimization	1	2%
NGA: New genetic algorithm	1	2%
NSGA II: Non-dominated Sorting Genetic Algorithm II	1	2%
ONSGA-II: Optimization Improved Non-dominated Sorting Genetic Algorithm	1	2%
PA: Polynomial-time algorithm	1	2%
PH-MOEAD: Problem-specific heuristics multi-objective evolutionary algorithm based on decomposition.	1	2%
REMO: Evolutionary multiobjective robust scheduling	1	2%
SFLA: Shuffled frogleaping algorithm	1	2%
TF-HI algorithm	1	2%
Total	**47**	**100%**

Tabla 4-4. OTROS ESQUEMAS DE CÁLCULO UTILIZADOS EN LS

ESQUEMA	CANTIDAD DE PAPERS	%
MILMM: Mixed-integer linear mathematical model	5	31%
Mathematical model	4	25%
MILP: Mixed integer linear programming	2	13%
"Técnicas de programación convexa existentes."	1	6%
CP: Constraint Programming	1	6%
TSM: Three-stage method	1	6%
- DSS: (sistema de soporte de decisiones) integrado que combina enfoques de simulación y toma de decisiones multicriterio (MCDM) - AHP: Analytical Hierarchy Process - WAM: Weighted Aggregation Method	1	6%
IMM: Integer mathematical models	1	6%
Total	**16**	**100%**

Las soluciones han sido parametrizadas en diferentes softwares de programación (C++ es el principal con 48% o programas estadísticos de optimización, como CPLEX con el 10%), demostrando en 60 de las publicaciones mediante la comparación con otras formas de cálculo que la solución planteada en cada paper es la óptima gracias al cálculo de ciertas métricas aplicadas a la función objetivo de manera estadística. De esta manera se llega a la conclusión de que se puede alcanzar una mejora en los procesos de producción y los costos implícitos, pero que, siempre habrá una nueva manera de seguir mejorando, como puede ser una nueva generación de algoritmos.

La comparación en la cantidad de publicaciones presentada según el software utilizado se puede evidenciar en la Tabla 4-5 y la Figura 4-3-3.

Tabla 4-5. ESTADÍSTICA DESCRIPTIVA SOFTWARE UTILIZADOS EN LS

SOFTWARE	CONTEO TOTAL	PORCENTAJE	PORCENTAJE ACUMULADO
Arena	1	1.59	1.59
C++	30	47.62	49.21
Cplex	6	9.52	58.73
eM-Plant	1	1.59	60.32
Fortran	2	3.17	63.49
Gams	2	3.17	66.67
Gurobi 7.0.1	1	1.59	68.25
Lingo	4	6.35	74.60
Matlab	5	7.94	82.54
Mex Api	1	1.59	84.13
Not Indicated	10	15.87	100.00

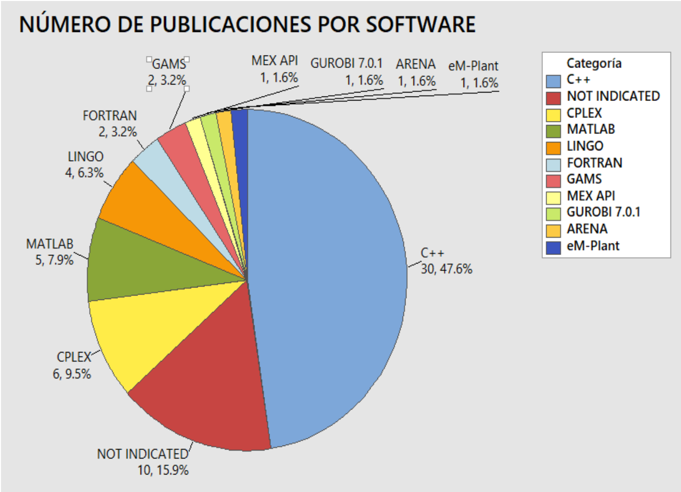

Figura 4-3. Publicaciones por software

4.4 ¿El LS es útil para disminuir el Makespan?

Dentro de las investigaciones revisadas, se mencionan varios objetivos de optimización, como el consumo de energía y los costos asociados a los procesos productivos, sin embargo, en la mayoría de los artículos (73%) se menciona explícitamente que la función objetivo de minimización corresponde al Makespan (o palabras asociadas), de esta manera, se vuelve claro el hecho de que ésta es la mejor utilidad del Lot Streaming (LS), si bien es cierto que las publicaciones tienen una clara inclinación a demostrar que el algoritmo elegido es mejor que otro u otros algoritmos de optimización validados ya por otros autores para la resolución del problema de optimización presente.

Entonces, se puede colegir que el aplicar esta técnica de optimización conduciría a una mejora en los tiempos de entrega del producto final, lo que mejoraría la satisfacción del cliente, pues puede ver cumplidas sus necesidades, además de que la empresa evitaría llegar a tener ventas perdidas, grave problema con que las empresas lidian continuamente, recayendo en la pérdida de la fidelidad de los clientes.

CAPÍTULO V

CONCLUSIONES, RECOMENDACIONES, BIBLIOGRAFÍA Y ANEXOS

5.1 Conclusiones

- Mediante el uso de la metodología PRISMA para la escritura de artículos científicos se ha podido realizar una revisión sistemática adecuadamente estructurada y fundamentada sobre la utilización de Lot Streaming que permitirá realizar mayor investigación a futuro sobre su aplicación en particular.

- El Lot Streaming se ha aplicado acertadamente en diferentes tipos de procesos productivos, en especial del Flow Shop y el Job Shop, tanto en su estado puro como híbrido, lo que permite deducir que se puede utilizar en procesos de cualquier sector industrial, una vez reconocidos y diferenciados los tipos de procesos con los que trabaja.

- Los artículos revisados para la ejecución de la revisión literaria presente realizan el análisis en lotes que sean consistentes, iguales o diferentes, lo que permite inferir que cualquiera que sea la definición del tipo de lote que se maneje en una industria, se puede aplicar esta técnica de optimización de recursos, aunque la mayor parte de investigadores se decanta por los sublotes iguales, probablemente por requerir de menor atención en la definición de las restricciones de cálculo de los modelos matemáticos.

- Manteniendo como función objetivo la de reducir el Makespan, se han empleado una amplia variedad de algoritmos de optimización, entre los que se destacan el Algoritmo Heurístico, el Algoritmo Híbrido Genético y el Recocido Simulado, aunque, también se ha hablado mucho de la utilización de la Programación Lineal de Enteros mixtos.

- Cada algoritmo que se ha utilizado para minimizar el Makespan ha sido avalado por sendas demostraciones numéricas, que ha permitido demostrar, más allá de la efectividad individual en la mencionada reducción, el que cada algoritmo es más efectivo que otro u otros, por lo que inferir de manera directa que se puede reducir el Makespan mediante la aplicación de Lot Streaming no es posible, más bien, esta demostración ya está implícita en cada demostración individual, adicional, se puede colegir que los diferentes algoritmos son efectivos, más no se puede emitir el criterio de mayor efectividad de uno o de otro.

5.2 Recomendaciones

- Analizar los algoritmos que han sido utilizados para el cálculo del Lot Streaming de manera que se pueda realizar la agrupación de los mismos y definir si existe alguna inclinación por alguna tipificación en particular e investigar si dentro de ésta existen algoritmos que no se hayan utilizado y cuales podrían ser las razones.

- Proponer nuevos algoritmos de vanguardia que no han sido utilizados anteriormente y analizar la efectividad de los mismos en un cálculo matemático teórico que permita una comparación efectiva de éstos nuevos algoritmos.

- Realizar en cálculo de Lot Streaming práctico, es decir, seleccionar un proceso real, definir sus restricciones y características especiales, plantear el modelo matemático, seleccionar el algoritmo a utilizar y finalmente realizado el cálculo a fin de poner en práctica el resultado central de la investigación presente.

5.3 Bibliografía

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5.4 Anexos

5.4.1 Anexo 1 – Protocolo para la selección de artículos

Sección y tema	Artículo No	Lista de verificación	Desarrollo
INFORMACIÓN ADMINISTRATIVA			
Título:			
Identificación	1a	Identificar el informe como un protocolo de una revisión sistemática	Protocolo para "Lot streaming in different types of production processes: A PRISMA systematic review"
Actualización	1b	Si el protocolo es para una actualización de una revisión sistemática anterior, identifique como tal	-
Registro	2	Si está registrado, proporcione el nombre del registro (como PROSPERO) y el número de registro	-
Autores			
Contacto	3a	Proporcionar nombre, afiliación institucional, dirección de correo electrónico de todos los autores del protocolo; proporcionar la dirección de correo físico del autor correspondiente	Alexandra Salazar - Moya 1. Facultad de Ingeniería en Sistemas, Electrónica e Industrial, Universidad Técnica de Ambato psalazar5759@uta.edu.ec Ecuador, Tungurahua, Ambato, Ficoa Las Acacias, calle los limones #02-73, entre aguacates y mandarinas
Contribuciones	3b	Describa las contribuciones de los autores del protocolo e identifique al garante de la revisión	Alexandra Salazar es autora del protocolo Marcelo García, es el Garante de la Revisión
Enmiendas	4	Si el protocolo representa una modificación de un protocolo previamente completado o publicado, identifique como tal y enumere los cambios; de lo contrario, el plan estatal para documentar importantes enmiendas de protocolo	-
Apoyo			
Fuentes	5a	Indicar fuentes de apoyo financiero u otro tipo de apoyo para la revisión	Apoyo con el acceso a fuentes de bases científicas por parte de la Universidad Técnica de Ambato
Patrocinador	5b	Proporcione el nombre del financiador de revisión y/o patrocinador	-
Papel del patrocinador o financiador	5c	Describa las funciones de los patrocinadores, patrocinadores y/o instituciones, si los hubiera, en el desarrollo del protocolo	-
Introducción			
Fundamento	6	Describa la justificación de la revisión en el contexto de lo que ya se conoce	El tiempo que se requiera en una industria para finalizar el proceso productivo va de la mano con la gestión de los costos operativos, ya que es conocido que mientras menor

Sección y tema	**Artículo No**	**Lista de verificación**	**Desarrollo**
			sea dicho tiempo, mayor será la productividad, factor imprescindible para el control de los costos. Existen una infinidad de métodos para disminuir el "Makespan", una de ellas es el Lot Streaming, o la gestión de los lotes de producción, además del cálculo del momento del ingreso de los lotes a producción, en referencia a los tipos de procesos de producción que se maneje, pero de sobremanera al esquema de cálculo basado en la estadística inferencial. Dada la importancia que lo anteriormente expuesto tiene dentro de la gestión de operaciones, se han realizado investigaciones a lo largo de los últimos años, sin embargo, una revisión sistemática permitirá contrastar estas investigaciones y definir si éstas han logrado demostrar que el Lot Streaming logra efectivamente disminuir el Makespan.
Objetivos	7	Proporcionar una declaración explícita de la(s) pregunta(s) que la revisión abordará con referencia a los participantes, intervenciones, comparadores y resultados (PICO)	De manera general, el objetivo de este trabajo es: "Escribir una revisión sistemática de literatura de la utilización de Lot Streaming para la reducción de Makespan mediante la revisión bibliográfica para proveer una nueva fuente de investigación en temas relacionados a la programación de producción" Para lograr dicho objetivo, se cumplirá específicamente con los objetivos: - Investigar los diferentes modelos de procesos de fabricación en los que se ha aplicado acertadamente el Lot Streaming mediante la lectura analítica de las publicaciones relacionadas para realizar un estudio comparativo de los diferentes sistemas de producción en que se ha aplicado. - Evaluar las diferentes soluciones que se han dado a los problemas de programación reduciendo el Makespan con la gestión de lotes mediante la exploración de fuentes científicas para determinar la incidencia de estas soluciones. - Realizar una revisión sistemática de literatura mediante la utilización de la metodología PRISMA para la escritura de artículos científicos.
Métodos			
Criterios de elegibilidad	8	Especifique las características del estudio (como PICO, diseño del estudio, configuración, marco de tiempo) y las	Los estudios se seleccionan en virtud de las siguientes observaciones: - Diseño del estudio: Se incluyen todos los estudios realizados, en los

Sección y tema	Artículo No	Lista de verificación	Desarrollo
		características del informe (como años considerados, idioma, estado de publicación) que se utilizarán como criterios de elegibilidad para la revisión	que se han esquematizado soluciones al problema del Lot Streaming, se desechan las revisiones de literatura y los estudios comparativos. - PICO: * Participantes: Se incluirán estudios de análisis del cálculo de Lot Streaming indicando en qué tipo de proceso de producción se desarrollan las investigaciones, es decir si son Flow Shop, Job Shop, Open Shop u otro que se reporte en el desarrollo del informe. * Intervenciones: Se consideran todas las intervenciones, con excepción de las intervenciones de carácter educativo y de aquellas que se consideren caso de estudio, dejando éstas últimas para un análisis de resultados. * Comparadores: Las comparaciones que se considerarán van en virtud de la disminución del Lot Streaming. * Resultados: Los resultados dados por válidos para el informe final son aquellos que informen sobre el impacto del cálculo del Lot Streaming sobre el Makespan. - Configuración: No habrá restricciones en la configuración del informe final. - Marco de tiempo: Dado que no son estudios experimentales, o casos de aplicación, el marco de tiempo no se considera como un factor determinante para valorar una investigación. Teniendo en el informe las siguientes características: - Años considerados: Se da un lapso de tiempo de 10 años, es decir se revisan publicaciones desde 2010 hasta 2020. - Idioma: Se buscan artículos en inglés prioritariamente, aceptando también artículos publicados en español. - Región de publicación: Se revisarán artículos de todas las regiones del mundo, ya que este aspecto puede conllevar a un análisis comparativo posterior - Estado de publicación: Se consideran artículos publicados por revistas indexadas, tomando como un factor fuerte de aceptación, el tener DOI (Digital Object Identifier) que permite hacer un seguimiento de los artículos de manera más fácil

Sección y tema	Artículo No	Lista de verificación	Desarrollo
Fuentes de información	9	Describa todas las fuentes de información previstas (como bases de datos electrónicas, contacto con autores de estudios, registros de ensayo u otras fuentes de literatura gris) con fechas planificadas de cobertura	La búsqueda de artículos científicos se realiza en: - Bases de datos de investigación académica: SCOPUS e IEEE Xplore - Editorial académica internacional: TAYLOR & FRANCIS y SPRINGER - Motor de búsqueda de publicaciones académicas: SEMANTIC SCHOLAR - Servicio en línea de investigación científica: WEB OF SCIENCE y SCIENCE DIRECT
Estrategia de búsqueda	10	El actual proyecto de estrategia de búsqueda se utilizará para al menos una base de datos electrónica, incluidos los límites previstos, de modo que pueda repetirse	El acceso a las bases de los artículos de registro obligatorio se realiza gracias a los convenios que tiene la Universidad Técnica de Ambato (Web of Science y Elsiever con Scopus y Science Direct), las otras bases son de acceso libre. La búsqueda se centra en artículos publicados en revistas, es decir, eliminando publicaciones de congresos, ya que éstas reflejan una mayor rigurosidad para la aceptación de su publicación. El criterio de búsqueda en las fuentes seleccionadas sólo se refiere a "LOT STREAMING" pues se necesita incluir todos los esquemas de tipos de procesos de producción y formas de solución del cálculo relacionado, ya que, de hecho, estos dos, son factores que se analizan y forman parte de los informes finales del artículo a presentar.
Registros de estudio			
Gestión de datos	11a	Describa los mecanismos que se utilizarán para administrar registros y datos a lo largo de la revisión	Para evitar el uso de fuentes duplicadas, se utiliza el gestor de fuentes bibliográficas Zotero, en el cual, mediante el ingreso de la referencia con su DOI, se puede gestionar toda la información necesaria para el control referencial de cada uno de los artículos
Proceso de selección	11b	Indique el proceso que se utilizará para seleccionar estudios (como dos revisores independientes) a través de cada fase de la revisión (es decir, cribado, elegibilidad e inclusión en el metaanálisis)	En la selección de los artículos participa únicamente el autor de esta investigación, pasando por las siguientes etapas: - Selección de artículos según la palabra clave: "Lot Streaming", a nivel de título, resumen o palabras claves - Eliminación de duplicados - Selección de artículos según el tipo de estudio (eliminando casos de estudio, revisiones, comparaciones) - Selección de artículos valorando el año de publicación, el número de citaciones y la revista en la que han

Sección y tema	Artículo No	Lista de verificación	Desarrollo
			sido publicados - Selección de artículos con menor riesgo de sesgo en virtud de un análisis Cochrane.
Proceso de recopilación de datos	11c	Describir el método planificado para extraer datos de informes (como formularios piloto, realizados de forma independiente, por duplicado), cualquier proceso para obtener y confirmar datos de los investigadores	Se utilizará un formulario piloto que contenga además de la información primaria de cada uno de los artículos, información sobre la solución: - Tipos de procesos de producción - Tipo de algoritmo utilizado - Restricción o Característica especial adicional - Software utilizado - Resultados obtenidos (reducción del Makespan)
Elementos de datos	12	Enumerar y definir todas las variables para las que se buscarán datos (como elementos PICO, fuentes de financiación), cualquier suposición de datos preplanificada y simplificaciones	Se extraerán los datos relacionados con: - Tipo de proceso de producción - Tipo de algoritmo o esquema de cálculo - Software auxiliar del cálculo - Restricciones o consideraciones especiales en el proceso de producción - Disminución del Makespan
Resultados y priorización	13	Enumerar y definir todos los resultados para los que se buscarán datos, incluida la priorización de los resultados principales y adicionales, con un ejemplo de razonamiento	Los resultados principales revisarán esquemática y estadísticamente (comparación) en orden de aparición dentro de los documentos de análisis a los valores relacionados con: - Tipo de proceso de producción, en cuanto a cuál es el tipo con el qué más se ha trabajado, es decir es más frecuente de encontrar dentro de las investigaciones. - Tipo de algoritmo o esquema de cálculo, validando que solución se plantea para el cálculo del Lot Streaming, corroborando cuál es el algoritmo o esquema más recurrente en los análisis realizados. - Restricciones o consideraciones especiales en el proceso de producción, revisando cuales son los aspectos adicionales que se consideran para complementar el cálculo del Lot Streaming. - Disminución del Makespan, ya que este es el objetivo del estudio, se considerará el resultado principal para validar finalmente en que tanto se puede hacer una disminución, consiguiendo el beneficio final. Como resultado secundarios, se revisará: - Software auxiliar del cálculo, a fin de sugerir algún software que permita realizar la solución del algoritmo propuesto

Sección y tema	Artículo No	Lista de verificación	Desarrollo
Riesgo de sesgo en estudios individuales	14	Describa los métodos previstos para evaluar el riesgo de sesgo de los estudios individuales, incluyendo si esto se hará a nivel de resultado o estudio, o ambos; indicar cómo esta información se utilizará en la síntesis de datos	Para evaluar el posible sesgo para cada estudio, se hará uso de la herramienta de la colaboración Cochrane para evaluar el riesgo de sesgo (Tabla 8.5.a del Manual de Cochrane), Con esta información se podrá juzgar si hay riesgo de sesgo en cada uno de los seis dominios, calificado como de "alto riesgo" o "bajo riesgo".
Síntesis de datos	15a	Describir los criterios bajo los cuales los datos del estudio se sintetizarán cuantitativamente	Para las variables de estudio señaladas anteriormente se realizará un estudio comparativo para establecer ponderaciones entre los diferentes valores que éstos puedan tener
	15b	Si los datos son apropiados para la síntesis cuantitativa, describa las medidas resumidas planificadas, los métodos de tratamiento de datos y los métodos de combinación de datos de estudios, incluida cualquier exploración planificada de la coherencia (como I^{2}, Kendall's)	Se realizará un estudio de medias mediante prueba T-student para variables independientes, con el fin de comparar estadísticamente los valores que se arrojan para cada variable de estudio.
	15c	Describir cualquier análisis adicional propuesto (como análisis de sensibilidad o subgrupo, metarregresión)	-
	15d	Si la síntesis cuantitativa no es apropiada, describa el tipo de resumen	Se incluirá una descripción narrativa de los análisis realizados, los cuadros presentados y las conclusiones a los que los estudios analizados han llegado.
Meta-bias(es)	16	Especificar cualquier evaluación planificada de meta-bias (como sesgo de publicación entre estudios, informes selectivos dentro de los estudios)	Se incluirán todos los documentos que cumplan los criterios de inclusión, independientemente de si los análisis muestran un resultado en apoyo al objetivo del estudio
Confianza en la evidencia acumulativa	17	Describir cómo se evaluará la fuerza del cuerpo de evidencia (como GRADE)	En virtud del resultado presentado como conclusión después de la realización de cada informe, se analizará la claridad de su presentación

5.4.2 Anexo 2 – Artículo profesional de alto nivel

Review

Lot streaming in different types of production processes: A PRISMA systematic review

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Abstract: At present, any industry that wanted to be considered of vanguard must be willing to improve itself, developing innovative techniques to generate a competitive advantage against its direct competitors. Hence, many methods are employed to optimize production processes, like Lot Streaming, which consists of partitioning the productive lots into overlapping small batches to reduce the overall operating times known as Makespan, reducing the delivery time to the final customer. This work proposes carrying out a systematic review following the PRISMA methodology to the extant literature in indexed databases that demonstrates the application of Lot Streaming in the different production systems. They have been identified 200 papers about the subject of this study. After applying a group of eligibility criteria, 63 articles have been analyzed, concluding that Lot Streaming is helpful to reduce the Makespan in various types of industrial processes by using several optimization algorithms.

Keywords: Lot Streaming, Productive Process Types, Makespan, Optimization Algorithms, Prisma Review

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1. Introduction

Operations Management manages the processes that transform labor, capital, materials, information, and other inputs into products and services for the internal or external customer[1]. It defines the end of manufacturing industries, an environment that, due to its impact, deserves the effort to be identifying, analyzing, and improving.

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In the framework of Operations Management, it is critical the "Control", that is, to take actions to ensure success by meeting the objectives set, according to a plan, monitoring the costs, quality, and management of the allocated resources [2]. In this sense, we emphasize the control of the costs of production processes, insomuch as it ultimately determines the success or failure of an industry, because they redound on the price the end customer must pay for the goods provided by the company[3].

So, it has been recognized that the management of production processes is essential; it is clear that any effort to continuously and dynamically improve them marks a constant change [4]. This improvement in engineering terms is part of optimization representing technological and management decision-making to minimize the required effort or maximize the forecast profit by looking for conditions that give the maximum and minimum value of an objective function [5].

It has been recognized that in the routine life of the industry, there are multiple drawbacks related to the delivery times of finished products to storage warehouses, and therefore, to the final consumer. After specific analyzes, it is estimated that one of the fundamental reasons is the extensive operation and transfer lots making the control activities ineffective. Consequently, they do not help decrease the operation times and production costs, so this becomes an optimization objective.

This work presents a systematic literature review of one method to optimize the Productive Processes, Lot Streaming (LS). It is the technique of splitting a productive batch into smaller batches or transfer lots and processing them simultaneously on different machines remaining their movement through the processes or machine with the essential criterion of reducing the Makespan. I.e., the time elapsed from the start of the first operation of the first sublot on the first machine and the end of the last process of the latest sublot on the last machine [6].

This systematic review has been carried out using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) methodology [7] to write scientific papers. In this case, for indexed documents that have DOI, with particular emphasis on the analytical reading of related publications, to carry out a comparative study of the different production systems in which The Lot Streaming has been applied. However, it is recognized that only indexed publications and DOI may be restrictions on the research and bias the results obtained in a certain way.

There are previously published works that present literature reviews about Lot Streaming, such as Cheng et al. [8] and Chang et al. [9] that describe the particularities of the application with the different operational characteristics, or Gómez-Gasquet et al. [10] and Bagchi et al. [11] who analyze the LS specifically in Flow Shop process, these being essential consultation tools. The present work generates a new source of consultation, which will allow future authors of further investigation on optimization process tools to have a greater insight into the most realistic environments to implement LS. According to the approaches reviewed in this paper, it offers a contrast of the main properties of the technique in question about the type of process in which it has been applied, being able to carry out new investigation on other strategies for optimizing production scheduling.

The following sections are detailed, Section 2 describing the methodology followed in selecting the cited articles, Section 3 describing the information found in scientific works and the results of the analyses about the crucial information, Section 4 where the research questions are answered, the conclusions build to after the conduct of this study, and the future research work based on the present learning, finally, Section 5 describes the sources of funding that supported the realization of the development presented.

2. Methodology

To achieve this systematic review, what has been done in other systematic reviews is followed [12], [13], [14], and according to the Prima methodology, the following steps are followed: (i) research questions, (ii) sources of information, (iii) search strategy, (iv) eligibility criteria, (v) risk of bias, (vi) data extraction.

2.1. Research Questions

Four research questions are raised, which will support the proposed systematic analysis to verify the LS's usefulness to the calculation of the Makespan. These questions are framed in two thematic axes: (TA1) Applicability of LS and (TA2) Solution and objective of the production scheduling problem. The proposed questions are given in **Table 1**.

Table 1. Research questions

N°	Research question	Motivation
RQ1	In what types of production processes has LS been applied?	Identify the production processes in which LS can be applied.
RQ2	What types of sublots is LS used?	Identify the different sublots to consider in LS.
RQ3	What optimization algorithms have been used for LS calculation?	Identify the use of optimization algorithms.
RQ4	Has LS been used to decrease Makespan?	Identify the LS's goal about Makespan.

The approach to these questions corresponds to a hierarchical tree, starting from the objectives proposed when selecting the research topic, progressing to essential issues that need to be validated. Starting from the need to solve a problem of programming and product flow, it is necessary to document a solution that can be applied in various specific production processes of industrial plants. Taking into account that LS forces to "play" with processing batches, so it must be analyzed in the first instance to what classification or definition they obey, reflected in mathematical modeling that allows a calculation through an appropriate method, that is, a specifically focused algorithm, finally arriving at the demonstration of the objective of LS which is the decrease of the Makespan.

2.2. Sources of information

The research for scientific papers focuses on papers published in journals, so publications of congresses are deleted because the former is considered to reflect a greater strictness for publication acceptance. It is carried out in the academic research databases SCOPUS and IEEE Xplore, academics international editorials TAYLOR & FRANCIS and SPRINGER, search motor of academic publications SEMANTIC SCHOLAR and the online services of scientific research WEB OF SCIENCE and SCIENCE DIRECT, where indexed research that has DOI (Digital Object Identifier) can be accessed to track the papers more efficiently.

2.3. Search methodology

Research in the different digital media focuses on a combination of the following keywords: "Lot Streaming" AND ("production processes" OR "operating lots" OR "lead time reduction" OR "lot size" OR "algorithms of optimization "OR "Makespan" OR "decrease in the use of resources"), which must appear both in the title, in the keywords or in the summary of the analyzed papers (subsequent revision) refining the information limiting the publications to the time range that has been indicated (2010 - 2020).

These sentences correspond to words related to the research questions indicated in 2.1, which allow discovering the investigations carried out, considering that the central axis is the "Lot Streaming", but that it is also required to know how applicable it is. Depending on the types of production processes, the batch sizes are essential to configure the methodology's usefulness analyzed in the operational reality. The application of the concept of optimization of the processes with the well-known objective of reducing the Makespan or the decrease in lead time leads to a decrease in the cost of production due to a decrease in resource use.

Table 2. Search in digital databases and number of publications (initial search)

Database	Search	Papers
SCOPUS	("lot streaming"; AND ("production processes" OR "operation lots" OR "decrease in lead time" OR "lot size" OR "optimization algorithms" OR "Makespan" OR "decrease in resource use") AND (LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT- TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012) OR LIMIT-TO (PUBYEAR, 2011) OR LIMIT-TO (PUBYEAR, 2010))	73
WEB OF SCIENCE	("lot streaming" AND ("production processes" OR "operation batches" OR "decrease in lead time" OR "lot size" OR "optimization algorithms" OR "Makespan" OR "decrease in resource use")	69
SCIENCEDIRECT	("lot streaming" AND ("production processes" OR "operation batches" OR "decrease in lead time" OR "lot size" OR "optimization algorithms" OR "Makespan" OR "decrease in resource use")	25
TAYLOR & FRANCIS	[All: "lot streaming"] AND [All: "production processes"] O [All: "operation lots"] O [All: "decrease in lead time"] O [All: "lot size"] O [All: "optimization algorithms"] OR [All: "Makespan"] OR [All: "decrease in resource use")] AND [Publication Date: (01/01/2010 TO 12/31/2020)]	19
IEEE	("lot streaming" AND ("production processes" OR "operation batches" OR "decrease in lead time" OR "lot size" OR "optimization algorithms" OR "Makespan" OR "decrease in resource use")	4
SEMANTIC SCHOLAR	("lot streaming" AND ("production processes" OR "operation batches" OR "decrease in lead time" OR "lot size" OR "optimization algorithms" OR "Makespan" OR "decrease in resource use")	7
SPRINGER	("lot streaming" AND ("production processes" OR "operation batches" OR "decrease in lead time" OR "lot size" OR "optimization algorithms" OR "Makespan" OR "decrease in resource use")	3
Total		**200**

As shown in Table 2, the search concepts in all the databases consulted (7) adhered to the criteria described, where the mandatory field is "Lot Streaming", which is the investigated technique. A combination was generated (with the Boolean operator AND) with the important or determining aspects in the current research (with the Boolean operator OR) so that the initial concepts are complemented; in addition, the initial filter is set so that the articles have as publication date the years between 2010 and 2020, although it has been indicated that the selected language is English; it is not necessary to indicate this filter because the articles found in the databases consulted are only published in that language.

2.4. Eligibility criteria

Papers are selected at first instance under the following criteria:

- Study design: All studies have been included in which solutions to the Lot Streaming problem have been outlined, and literature reviews and comparative studies are discarded;

- Years considered: There are ten years, i.e., publications are reviewed from 2010 to 2020. Although there are previous papers, it is decided to limit the search in this way, to present fresher information, due to in essence this is based on previous studies;
- Language: English papers are searched, as there are a more significant number of publications in that language;
- Publishing region: Papers from all regions of the world will be reviewed, as this will result in further comparative analysis;
- Publication status: Papers published by indexed journals are considered, taking as a decisive factor of acceptance, having DOI (*Digital Object Identifier*);

2.5. Risk of bias in individual studies

Understanding that bias in a study refers to a deviation in the information presented, either during the preparation or management of the information [15], to assess the possible bias for each study, the Cochrane collaboration tool is used to assess the risk of bias (Table 8.5.a of the Cochrane Manual) [16]. This information judge whether there is a risk of bias in each of six domains, classified as "high risk" or "low risk". Additional weight is given to the year of publication (rating scale) and the number of citations that the studies submit at the time of the respective research. These three values are then multiplied by each other, and those studies with the highest value are those considered eligible to analyze them and be part of this analysis.

2.6. Selection of studies

Only the author of this research participates in the selection of the papers following four stages. In the first stage, there is a choice of papers according to "Lot Streaming". In the second stage, duplicate papers are eliminated, with 94 items left. In the third stage, the papers are selected according to the type of study, eliminating case studies and reviews, moving on to the next stage, 71 papers. In the fourth stage, the papers are selected by the lower risk of bias presented according to the rule designed, being accepted for final analysis 63 papers. This selection scheme is shown in **Figure 1** that presents the PRISMA flowchart for this selection of papers.

Table **3** presents the papers selected for the review submitted, sorted by the database in which they were collected and their year of publication, presenting the basic information of each publication and the information regarding the research questions raised at the beginning of the present work.

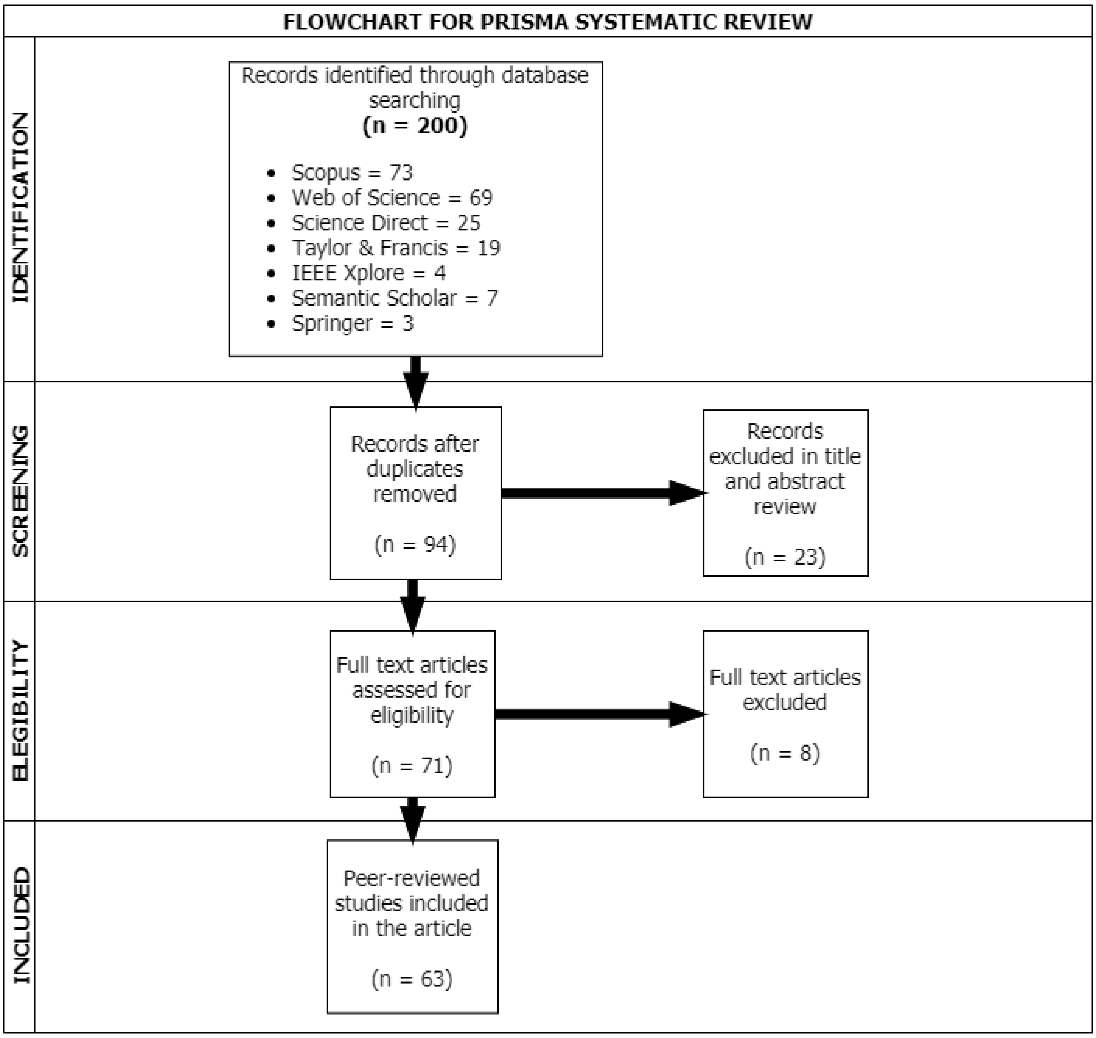

Figure 1. Flowchart for Prisma systematic reviews

Table 3. Selected papers

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
1	A lot streaming based flow shop scheduling problem using simulated annealing algorithm	SCIENCE DIRECT	2020	INDIA	Ramesh, C.; Kamalakannan, R.; Karthik, R.; Pavin, C.; Dhivaharan, S.	Flow Shop	j jobs m machines	Variables	SA: Simulated Annealing	Propose a solution for the calculation of Makespan that minimizes four objectives, i.e., the penalty for the average time of stay, the energy consumption in the last stage, the values of precocity and delay.
2	Efficient multi-objective algorithm for the lot-streaming hybrid flowshop with variable sub-lots	SCIENCE DIRECT	2019	CHINA	Li, Jun-qing; Tao, Xin-rui; Jia, Bao-xian; Han, Yu-yan; Liu, Chuang; Duan, Peng; Zheng, Zhi-xin; Sang, Hong-yan	Flow Shop Hybrid or Flexible	j jobs m parallel machines s stages	Variables	PH-MOEAD: Problem-specific heuristics multi-objective evolutionary algorithm based on decomposition.	Study the allocation of jobs and machines to decrease the instance and save the accumulated cost by decreasing the Makespan, the penalties caused by the time of stay, the consumption of energy in the last stage, and the values of precocity and delay.
3	Dynamic programming algorithms and Lagrangian lower bounds for a discrete lot streaming problem in a two-machine flow shop	SCOPUS	2020	CHINA	Alfieri, Arianna; Zhou, Shuyu; Scatamacchia, Rosario; van de Velde, Steef L.	Flow Shop	j jobs 2 machines	Consistent	DPA: Dynamic programming algorithms	Propose exact and heuristic solutions whose objective is to minimize total flow time for the discrete version of a batch flow problem.

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
4	Improved Migrating Birds Optimization Algorithm to Solve Hybrid Flowshop Scheduling Problem With Lot-Streaming	SCOPUS	2020	CHINA	Wang, Ping; Sang, Hongyan; Me, Qiuyun; Guo, Hengwei; Li, Junqing; Gao, Kaizhou; Han, Yuyan	Flow Shop Hybrid or Flexible	j jobs m machines s stages	Equal	IMMBO: Improved migrating birds optimization	Preset an improved optimization algorithm to minimize growth capacity
5	Lot streaming in a two-stage assembly system	SCOPUS	2020	CHINA	heng, Ming; Sarin, Subhash C.	Flow Shop Hybrid or Flexible	j jobs m parallel machines on Stage 1 n parallel machines on Stage 2	Equal	HA: Heuristic algorithm	Address a programming issue that belongs to a two-stage assembly system that can also be seen as a massive customization system, developing two heuristic methods based on column generation.
6	Multi-objective genetic algorithm for energy-efficient hybrid flow shop scheduling with lot streaming	SCOPUS	2020	TAIWAN	Chen, Tzu-Li; Cheng, Chen-Yang; Chou, Yi-Han	Flow Shop Hybrid or Flexible	j jobs m parallel machines l stages	Variables	NSGA II: Non-dominated Sorting Genetic Algorithm II	Propose programming of multi-object mixed integers to minimize both the production margin and the consumption of electrical energy, adopting a genetic algorithm.
7	Multi-objective optimisation in flexible assembly job shop scheduling using a distributed ant colony system	SCOPUS	2020	CHINA	Zhang, Sicheng; Li, Xiang; Zhang, Bowen; Wang, Shouyang	Job Shop Flexible	j jobs m non-identical machines	Equal	DACS: Distributed ant colony system	Study the problem of production scheduling in a flexible manufacturing system with two adjacent work areas, with duration, total delay, and total workload as objectives to optimize, proposing an algorithm as a solution

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
8	Speed scaling in two-machine lot-streaming flow shops with consistent sublots	SCOPUS	2020	CHINA	Fang, Kan; Luo, Wenchang; Che, Ada	Flow Shop	1 jobs on machine 1 n jobs on machine 2 2 machines	Consistent	"Existing convex programming techniques."	Consider a programming problem that aims to find an optimal schedule that determines both the sizes and processing speeds of the sublots, so, the work can be completed before a certain period and the total energy consumption is minimized.
9	A three-stage method with efficient calculation for lot streaming flow-shop scheduling	SCOPUS	2019	CHINA	Wang, Hai-yan; Zhao, Fu; Gao, Hui-min; Sutherland, John W.	Flow Shop	j jobs m machines 3 stages	Variables	"TSM: Three-stage method"	Propose a decomposition procedure about the decision on the size of the sublots in the calculation, minimizing the Makespan
10	Evolutionary Multiobjective Blocking Lot-Streaming Flow Shop Scheduling With Machine Breakdowns	SCOPUS	2019	CHINA	He, Yuyan; Gong, Dunwei; Jin, Yaochu; Pan, Quanke	Flow Shop	j jobs m machines	Equal	REMO: Evolutionary multiobjective robust scheduling	Present a multi-objective model that includes criteria of robustness and stability, oriented mainly to the reduction of Makespan.
11	Lot Streaming Flow Shop with a Heterogeneous Machine	SCOPUS	2019	Argentina	Ferraro, Augustus; Rossit, Daniel; Toncovich, Adrian; Fruits, Mariano	Flow Shop	j jobs m heterogenous machines	Consistent	"Mathematical model"	It proposes a decomposition procedure about the decision on the size of the sublots seeking to minimize the Makespan.

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
12	Multi-Objective Migrating Birds Optimization Algorithm for Stochastic Lot-Streaming Flow Shop Scheduling With Blocking	SCOPUS	2019	CHINA	He, Yuyan; Li, Jun-Qing; Gong, Dunwei; Song, Hongyan	Flow shop	j jobs m machines	Equal	MOMBO: Multi-Objective Migrating Birds Optimization	Propose a multi-objective optimization through an optimization algorithm to solve the problem of programming to minimize the Makespan.
13	Production scheduling and lot streaming at flexible job-shops environments using constraint programming	SCOPUS	2019	Argentina	New, Juan M.	Job Shop Flexible	j jobs m machines	Consistent	"CP: Constraint Programming"	Address a programming problem and LS through a new Constraint Programming (CP) approach to minimize the Makespan..
14	Two-stage hybrid flow shop batching and lot streaming with variable sublots and sequence-dependent setups	SCOPUS	2019	USA	Wang, Shasha; Kurz, Mary; Mason, Scott Jennings; Rashidi, Eghbal	Flow Shop Hybrid or Flexible	2 parallel machines 2 stage	Variables	HA: Heuristic algorithm	Introduce a linear mixed-integer program for batching and LS problem with variable sublots, incompatible job families, and sequence-dependent setup times to minimize total weighted completion time

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
15	A Novel Hybrid Multi-Objective Artificial Bee Colony Algorithm for Blocking Lot-Streaming Flow Shop Scheduling Problems	SCOPUS	2018	CHINA	Gong, Dunwei; Han, Yuyan; Sun, Jianyong	Flow Shop	j jobs m machines	Equal	HDABC: Hybrid discrete artificial bee colony	Present a hybrid algorithm for the programming problem with two conflicting reduce criteria: timeout and precocity time.
16	An effective discrete invasive weed optimization algorithm for lot-streaming flowshop scheduling problems	SCOPUS	2018	CHINA	Sang, Hong-Yan; Pan, Quan-Ke; Duan, Pei-Yong; Li, Jun-Qing	Flow Shop	j jobs 1 machines m stages	Equal	DIWO: Discrete invasive weed optimization	Present an effective optimization algorithm to address the LS problem to reduce the Makespan
17	An improved migrating birds optimization for an integrated lot-streaming flow shop scheduling problem	SCOPUS	2018	CHINA	Meng, Tao; Pan, Quan-Ke; Li, Jun-Qing; Sang, Hong-Yan	Flow Shop	j jobs m machines	Equal	IMMBO: Improved migrating birds optimization	Provide a mathematical model for the indicated problem and present an improved optimization to minimize the maximum completion time or preparation time

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
18	Flexible job shop scheduling with lot streaming and sublot size optimisation	SCOPUS	2018	Germany	Bożek, Andrzej; Werner, Frank	Job Shop Flexible	j jobs m machines	Equal	GEA: Greedy constructive algorithm	Propose a two-stage optimization procedure to minimize Makespan, in addition to minimizing the sum of sublot sizes and minimizing the number of operations that do not need to be divided at all.
19	Integrating simulation modelling and multi criteria decision making for customer focused scheduling in job shops	SCOPUS	2018	Turkey	Powerdemir, Hulya; Selim, Hasan	Job Shop	j jobs l machines	Equal	"DSS: Integrated Decision Support System that combines multi-criteria simulation and decision-making (MCDM)AHP: Analytical Hierarchy ProcessWAM: Weighted Aggregation Method"	Propose an integrated decision support system that combines simulation modeling and multicriteria decision-making with three performance-oriented criteria, average flow time, percentage of late orders, time frame, and a customer-oriented criterion
20	A multi-objective lot-streaming optimization scheduling model considering the blocking effect	SCOPUS	2017	CHINA	Li, Y. G.; Zhang, M. S	Flow Shop	j jobs m machines	Equal	ONSGA-II: Optimization Improved Non-dominated Sorting Genetic Algorithm	Build a multi-object batch programming model to measure maximum product completion time, total product flow time, total machine timeout on the assembly line, and delayed completion time.

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
21	An Effective Modified Migrating Birds Optimization for Hybrid Flowshop Scheduling Problem with Lot Streaming	SCOPUS	2017	CHINA	Zhang, Biao; Pan, Quan-ke; Gao, Liang; Zhang, Xin-li; Sang, Hong-yan; Li, Jun-qing	Flow Shop Hybrid or Flexible	j jobs m identical parallel machines s stages	Equal	EMMBO: Effective modified migrating birds optimization (EMBO)	A mathematical model and effective optimization is proposed to solve the problem in an acceptable computational time and minimize total flowtime
22	Lot streaming in [N-1](1)+N(m) hybrid flow shop	SCOPUS	2017	INDIA	Lalitha, J. Laxmi; Mohan, Naru; Pillai, V. Madhusudanan	Flow Shop Hybrid or Flexible	j jobs m parallel machines s stages	Consistent	HA: Heuristic algorithm	Develop a schedule that minimizes production using an optimization algorithm
23	Lot streaming in the presence of learning in sublot-attached setup times and processing times	SCOPUS	2017	USA	Mukherjee, Niloy J.; Sarin, Subhash C.; Singh, Sanchit	Flow Shop	j jobs 2 machines	Consistent	PA: Polynomial-time algorithm	Study the use of LS to process a batch to determine the number of sublots, sublot sizes and minimize production capacity with the learning effect.
24	Transfer batch size impact on a job shop environment performance	SCOPUS	2017	Colombia	López, Myriam Leonor Niño; Diaz, Henry Lamos; Sanmiguel, Paula Julieth Jaimes; Gonzalez, Julieth Vanessa Rivera	Job Shop	3 jobs 1 machine on Stage 1 and 2 2 machines on Stage 3 3 stages	Equal	"MILP: Mixed-integer linear programming"	Assess statistically value the impact of batch flow on resource amplitude and idle capacity dependent variables in a workshop, taking into account transport activities, to minimize the inactive capacity of resources

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
25	A non-permutation flowshop scheduling problem with lot streaming: A Mathematical model	SCOPUS	2016	Argentina	Rossit, Daniel; Tohmé, Fernando; Frutos, Mariano; Bard, Jonathan; Broz, Diego	Flow Shop	j jobs m machines	Variables	"MILMM: Mixed-integer linear mathematical model"	Investigate the use of LS in programming problems without permutation. The goal is to minimize workspace subject to standard constraints
26	Evolutionary Multi-objective Blocking Lot-streaming Flow Shop Scheduling with Interval Processing Time	SCOPUS	2016	CHINA	Han, Yuyan; Gong, Dunwei; Jin, Yaochu; Pan, Quan-ke	Flow Shop	j jobs m machines	Equal	NEMO: Novel evolutionary multi-objective optimization	Solve a multi-goal optimization problem with a novel multi-goal optimization algorithm to minimize Makespan in addition to uncertainties and precocity time
27	Lot streaming in a two-stage assembly hybrid flow shop scheduling problem with a work shift constraint	SCOPUS	2016	IRAN	Nejati, Mohsen; Mahdavi, Iraj; Hassanzadeh, Reza; Mahdavi Amiri, Nezam	Flow Shop Hybrid or Flexible	j jobs m identical parallel machines s stages	Consistent	SA: Simulated Annealing	Address the problem of two-stage assembly programming, proposing a genetic algorithm to calculate the best sequence and programming
28	Two-stage, single-lot, lot streaming problem for a 1 + 2 hybrid flow shop	SCOPUS	2016	USA	Cheng, Ming; Sarin, Subhash C.; Singh, Sanchit	Flow Shop Hybrid or Flexible	1 machine at Stage 1 2 identical parallel machines at Stage 2	Consistent	TF-HI algorithm	Adress an LS problem to minimize production capacity by approaching an optimization algorithm

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
29	Lead time considerations for the multi-level capacitated lot-sizing problem	SCOPUS	2015	Germany	Almeder, Christian; Klabjan, Diego; Traxler, Renate; Almada-Lobo, Bernardo	other	j jobs m machines	Equal	"Mathematical model"	Model production processes to calculate the Makespan and minimize the fixed installation cost and underlying maintenance cost.
30	A Study on Integration of Lot Sizing and Flow Shop Lot Streaming Problems	SCOPUS	2014	Malaysia	Mortezaei, Navid; Lyn, Norzima	Flow Shop	j jobs m non-identical machines	Consistent, Variable, and Equal	"MILMM: Mixed-integer linear mathematical model"	Develop linear mathematical models for integrating batch size and LS problems where machines are unavailable because they undergo preventive maintenance to reduce Makespan.
31	An improved NSGA-II algorithm for multi-objective lot-streaming flow shop scheduling problem	SCOPUS	2014	CHINA	Han, Yu-Yan; Gong, Dun-wei; Sun, Xiao-Yan; Pan, Quan-Ke	Flow Shop	j jobs m machines	Equal	INSGA-II: Improved Non-dominated Sorting Genetic Algorithm II	Apply an algorithm to solve the programming problem with four minimization criteria, Makespan, total flow time, downtime of all machines, and precocity time
32	An Iterated Local Search Algorithm for the Lot-Streaming Flow Shop Scheduling Problem	SCOPUS	2014	CHINA	Blood, Hongyan; Gao, Liang; Li, Xinyu	Flow Shop	j jobs m machines	Equal	ILS: Iterated local search	A simple but effective algorithm is proposed to minimize total weighted penalties in advance and delay.

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
33	Lot Streaming and Preventive Maintenance in a Multiple Product Permutation Flow Shop with Intermingling	SCOPUS	2014	Malaysia	Mortezaei, Navid; Norzima, Zulkifli; Tang, S.H.; Rosnah, Mohd Yusuff	Flow Shop	j jobs m non-identical machines	Consistent	"MILMM: Mixed-integer linear mathematical model"	Propose a mathematical model for the problem of LS with preventive maintenance, seeking to reduce the Makespan
34	Mixed-integer Formulation for Integration of Lot Sizing and Lot Streaming Problem with Scheduled Preventive Maintenance	SCOPUS	2014	CHINA	Mortezaei, Navid; Lyn, Norzima	Flow Shop	j jobs m non-identical machines	Consistent	"MILMM: Mixed-integer linear mathematical model"	Propose a mathematical model for batch size integration and production scheduling, developing a linear model of mixed integers for the batch size of various products and LS, where the goal is to reduce The Makespan
35	Multi-job lot streaming to minimize the weighted completion time in a hybrid flow shop scheduling problem with work shift constraint	SCOPUS	2014	IRAN	Nejati, Mohsen; Mahdavi, Iraj; Hassanzadeh, Reza; Mahdavi Amiri, Nezam; Mojarad, MohamadSail m	Flow Shop Hybrid or Flexible	j jobs m parallel machines s stages	Consistent	GA: Genetic algorithm	Study the LS to minimize the sum of the weighted completion times of the work in each work shift to provide better machine utilization for the following work shifts considering the size of the sublots in the work shifts, the completion times of the work, and the WIP, proposing a genetic algorithm

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
36	Research on swarm intelligence algorithm with an artificial bee colony algorithm for lot streaming problem in job shop	SCOPUS	2014	CHINA	Xu, Xiao Qiang; Law, De Ming	Job Shop	j jobs m machines	Equal	ABC: artificial bee colony	Propose an effective intelligence algorithm to minimize total sanctions of tardiness and precocity
37	Utilising the chaos-induced discrete self organising migrating algorithm to solve the lot-streaming flowshop scheduling problem with setup time	SCOPUS	2014	Czech Republic	Davendra, Donald; Senkerik, Roman; Zelinka, Ivan; Pluhacek, Michael; Bialic-Davendra, Magdalena	Flow Shop	j jobs m machines	Equal	DSOMA: Discrete self-organizing migrating algorithm	Propose an optimization algorithm to minimize the Makespan
38	A new genetic algorithm for lot-streaming flow shop scheduling with limited capacity buffers	SCOPUS	2013	USA	Ventura, Joseph A.; Yoon, Suk-Hun	Flow Shop	j jobs m machines	Equal	NGA: New genetic algorithm	Propose a new genetic algorithm for a programming problem in which the goal is to minimize total penalties for anticipation and delay.

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
39	Integration of Lot Sizing and Flow Shop Scheduling with Lot Streaming	SCOPUS	2013	Malaysia	Mortezaei, Navid; Lyn, Norzima	Flow shop	j jobs m machines	Consistent	"MILMM: Mixed-integer linear mathematical model"	Develop a mathematical model for batch size integration and scheduling to find optimal production quantities, optimal inventory levels, optimal sublot sizes, and an optimal sequence simultaneously to minimize Makespan
40	Lot streaming multiple jobs with values exponentially deteriorating over time in a job-shop environment	SCOPUS	2013	TAIWAN	Liu, Cheng-Hsiang; Chen, Long-Sheng; Lin, Pei-Shiun	Job Shop	j jobs m machines	Equal	GAJS: Genetic algorithm-based job splitting approach	Determine whether the expected benefits of LS would be evident in the programming problem to maximize the total value of the jobs. Also proposing a work division approach based on genetic algorithms.
41	Lot streaming with flexible process plans	SCOPUS	2013	Turkey	Yavuz, Jasmine	Other	j jobs m machines	Consistent	"IMM: Integer mathematical models"	Address the potential improvement in schedules that can be achieved by integrating process planning and LS decisions to minimize the duration of programming

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
42	Performance evaluation of proposed Differential Evolution and Particle Swarm Optimization algorithms for scheduling m-machine flow shops with lot streaming	SCOPUS	2013	INDIA	Vijay chakaravarthy, G.; Marimuthu, S.; Naveen Sait, A.	Flow Shop	j jobs m machines	Equal	DEA: Differential Evolution AlgorithmPSO: Particle Swarm Optimization	Propose an optimization algorithm to develop the best sequence for the total flow time/interval criterion
43	Scheduling job shop with lot streaming and transportation through a modified artificial bee colony	SCOPUS	2013	CHINA	Law, Deming; Guo, Xiuping	Job Shop	j jobs m machines	Consistent	MABC: Modified artificial bee colony	Consider an LS problem where individual work is considered to reduce management complexity, proposing an algorithm to minimize production capacity
44	Utilising the Chaos-Induced Discrete Self Organising Migrating Algorithm to Schedule the Lot-Streaming Flowshop Scheduling Problem with Setup Time	SCOPUS	2013	Czech Republic	Davendra, Donald; Senkerik, Roman; Zelinka, Ivan; Pluhacek, Michael; Bialic-Davendra, Magdalena	Flow Shop	j jobs m machines	Equal	DSOMA: Discrete self-organizing migrating algorithm	Propose an optimization algorithm to minimize the Makespan.

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
45	An estimation of distribution algorithm for lot-streaming flow shop problems with setup times	SCOPUS	2012	CHINA	Bread, Quan-Ke; Ruiz, Ruben	Flow Shop	j jobs m machines	Equal	EDA: Estimation of distribution algorithm	Minimize the duration with an estimation of distribution algorithm with a representation based on job permutation
46	Analysis on multi-stage lot streaming: The effect of transfer	SCOPUS	2012	CHINA	Eat, Taofeng	Other	m jobs l machines s stages	Equal	"Mathematical model"	Identify the effects of the different transfer types (based on the previous operator, on the successive operator, and not based on the operator) between each pair of stages about the optimal number of transfer lots in the Makespan calculation, providing a mathematical model
47	Discrete Artificial Bee Colony Algorithm for Lot-streaming Flowshop with Total Flowtime Minimization	SCOPUS	2012	CHINA	Blood, Hongyan; Gao, Liang; Pan, Quanke	Flow Shop	j jobs m machines	Equal	DABC: Discrete artificial bee colony	Present an algorithm for a programming problem with total flowtime criterion

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
48	Discrete Particle Swarm Optimization Algorithm for Lot-streaming No-wait Flow Shop Scheduling Problem	SCOPUS	2012	CHINA	Yang, Lin; Pan, Yu Xia	Flow Shop	j jobs m machines	Equal	DPSO: Discrete particle swarm optimization	Propose an optimization algorithm to solve the programming problem with the aim of the maximum completion time
49	Mathematical model and parallel genetic algorithm for hybrid flexible flowshop lot streaming problem	SCOPUS	2012	CANADA	Defersha, Fantahun Melaku; Chen, Mingyuan	Flow Shop Hybrid or Flexible	j jobs m parallel machines s stages	Consistent	GA: Genetic algorithm	Contribute to closing the gap between research efforts in flowshop LS and hybrid flowshop programming, proposing a mathematical model and a genetic algorithm for the indicated problem
50	Two-machine lot streaming with attached setup times	SCOPUS	2012	Italy	Alfieri, Arianna; Glass, Celia; van de Velde, Steef	Flow Shop	j jobs 2 machines 2 stages	Consistent	DPA: Dynamic programming algorithms	Present a dynamic programming algorithm for the discrete variant of the problem, in which all sublots sizes must be integral to minimize the Makespan.
51	A comprehensive mathematical model for hybrid flexible flowshop lot streaming problem	SCOPUS	2011	CANADA	Defersha, Fantahun M.	Flow Shop Hybrid or Flexible	j jobs m parallel machines s stages	Consistent	“Mathematical model”	Take the first step to start research by closing the research gap in flowshop lot streaming and hybrid flowshop programming, by running a complete mathematical model for programming to minimize Makespan

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
52	A discrete artificial bee colony algorithm for the lot-streaming flow shop scheduling problem	SCOPUS	2011	Singapore	Pan, Quan-Ke; Fatih Tasgetiren, M.; Suganthan, P.N.; Chua, T.J.	Flow Shop	j jobs m machines	Equal	DABC: Discrete artificial bee colony	An algorithm is proposed to solve the programming problem in cases of idling as in cases of absence of idling to minimize total weighted penalties in advance and delay.
53	A genetic algorithm for one-job m-machine flowshop lot streaming with variable sublots	SCOPUS	2011	CANADA	Defersha, Fantahun M.; Chen, Mingyuan	Flow Shop	1 jobs m machine	Variables	HGA: hybrid genetic algorithm	Develop a hybrid genetic algorithm for a single-job mobile machine LS problem with variable sublots and configuration to minimize the Makespan.
54	A local-best harmony search algorithm with dynamic sub-harmony memories for lot-streaming flow shop scheduling problem	SCOPUS	2011	CHINA	Pan, Quan-Ke; Suganthan, P.N.; Liang, J.J.; Tasgetiren, M. Fatih	Flow Shop	j jobs m machines	Equal	DLHS: Local-best harmony search with dynamic sub-harmony memories	A dynamic search algorithm is proposed to minimize total weighted penalties in advance and delay for a flow scheduling problem.
55	An effective shuffled frog-leaping algorithm for lot-streaming flow shop scheduling problem	SCOPUS	2011	CHINA	Pan, Quan-Ke; Wang, Ling; Gao, Liang; Li, Junqing	Flow Shop	j jobs m machines	Equal	SFLA: Shuffled frogleaping algorithm	Present an effective algorithm to solve a scheduling problem, where the criterion is to minimize the maximum completion time with idling and without idling

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
56	Lot streaming multiple jobs in a flow shop	SCOPUS	2011	United Kingdom	Glass, Celia A.; Possani, Edgar	Flow Shop	- j identical jobs on m machines - j non-identical jobs on 2 machines	Equal	Glass – Potts Johnson's algorithm	Consider the advantages of applying the LS by providing a polynomial-time algorithm to minimize production capacity, taking into account the configurations of the first machine and transport times
57	The Lot-streaming Flow Scheduling Shops based on a hybrid discrete harmony search algorithm	SCOPUS	2011	CHINA	Han, Hong Yan	Flow Shop	j jobs m machines	Equal	HDHS: Hybrid discrete harmony search	Propose a hybrid algorithm to minimize anticipation and total weighted delay
58	A hybrid genetic algorithm for flowshop lot streaming with setups and variable sublots	SCOPUS	2010	CANADA	Defersha, Fantahun M.; Chen, Mingyuan	Flow Shop	j jobs m machines	Variables	HGA: hybrid genetic algorithm	Develop a hybrid genetic algorithm for a recent model for single-job mobile machine LS problems with variable sublots to reduce manufacturing delivery time
59	Critical Path Method for Lot Streaming Problem in Flexible Job Shop Environment	WEB OF SCIENCE	2017	IRAN	Yousefi Yegane, B.; Nakhai Kamalabadia,, I.; Khanlarzade, N.	Job Shop Flexible	j jobs m machines	Equal	MA: Memetic algorithm	Address a flexible programming problem to minimize the maximum completion time or Makespan allowing the division of work

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
60	A simulated annealing with multiple-search paths and parallel computation for a comprehensive flowshop scheduling problem	WEB OF SCIENCE	2015	CANADA	Defersha, Fantahun M.	Flow Shop Hybrid or Flexible	j jobs m parallel machines s stages	Variables	SA: Simulated Annealing	Solve a complete mathematical model for a described problem to minimize the completion time of the last sublot that is processed in the system
61	Lot Streaming in No-wait Multi Product Flowshop Considering Sequence Dependent Setup Times and Position Based Learning Factors	WEB OF SCIENCE	2015	IRAN	Fattahi, P.; Azizi, V.; Jabbari, M.	Flow Shop	j jobs m machines	Equal	MHA: Metaheuristic algorithm	Study a programming problem considering different restrictions simultaneously, batch transmission, position-based learning factors, sequence-dependent setup times, and the fact that the flow shop line does not have to wait to minimize the Makespan
62	Minimizing the Total Stretch when Scheduling Flows of Divisible Requests without Interruption	WEB OF SCIENCE	2015	SOUTH KOREA	Yoon, Sigh-Hun	Flow Shop	j jobs m series machines	Equal	HGA: hybrid genetic algorithm	Propose a solution for scheduling divisible requests without interruption in which the goal is to minimize the total stretch (relationship between the amount of time the request spent in the system and its response time)

No	Study title	Database	Year	Country	Author	Type of production process	Number of work - machines	Types of sublots	Proposed algorithm	Objective
63	How important is the batch splitting activity in scheduling of virtual manufacturing cells (VMCs)?	WEB OF SCIENCE	2011	Turkey	Kesen, Saadettin Erhan; Gungor, Zülal	Job Shop Flexible	j jobs m machines	Variables	"MILP: Mixed-integer linear programming"	Consider several jobs with different processing sequences, following two programming objectives, minimizing the route and minimizing the total travel distance

3. Results

Data to be reviewed schematically and statistically (comparison) are mainly focused on answering the research questions; however, it is considered that other scopes are worth analyzing. To better understand these scopes, they have been divided into three subcategories: the initial data that are the basic scopes when reviewing research, background data or weight factors to be analyzed, and the final data or conclusive aspects in the revised papers. The data that are framed in each subcategory are detailed in **Table 1**.

Table 1. Data to be analyzed

Initial data	Background data	Final data
1. Base	1. Problem/type of production process studied	1. Conclusion
2. Year	2. Additional features and times	2. Future works
3. Country	3. Configuration / work number - machines	
4. Pages	4. Types of sublots	
	5. Idling	
	6. Buffer	
	7. Setup Time	
	8. Objectives	
	9. Calculating the problem solution	
	10. Software for solving the problem	
	11. Compared to	
	12. Metrics to evaluate	

3.1. Initial Data

1. Base:

Even though seven databases were consulted, once the duplicate papers have been deleted, prioritizing the basis where the most significant number of citations is located; finally, only three bases are keeping up. These bases are Scopus with 56 papers, i.e., 89% of the papers referenced, Web of Science with five papers or 8%, and Science Direct with two papers which is 3% of selected papers.

2. Year:

As noted, the range of years considered for publication research ranges from 2010 to 2020; the distribution of papers according to the year of publication is shown in **Figure 2**.

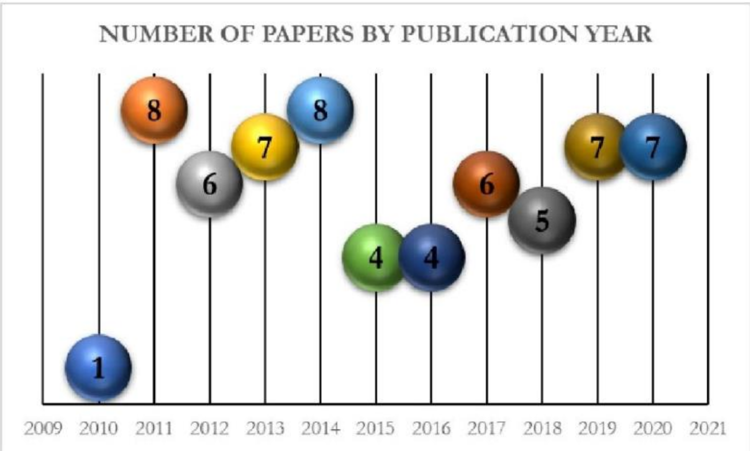

Figure 2. Number of papers by year of publication

3. Country

The papers that are part of this analysis are distributed in 16 countries, listed in **Table 5**, and whose distribution around the world can be shown in **Figure 3**.

Table 5. Number of papers by country

Country	Number of papers	%
China	27	43%
Canada	5	8%
Iran	4	6%
USA	4	6%
India	3	5%
Argentina	3	5%
Turkey	3	5%
Malaysia	3	5%
Taiwan	2	3%
Germany	2	3%
Czech Republic	2	3%
Singapore	1	2%
Colombia	1	2%
South Korea	1	2%
United Kingdom	1	2%
Italy	1	2%
Total	**63**	**100%**

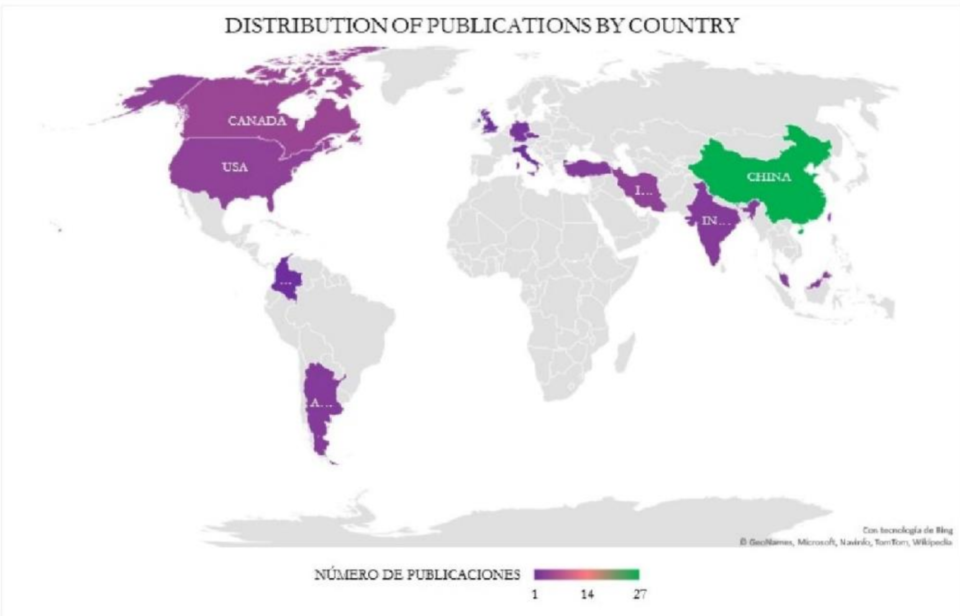

Figure 3. Distribution of publications by country

4. Pages

Publications have between 4 and 38 pages, identifying that 46% of publications correspond to the series from 11 to 17 pages, 22% have between 4 and 10 pages, 19% between 18 and 24, and the ranges between 24 and 31 and between 32 and 38 share 6% of the publications respectively. This distribution is reflected in **Figure 4**.

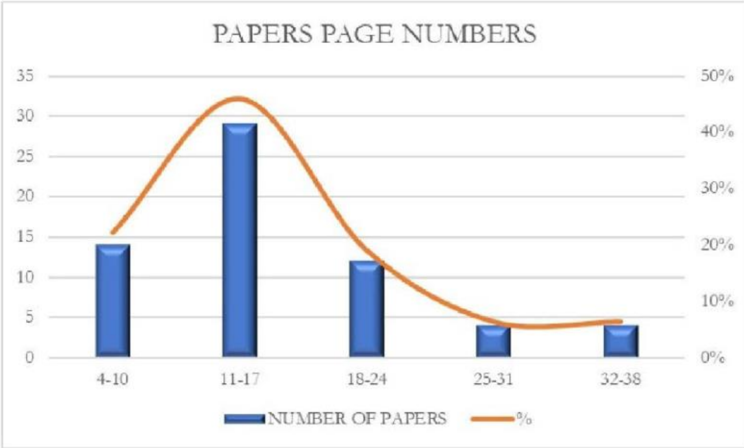

Figure 4. Papers page numbers

3.2. Background data

1. **Problem/type of production process studied**

The problems or types of production processes found in the analyzed papers are:

Flexible process: Refers to the opportunity to produce the same part with different sets of operations, such as in workshops and flexible machining cells [17].

Flow Shop: N jobs are processed in m machines with the same sequence, and a job cannot be delivered before all processing ends on the current machine [18] for use in industries such as textiles, plastics, chemistry, semiconductor, tiles, and many others [19].

Hybrid or Flexible Flow Shop: Commonly, there are several stages, in each of which there are parallel machines that may not be the same and each work must flow through each of the previous stages according to the same sequence, the performance of the system is given by the performance of each work at each stage [20], cases presented in industries such as glass, steel, plastic, and pharmaceutical. Its main feature is that the job is not allowed to move to the next stage until the process is completed, which leads to the machine timeout [21].

Job Shop: Each job follows a default path on m machines. There is a differentiation between job shops in which each job visits each maximum machine once and job shops in which a job can visit each machine more times [22].

Flexible Job Shop: Generalization of the job shop and parallel machine environments. There are c work centers, and in each work center, there are several identical machines in parallel. Each job has its path to follow, so it requires processing at each work center on a single machine, and any machine can do so [22].

Other: Other types of structure of production processes are recognized but differ from the classes indicated above.

Table 6 lists the papers grouped into these categories, while **Figure 5** shows the weight of each type on all the publications analyzed.

Table 6. Papers grouped according to the type of Productive Process

Process	Papers
Flow Shop	[18], [19], [21], [23], [24], [25], [26], [27], [28], [29], [30],[31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56]

Process	Papers
Hybrid or Flexible Flow Shop	[20], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68]
Job Shop	[69], [70], [71], [72], [73]
Flexible Job Shop	[74], [75], [76], [77], [78]
Other	[17], [79], [80]

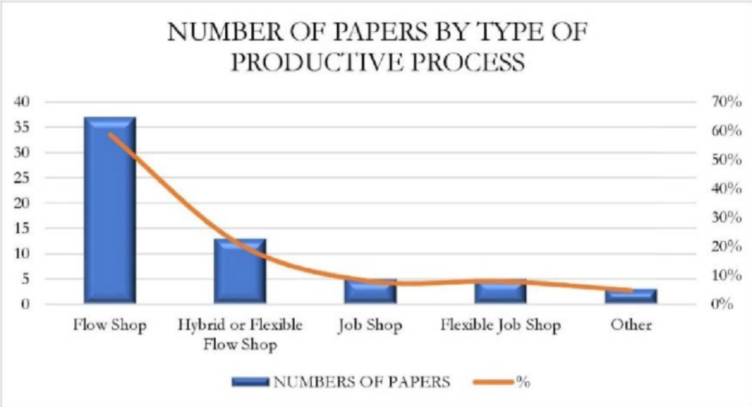

Figure 5. Number of papers depending on the type of Production Process

2. Additional features and times considered

In addition to the basic features of the problem analyzed, other further features or additional times are mentioned, which are restrictions on the formulation of the principal problem and are not necessarily mutually exclusive. Among those that are indicated:

Transport activities: For the transfer or handling of lots, with a limited capacity, as in the case of [71] and [39].

Blocking: Programming problems that do not consider intermediate buffers between adjacent machines and the first machine is inactive until the next machine can process the work, restriction proposed by [23], [24], [25], [26], [28] and [43].

Learning effect: Processing time decreases as operator experience increases; this is indicated in investigations of [41] and [45].

Preventive maintenance: Machines are not available all the time and are performed for a predefined time, present in the studies of [23], [49], [50], [51].

3. Configuration / work number - machines

Although nomenclatures are not always the same, configurations can be subdivided into two:

Generic: Where, once the calculation of the solution has been developed, it can "play" with the number of jobs, machines, and stages, the authors who have indicated these configurations are displayed in **Table 7**. 81% of the investigated papers belong to this group.

Table 7. Papers according to Configuration/Work Number - Generic Machines

Configuration	Number of papers	%
j jobs m machines	35	55%

Configuration	Number of papers	%
j jobs m parallel machines s stages	7	11%
j jobs m machines s stages	2	3%
j jobs m non-identical machines	2	3%
j jobs m identical parallel machines s stages	2	3%
j jobs m non-identical machines	2	3%
j jobs m heterogenous machines	1	2%
j jobs m series machines	1	2%
Total	**52**	**81%**

Specific: Where the problem's solution has been developed in a particular number of jobs, machines, and stages, the authors have pointed out the configurations indicated in **Table 8**. 19% of the investigated papers belong to this group.

Table 8. Papers according to Configuration/Work Number - Specific Machines

Configuration	Number of papers	%
j jobs 2 machines	3	5%
1 job m machine	1	2%
1 jobs on machine 1 j jobs on machine 2 2 machines	1	2%
1 machine at Stage 1 2 identical parallel machines at Stage 2 2 stages	1	2%
2 parallel machines 2 stage	1	2%
3 jobs 1 machine on Stage 1 2 machines on Stage 3 3 stages	1	2%
j jobs m parallel machines on Stage 1 n parallel machines on Stage 2 2 stages	1	2%

Configuration	Number of papers	%
j jobs 1 machines s stages	1	2%
j jobs m machines 3 stages	1	2%
j jobs 2 machines 2 stages	1	2%
Total	**52** [1]	**81%**

1 The sum of papers of the two types is 64 because one paper analyzes cases belonging to the two types.

4. **Types of sublots or jobs:**

Sublots are the partitioning of the transfer batch into smaller batches, appropriate for minimizing the target function. Three types of sublots are identified as described in [6]:

Consistent: If the lot size is the same for each pair of machines, with this type of batches work [17], [21], [34], [38], [41], [42], [49], [50], [51], [48], [57], [59], [61], [64], [67], [68], [69], [75].

Variables: If the lot size varies on all machines, this type of lot is found in work performed by [20], [32], [39], [40], [47], [49], [54], [58], [63], [66], [78].

Equal: If all sublots along all machines are the same size, [18], [19], [23], [24], [25], [26], [27], [28], [29], [30], [31], [33], [35], [36], [37], [43], [44], [45], [46], [48], [49], [52], [53], [56], [60], [62], [65], [70], [71], [72], [66], [74], [76], [77], [79], [80], investigate this type of sublot.

The proportionality of the number of publications per sublot is shown in **Figure 6**.

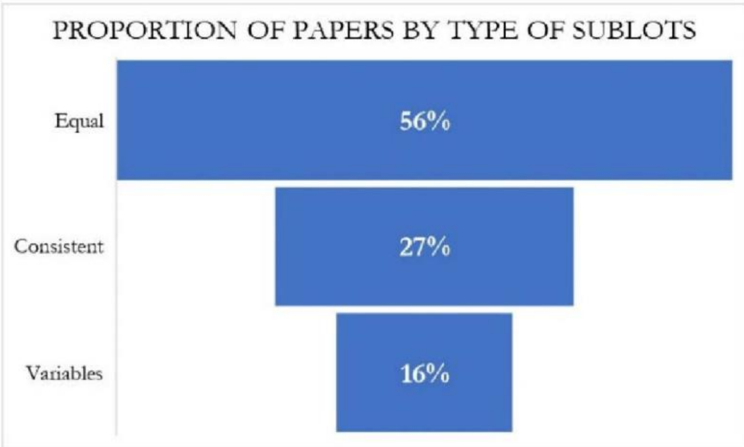

Figure 6. Percentage of papers depending on the type of Sublot

5. **Idling**

It is considered as a restriction when designing the models that will solve the problems formulated, being able to understand various types, such as idling between adjacent sublots but on the same machine or in one or more stages, in the exchange of jobs, or when there are no pending jobs.

Of the papers analyzed, only 26 (41%) report that they consider this restriction; in turn, of these publications, 6 (10%) check the utility of Lot Streaming under idling conditions against non-idling conditions.

6. **Buffer**

This additional inventory strategically placed to avoid disruptions to operations [1] is a new constraint to consider. Eleven publications (17%) report that buffers are taken into account, of which only 1 (2%) is of limited capacity; the others are described as unlimited or infinite capacity.

7. **Setup Time**

It is the time to prepare a machine or process for the next production order [1]; this would be another restriction for developing the optimization problem solution. 86% (54) of the revised publications mention in some way the existence of a setup time; however, of these, 18 papers (29%) indicate that setup time is negligible or already included in processing time. In 18 papers (29%), setup time depends on the sequence that jobs have on different machines, 16 papers (25%) point out that their setup time restriction has a sequence-independent configuration; finally, two papers (3%) make a comparison in the Lot Streaming with and without setup time.

8. **Objectives**

As noted, the goal of Lot Streaming is to minimize Makespan; 55 of the revised papers (87%) point to this as the main objective to be achieved, being able to express it in other words. Subsequently, the following objectives sought to meet are to minimize precocity and tardiness times, defined as the difference between actual end times and the date at which it was scheduled [24]; although there are other objectives, they are a minority.

9. **Calculating the problem solution**

According to the different demonstrations and studies, the problem we are referring to is the NP-Hard type [58]. Under this definition, different schemes have been developed to suggest a solution to the proposed problem; taking into account the characteristics of machines, sublots, and the restrictions determined by each configuration; two significant subgroups are generated:

Optimization algorithm: These can be generic algorithms generated according to the problem to be solved. These have already been developed and tested by an author and coupled to the type of problem to be solved. The papers that propose this type of solution are indicated in **Table 9**, with 47 publications or 75%.

Table 9. Papers that propose an algorithm to calculate the solution

Algorithm	Papers
HA: Heuristic algorithm	[62], [63], [68]
HGA: Hybrid genetic algorithm	[46], [47], [54]
SA: Simulated annealing	[57], [40], [66]
DABC: Discrete artificial bee colony	[37], [44]
DPA: Dynamic programming algorithms	[21], [55]
DSOMA: Discrete self organising migrating algorithm	[31], [52]
GA: Genetic algorithm	[61], [64]
IMMBO: Improved migrating birds optimization	[18], [60]
DEA: Differential Evolution Algorithm / PSO: Particle Swarm Optimization	[29]
GLASS – POTTS / JOHNSON’S	[48]

Algorithm	Papers
ABC: Artificial bee colony	[72]
DACS: Distributed ant colony system	[76]
DIWO: Discrete invasive weed optimization	[19]
DLHS: Local-best harmony search with dynamic sub-harmony memories	[35]
DPSO: Discrete particle swarm optimization	[53]
EDA: Estimation of distribution algorithm	[30]
EMMBO: Effective modified migrating birds optimization (EMBO)	[65]
GAJS: Genetic algorithm-based job splitting approach	[73]
GEA: Greedy constructive algorithm	[74]
HDABC: Hybrid discrete artificial bee colony	[24]
HDHS: Hybrid discrete harmony search	[56]
ILS: Iterated local search	[33]
INSGA-II: Improved Non-dominated Sorting Genetic Algorithm II	[27]
MA: Memetic algorithm	[77]
MABC: Modified artificial bee colony	[69]
MHA: Metaheuristic algorithm	[45]
MOMBO: Multi-Objective Migrating Birds Optimization	[25]
NEMO: Novel evolutionary multi-objective optimization	[26]
NGA: New genetic algorithm	[28]
NSGA II: Non-dominated Sorting Genetic Algorithm II	[58]
ONSGA-II: Optimization Improved Non-dominated Sorting Genetic Algorithm	[43]
PA: Polynomial-time algorithm	[41]
PH-MOEAD: Problem-specific heuristics multi-objective evolutionary algorithm based on decomposition.	[20]
REMO: Evolutionary multiobjective robust scheduling	[23]
SFLA: Shuffled frogleaping algorithm	[36]
TF-HI algorithm	[59]

Other calculation schemes: Other formulations do not indicate belonging to a specific algorithm. The publications that propose this type of solution are detailed in **Table 10**, with 16 papers or 25%.

Table 10. Papers that propose other schemes to calculate the solution

Algorithm	Papers
MILMM: Mixed-integer linear mathematical model	[32], [42], [49], [50], [51]
Mathematical model	[79], [38], [80], [67]
MILP: Mixed-integer linear programming	[71], [78]

Existing convex programming techniques	[34]
CP: Constraint Programming	[75]
TSM: Three-stage method	[39]
DSS: Integrated decision support system that combines multicriteria/AHP simulation and decision-making approaches: Analytical Hierarchy Process / WAM: Weighted Aggregation Method	[70]
IMM: Integer mathematical models	[17]

10. Software for solving the problem

To solve the problem and verify that the objective is appropriate, programming software or statistical analysis was used. The percentage of use of each software is indicated in **Figure 7**; 16% of the publications do not indicate the program to test their solution. Also, the software has been grouped according to its base; for example, C++ is a general name that includes Visual C++, C++, or C.

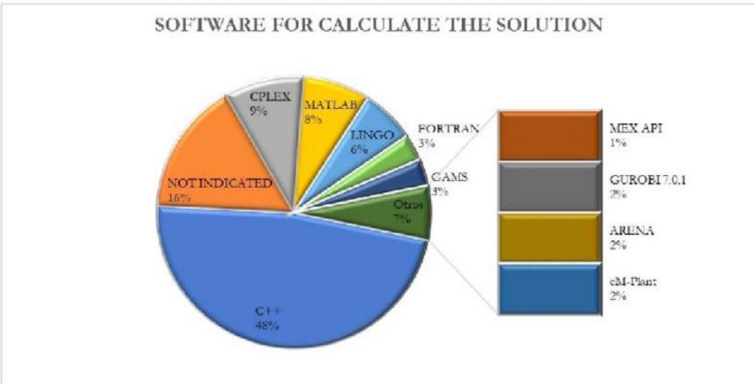

Figure 7. Software used to solve the problem

As can be seen in **Figure 7**, software such as Cplex and Lingo have been used to calculate the solution called "other calculation schemes" (as indicated in the previous characterization), or classical mathematical programming, that is, variants of linear programming, as indicated by Sun [81] and validated by Anand et al [82]. In contrast, programming software (C ++, Fortran) has been used to program-specific algorithms previously tested due to their ability to solve and the more effective assignment of operational restrictions, pointed out by Kovács in his study [83] and Azzi et al in [84].

11. Compared to

95% of the papers compare the proposed scheme to solve the problem with another scheme, another algorithm, or the same algorithm with other conditions. **Table 11** shows how each author has compared his proposed solution against another previously demonstrated solution(s) in the papers that propose an algorithm as a calculation scheme, while **Table 12** does so for other schemes.

Table 11. Comparisons for algorithms proposed to calculate the solution

Algorithm	Compared to
HA: Heuristic algorithm	The same TSAS-MP-MIP/TSAS-CP-MIP issue resolved in Solver, RK: Random Key Method / WSPT: Weighted Shortest Processing Time / JR: Johnson's Rule, and the same issue resolved in LINGO 11.0 with a Brauch and Bound algorithm
HGA: Hybrid genetic algorithm	GA, the same problem solved in Cplex, and the same problem but comparing the use of Variable Sublots and Consistent Sublots
SA: Simulated annealing	The same problem solved in Lingo, GA, Baker, the same problem solved in Cplex, and the performance of the parallel SA is evaluated against a sequential SA
DABC: Discrete artificial bee colony	HGA, HDPSO, SA, TA, ACO y DPSO
DPA: Dynamic programming algorithms	Proposal by Bukchin et al. (2002) and the same algorithm with different working values
DSOMA: Discrete self organising migrating algorithm	The same algorithm using the venerable MersenneTwister, and the same but generic algorithm
GA: Genetic algorithm	The same algorithm executed on both sequential and parallel computing platforms (using the PGA island model), SA and MILP solved in Lingo
IMMBO: Improved migrating birds optimization	TLGA, iFOA, DIWO, DE-ABC, EMBO, MBO, EGA, DIWO Y ABC
DEA: Differential Evolution Algorithm / PSO: Particle Swarm Optimization	TEA y ACO
GLASS – POTTS / JOHNSON'S	
ABC: Artificial bee colony	GA y TS
DACS: Distributed ant colony system	PSO and CP
DIWO: Discrete invasive weed optimization	EDA, ISFH, and ABC
DLHS: Local-best harmony search with dynamic sub-harmony memories	HGA y HDPSO
DPSO: Discrete particle swarm optimization	GA, GOOD, ACO y TA
EDA: Estimation of distribution algorithm	EDA (and variants), DABC, ACO, DPSO, HGA, SA (and variants), TA (and variants), and TS
EMMBO: Effective modified migrating birds optimization (EMBO)	MBO, IMBO, MMBO, GA, GAR, DPSO y DABC
GAJS: Genetic algorithm-based job splitting approach	Fixed Number Work Division Approach (FNJS), taking into account different dispatch rules
GEA: Greedy constructive algorithm	CPO, MILP-CN /MILP-MM solved with Solver and the same problem with and without Lot Streaming
HDABC: Hybrid discrete artificial bee colony	TA, INSGA, NGA y BBEDA

Algorithm	Compared to
HDHS: Hybrid discrete harmony search	DPSO
ILS: Iterated local search	HGA, DPSO y DLHS
INSGA-II: Improved Non-dominated Sorting Genetic Algorithm II	DHS, TA, basic NSGA-II
MA: Memetic algorithm	The same algorithm allowing or not to preemption
MABC: Modified artificial bee colony	GA, OPGA y TS
MHA: Metaheuristic algorithm	SA y TS
MOMBO: Multi-Objective Migrating Birds Optimization	BASIC MBO, h-MOEA, m-MOEA/D y REMO
NEMO: Novel evolutionary multi-objective optimization	INSGA-II and PBEDA
NGA: New genetic algorithm	GA
NSGA II: Non-dominated Sorting Genetic Algorithm II	i-AWGA, SPEA2
ONSGA-II: Optimization Improved Non-dominated Sorting Genetic Algorithm	DHS, NSGA-II, and TA
PA: Polynomial-time algorithm	
PH-MOEAD: Problem-specific heuristics multi-objective evolutionary algorithm based on decomposition.	EMBO, GA, GAR, DPSO y DABC
REMO: Evolutionary multiobjective robust scheduling	INSGA-II, PBEDA, MMSA, MOMA
SFLA: Shuffled frogleaping algorithm	HGA, TA y ACO
TF-HI algorithm	TF-I y TSHF-LSP

Table 2. Comparisons for other schemes proposed to calculate the solution

Solution	Compared to
MILMM: Mixed-integer linear mathematical model	The same problem with and without Lot Streaming and using various conditions and constraints (lot size, intermingling, maintenance times, sublot types)
Mathematical model	The same problem solved in Cplex, using different sublot sizes and transfer types and pure Flowshop against Hybrid Flowshop
MILP: Mixed-integer linear programming	The same problem with and without Lot Streaming using various conditions and restrictions
Existing convex programming techniques	
CP: Constraint Programming	The same problem with and without Lot Streaming using various conditions and restrictions
TSM: Three-stage method	GA, DEA, PSO, y HEA
DSS: Integrated decision support system that combines multicriteria/AHP simulation and decision-making approaches: Analytical Hierarchy Process / WAM: Weighted Aggregation Method	Use of different dispatch rules

Solution	Compared to
IMM: Integer mathematical models	Flexible Lot Streaming against Basic Lot Streaming

12. Metrics to evaluate

After proposing the problem-solving scheme, a comparison with another type of solution has been proposed, and different tests are carried out to demonstrate the proposed solution's effectiveness. Among the main comparison arguments are:

- The objective function and the maximum, minimum, and standard deviations.
- Cpu Time
- Average Rpi Value
- Hypervolume, Convergence
- Statistical tests to solutions such as ANOVA, Mood Median Test, Mann-Whitney Test, T-Test, U-Test

3.3. Final Data

1. Conclusion

In comparative studies, the benefit of using the proposed algorithm under the indicated restrictions is proposed as a percentage, taking into account machine and job numbers. The general conclusion is that the algorithm proposed by each author presents more consistent solutions than the others about the objective function, based on the metrics that are evaluated in each publication. Concerning non-comparative studies, the conclusion is that the proposed development has reduced Makespan through Lot Streaming.

2. Future works

Fifty-one publications (81%) propose future works born from the results or observations of the analyzed paper. Among the plans is the formulation of working conditions or more realistic problems regarding the different production processes and dynamic characteristics, reducing computational complexity, proposing different restrictions or uncertainties. Alternatively, work on defining new objectives or converting single-objective algorithms into multi-objectives, using self-adaptive algorithms focused on self-learning, or extend the proposed algorithm to a heuristic or metaheuristic algorithm to achieve a more intuitive and iterative result that reaches a broader and broader universe.

4. Discussion

4.1. Research questions

After making the investigation, it is possible to answer the question proposed in **Table 1**

QR1. In what types of production processes ***has LS been applied?***

This is the central data to be analyzed in the present systematic review, as it allows to recognize the applicability of the Opportunity for Improvement that is the LS concerning the industrial environments.

In the analyzed papers, the two main reported types of processes are the Flow Shop, as the most studied process, both in its pure scheme or hybrid, the 79% (50 of 63 papers), which would indicate at a glance that it is the most repetitive process at the industrial level. The Job Shop (both pure and hybrid) has only 16% (10) of publications.

It can add different restrictions or particular characteristics in the two types so that the designed model is more attached to the day-to-day living industries, pointing as main restrictions the transport, blocking maintenance, or effect of the so-called learning curve.

By answering this research question, we can infer that the LS can be extended to any production process once it is recognized its type and thus can generate a model according to the reality of the industry that is looking to optimize.

QR2. What types of sublots is LS used?

To formulate the problem to be solved, it is necessary to recognize different characteristics of the model to be developed initially; among them, the type of sublot has a critical weight. In this analysis, most papers provide solutions for schematics with equal sublots, i.e., more than half of papers (56%), while 27% generate solutions with consistent sublots and 16% with variable sublots.

Also, several of the revised papers mention different special considerations, such as idle times; however, only 41% mention their existence, or the case of buffers, in which only 17% talk about the presence of interprocess security inventories, the most mentioned aspect being preparation times, which 86% of the items take into account.

QR3. What optimization algorithms have been used for LS calculation?

The calculation of the solution for the proposed problem is the objective function of an optimization algorithm (widely mentioned in the literature) in 47 of the reviewed publications. The algorithms HA: Heuristic algorithm, HGA: Hybrid genetic algorithm, and SA: Simulated annealing are highlighted, which are mentioned several times in the review.

For their part, 16 publications do not indicate the use of an algorithm but instead use other solution schemes, such as a mathematical formulation with some variant to get a coupling with the sketch initially lifted.

The solutions have been parameterized in different programming software, such as C++ with 48%, or statistical optimization programs, such as CPLEX with 10%, demonstrating in 60 of the publications when comparing with other forms of calculation that the solution proposed in each paper is optimal thanks to specific metrics applied to the objective function statistically. In this way, it is concluded that an improvement in production processes and implicit costs can be achieved, but there will always be a new way to continue improving, such as a new generation of algorithms.

QR4. Has LS been used to decrease Makespan?

Among the revised papers, several optimization objectives are mentioned, such as energy consumption and costs associated with production processes; however, most papers (73%) explicitly mention that the objective minimization function corresponds to Makespan (or associated words), thus becomes clear the fact that this is the best utility of Lot Streaming (LS).

So, it can be concluding that applying this optimization technique would result in an improvement in the delivery times of the final product, which would generate customer satisfaction, because it can see its needs fulfilled, in addition to the company avoiding having lost sales, which is a conflict that companies have to face and makes them lose customers.

4.2. Comparison of current work with existing work

As a result of the search for publications in indexed journals referring to literature reviews on Lot Streaming (maintaining the search strategy of the present work), four articles were found, the first of these (in order of publication) is the one presented by Bagchi et al. in 2006 [11]. This paper proposes a review of applications of blocking programming models in robotic cells modeled with TSP (traveling salesman problems) but oriented only to a Flow Shop environment. Hence, it is not an open investigation like the present one, which investigates the different approaches to programming problems that can be solved with LS and the different production processes.

The following article is presented by Chang et al. in 2007 [9], where a complete review of LS is carried out, in which the evolution of LS research is outlined; that is, the research was not blinded to a current period. This work proposes a structure of dimensions, subdimensions, and levels that allow maintaining a more centered skeleton; however, it does not contrast the optimization algorithms that allow calculating and solving programming problems using LS.

Gómez - Gasquet et al. presented the third article in 2013 [10], where an investigation state of the art about LS is also carried out in a Flow Shop. That means that it does not consider other types of production processes such as the Job Shop or the Open Shop (of which definitively no references have been found). However, in his references, he does not discriminate the age of the publications, finding articles published in 1989, also if he presents a graph that refers to the techniques to solve the problem described, where the types of algorithms used, but does not indicate what they are, and this, according to the authors, is an essential aspect for future research.

Finally, Cheng et al. [8] also in 2013 proposed a review of the practically theoretical literature about LS in a scheme based on the objective of the application, that is, based on cost or based on time. In this paper, the different aspects, restrictions, and considerations for the mathematical model approach to be solved are raised, and a description of the solutions used, with references to publications in 1975, in a very sober way. This publication is a reasonable frame of reference to carry out this research.

Based on the articles mentioned, the present research provides a better source of study because it considers all the production processes in which LS has been applied; that is, it does not focus on any specific one. Additionally, due to having followed the guidelines of the PRISMA methodology, the systematic review is managed in a better way because it avoids redundancy in the information and bias towards a particular criterion.

Considering only research from indexed publications also allows generating a more austerity scheme to researchers to ensure that the sources cited in this paper have been the best by the methodological quality of the information contained in each document.

In addition, more factors have been analyzed apart from the background ones, so that they constitute different aspects that could be analyzed and be a source of new specific research, for example, the country is published, which defines that in specific continents such as Africa it is not have reported research on LS. Based on this information, analysis or implementation focused on the industry in this country could be carried out.

It is considered that the segmentation of the information sources after ten years of publication, while the four papers found on LS cite references with many more years of antiquity, does not limit the publication in terms of conceptual references. The reviewed research cites references that, in turn, are based on these ancient investigations, which ultimately proposes a frame of reference with solid and well-documented bases.

4.3. Contributions to literature

The work developed presents a compendium of relevant information found in 63 scientific articles on Lot Streaming, adding descriptive graphics so that the results obtained are visually contrasted at a glance. The summary tables allow detailing the scope of the consulted sources in a structured scheme. In addition, a scale of the analyzed information is carried out to cover with better specificity the data that constitute a literature review.

Having raised several research questions from the start has allowed the research to be guided in a way that focuses on the aspects considered to be central within the systematic review carried out, that is, the types of production processes, the types of batches with which they work, the algorithms to calculate the solution, and the objective of applying LS in an industry. With this strategy, the transcendental is demonstrated; therefore, the research is presented as valid in specific topics of LS.

In addition, considering that the limitation of the publication years (10 years), more modern and fresh research is proposed, based more than anything on the evolution of optimization algorithms since every day it is proposed more intelligent and developed. In addition to specific software and statistical programs, to solve programming problems in a more orderly way but also showing the different limitations or gaps that must be covered to make the calculation more precise, mainly considering that recent publications refer to Previous research has since been evaluated as of the necessary quality to nurture a proposed work.

4.4. Implications for practice

For future practical research, it can be made from the production processes applying LS. The new investigation will identify the need to optimize the production processes and validate that this is a tool according to the requirements. Next, they will be pigeonholed within these types of processes, the types of batches used, and the configuration of jobs, machines, and stages to adequately model the problem to be solved. Finally, select the algorithms with which one works, or propose a new algorithm or mathematical formulation to solve the specific programming problem.

4.5. Limitations

This revision has several limitations, including specific knowledge on the subject raised at the beginning of the review. However, while the research was being carried out, the spectrum was opening up so that more significant and better analysis objectives could probably have been identified with a broader knowledge of Lot Streaming.

Another limitation may be the scientific data banks consulted because several more could have been included, but an eligibility criterion was the Doi (Digital Object Identifier); it could slant the number and quality of the revised papers.

An additional limitation that, although it does not correspond to a probable execution error but rather to a restriction on the types of articles reviewed, it was initially proposed to present an analysis regarding the different industries that had applied the Lot Streaming. However, this was not found as a phenomenon analyzed in the reviewed publications.

4.6. Future works

The analytical review of papers allowed us to recognize that this technique is positively used in various types of Production Processes, so it can be extended to a lot of Industries, with their specific characteristics, thus, it is proposed to review the use of Lot Streaming in different industrial production approaches. Then, based on the primary analysis of the operational characteristics of the production processes and the formulation of different types of fundamental uncertainties that in turn become programming constraints, formulate mathematical modeling according to the most appropriate Algorithm (which includes comparing the operation of the different algorithms, as has been done in most of the reviewed studies). Consequently, calculate the optimized Makespan, comparing the application of this technique in different industrial axes, to show the differences or difficulties presented.

Another issue to be validated for future research and applications is using other methods of modelizing, optimization, and comparison of the improvement made to production processes. The premise to maintain is to reduce the use of resources and improve productivity without altering the application of the concepts of the flexibility of resources, product families, and innovation of the processes and the operational staff's knowledge.

4.7. Conclusions

The systematic review through the PRISMA methodology has shown that the use of the Lot Streaming is helpful to reduce the Makespan, in addition to allowing to achieve other objectives, such as the reduction of Operating Costs (maintenance, inventory management, electricity), which lead to the correct Productivity Management, resulting in improving the profitability margin of industries.

One of the strategies to achieve operational excellence in the industry is the adoption of Continuous Improvement tools. Lot Streaming allows being framed in this philosophy, taking into account that it makes use, according to the publications analyzed, of different Optimization Algorithms. Which are of maximum use for the mathematical modeling of the problem to be analyzed (the operational reality of the industry) and that they can capture different scenarios aimed at an increase in production with the minor use of resources (human, material, time).

The evolution of technology leverages the development of the industry because the development of new alternatives for organization, administration, control, improvement for industrial management is essential due to the emergence of new software and hardware with better benefits, which are not constituted in a kind of limitation for the execution of the applications that are required in the different business uses.

To carry out practical work in the future, the learning left by the realization of this research will be taken into account, and an application of LS in a specific manufacturing industry process will be proposed. It identifies the type of production process, modeling it with all its specific characteristics, selecting the algorithm considered the most effective, capable software, solving the problem, and analyzing the improvement obtained with the application of LS.

The criteria for the search and selection of papers (the years of publication, having DOI, only evaluating indexed journals, and using an own scheme to qualify the publications according to a weight of citations and age of publication) could be considered limitations to execute the investigation and validation of referenced documents more clearly. However, both the guide for the execution of Prisma reviews and its protocol has helped make a more focused and formal publication.

5. Patents

Author Contributions: AS conducted the literature search (all the phases of the study selection procedure), performed the quality assessment of primary studies, interpreted the results, and wrote the manuscript. MG guided the writing of the manuscript and was involved in finalizing it.

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5.4.3 Anexo 3 – Carta de Aceptación de artículo profesional

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Authored by:
Alexandra Salazar-Moya, Marcelo V. Garcia

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5.4.4 Anexo 4 – Sugerencias de los revisores

1.- Are there any other reviews on this research topic? And compared with the existing studies, what are the main contributions of this review article?

Response: *Other reviews on the subject have been found and are cited and compared in different places in the paper, and the contribution to the literature has been indicated.*

2.- The authors need to present the interrelationships among the four research questions proposed in Section 2.1

Response: *The relationship between the research questions has been pointed out.*

3.- The authors limited the publications within recent 10years in Section 2.4, which might lose some foundational studies appeared earlier. Therefore, the authors need to look out if there are such publications ignored.

Response: *Yes, the study is limited a bit, but priority is given to fresh research, this is disclosed within the body of the paper.*

4.- What does "risk" mean in Section 2.5? It is very confusing to see it to represent existing literature.

Response: *Risk of bias assessment (sometimes called "quality assessment" or "critical appraisal") helps to establish transparency of evidence synthesis results and findings. Risk of bias assessment is often performed for each included study in your review. Evidence syntheses strive to eliminate bias in their findings. Individual studies that are included in synthesis may include biases in their results or conclusions, for example, design flaws that raise questions about the validity of findings or an overestimate of intervention effect.*

5.- The NP hardness of the problem should be clarified in this study before they introduced the algorithms. Furthermore, they should focus on two kinds of algorithms, including intelligent algorithms and exact solution algorithms.

Response: *the NP-hard is explained in detail across the text. However, the algorithms are not grouped because it is listed which ones have been found in the investigation, without focusing on any particular type.*

6.- The authors should notice the importance of using exact benchmark to examine the accuracy and efficiency of intelligent algorithms when dealing with the problem of this study and similar problems such as routing problem and scheduling problem. There are many studies that consider above issue,

e.g., Tang and Palekar (https://doi.org/10.1016/j.cor.2010.10.006), Sun et al. (https://doi.org/10.1155/2018/8645793) and Fazayeli et al. (https://doi.org/10.1007/s40092-017-0218-6, see their conclusions)

Response: *Only the algorithms used have been indicated, a subsequent analysis could generate a further study on the selected algorithm schemes.*

7.- When discussing the software, the authors need to analyze their feasibility. For example, CPLEX and LINGO are more suitable to solve the problems formulated by linear programming models, which is stated by Xie et al. (2010,https://doi.org/10.1016/j.jhazmat.2012.05.028) and Sun (https://doi.org/10.1007/s40815-020-00905-x).

Response: *Considering the Reviewer's suggestion, we updated the manuscript by* clarifying the difference between software like Lingo and programming languages like C ++.

8.- The authors didn't discuss the problem under uncertainty. Are there any sources of uncertainty in this problem, e.g., demand uncertainty, capacity uncertainty and time uncertainty? Will this be one of the directions of future works of this field?

Response: *It is pointed out that in future research or in a practical application the behavior of the LS could be analyzed under specific uncertainties the goal of this article is to show a general vision of LS.*