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Assembly Line Balancing: A Bibliometric Analysis and Use Case

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ABSTRACT
One of the main elements in manufacturing companies is to achieve an adequate balance of production lines. The main objective is to distribute the workloads by balancing the manufacturing process. Within the production of vehicles, the automotive industry represents the biggest export market for Mexico since there are currently several automotive manufacturing plants that, directly or indirectly, within the production supply chain, represent a considerable portion of the national and export market. One of the main challenges is optimizing production lines by balancing operational resources such as production time to satisfy the market in the required time and form. This article addresses the main points necessary for line balancing.

***Keywords* –** Assembly Line Balancing, Discrete Event Simulation, Automotive, Industry, Bibliometric Analysis

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I. INTRODUCTION

The production system can be classified into the mass production system and the batch production system. In the mass production system, the plant facilities are designed to produce products in large volumes, while in the batch production system, such facilities manufacture products in small volumes. Mass production lines usually operate product flow lines to produce the same outcome over a long period, while in batch production, there are different work locations within the factory to transform the product [1].

The design of a mass production line is the basis for improving the productivity of today's manufacturing companies. These production systems can be classified into transformation production lines for machining components and product assembly lines [2]. They should be considered flexible due to the dynamic market and user demands.

Assembly lines are used in mass production, such as in the automotive industry, as they allow products to be finished faster with higher levels of efficiency. One of the first assembly lines was introduced in the early 1900s at Ford factories in the assembly of the Model T, which allowed for fast unit construction -manufacturing each car was executed in the same way. Nowadays, customers expect high customization while still maintaining a short lead time and competitive costs.

Manual labor allows a broad gamma of models to be manufactured on the same production line, as operators are very flexible with several tasks. On the other hand, keeping workers up-to-date with the correct training and high-end machinery implies high operational costs and investment for companies. Those are the main reasons for setting the proper planning and configuration of these assembly lines [3]. Each failure generates additional costs and a loss of competitiveness.

The most representative variables usually found in automotive production lines are the time invested in product processing, waiting times, the production capacity of the line, the skill of the operators, the available time (in hours), the efficiency percentage of the line, and the different times according to the model. In addition, it is necessary to maximize resources using the time available for the operation [4], thus trying to achieve the volumes required by the market. It again remarks a key reason why line production must be balanced [5]. Line balancing is essential to ensure that the load at each workstation is as uniform as possible [6,7].

Assembly optimization has relied on traditional methods such as time and motion study. However, Industry 4.0 implementation enables key technologies such as digital twins (DT), internet of Things (IoT), discrete event simulation (DES) models, and data analysis technologies.

For instance, by employing DES tools, companies can model their processes before implementing physical changes, minimizing risks, and maximizing results. The increasing customization in the car industry has raised the need for manufacturing flexibility backed by such tools.

Adding such flexibility to the assembly lines makes line balancing a critical aspect of manufacturing. The time to produce an assembly unit should be the same for the rest. The design of an assembly line for a product mainly involves optimizing the number of workstations by achieving a workload balance between workstations. It helps companies to reduce non-value-added tasks and utilize their facilities to produce the exact number of units or products to meet market demand [8].

II. BIBLIOMETRIC ANALYSIS

This section shows a couple of network maps to visualize authors, countries, and keywords involved in topics related to assembly line balancing and DES models. In addition, a table with the most cited documents is presented and used to describe the six works most cited.

The following search string was used to retrieve records from the SCOPUS database, restricted to documents since 2011. 144 records were retrieved by executing the search string on February 20th.

TITLE-ABS-KEY ((simulation OR "discrete event" OR des) AND ("line balancing")) AND PUBYEAR > 2010 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final"))

Each network map is represented by nodes, links, and a numerical value that indicates the strength of the link between two nodes. Similarly, the nodes' size is proportional to the number of documents published by the author, country, or the existing keywords appearing on such documents. Fig. 1 shows the main authors involved in topics of assembly line balancing and DES restricted to have at least two articles published, given 42 authors. They formed 20 clusters of different sizes (some interconnected), and the biggest contains five authors. For instance, Tiacci appears on five documents, and Lopes and Magatao contribute to producing two articles (see at the bottom).

Furthermore, there are a total of 28 countries represented in 13 clusters. It is worth mentioning that six countries appear isolated: Sweden, Hungary, Thailand, Greece, Egypt, and Iran. Of the rest, 22 are contained in seven clusters, two of them far away: Brazil connected with Australia and Spain, and Kenya with Uganda. The rest of the countries appear connected, as shown in Fig. 2.

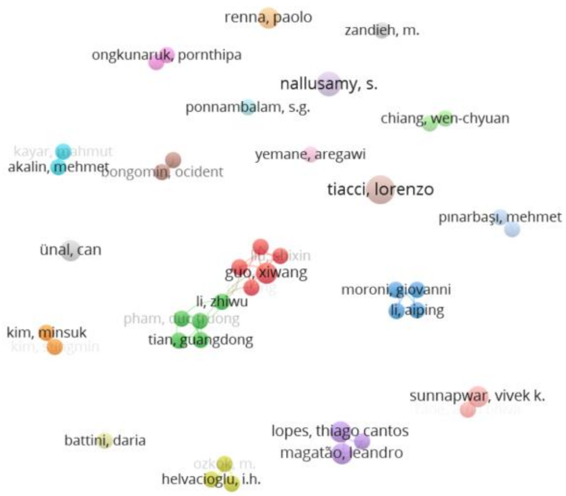

Fig. 1 There are 42 authors that appears at least on two documents.

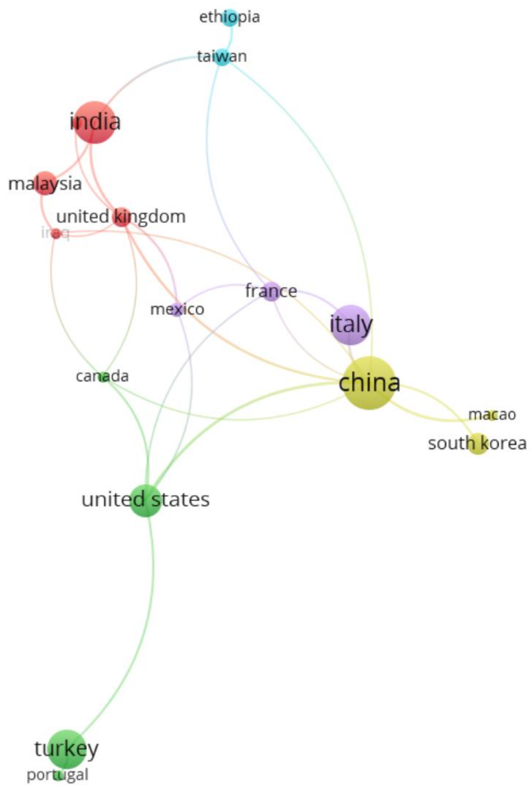

Fig. 2 The countries relationships.

China appears as a prominent country with 25 documents, followed by India with 17, Italy with 16, Turkey with 15, and the United States with 11. Some developing countries, such as Ethiopia and Mexico, exhibit 4 and 3 documents, respectively. The stronger link value belongs to China, which cooperates with Italy and the United States, with a strengthened link of 2. Ethiopia cooperates only with

Taiwan, whereas Mexico cooperates with the United Kingdom, the United States, and France. Furthermore, Fig. 3 presents the information in a temporal way of the participating countries. It can be seen that older publications belong to countries with leadership in line balancing problems with simulation tools, such as the United States, Turkey, and India. More recently, the United Kingdom and Mexico appear with five and three documents.

Fig. 4 displays the most cited documents, each containing ten or more citations. There is a total of 62 enclosed in 44 clusters. There are a couple of clusters interlinked, such as Tiacci and Bagher. Table 1 displays the 10 most cited documents. Altekin and Akkan [9] improved the profitability of a disassembly line by employing mixed-integer programming. They carried out a DES study to analyze the performance of the disassembly lines. Caputo et al. [10] presented a framework for DT of stations to reduce the time to design a new line. They used a DT of an automotive assembly line to validate results, strengthening the importance of ergonomics for human-centered smart factories.

Moreover, Guo et al. [11] worked with a stochastic multi-product and multi-objective disassembly line balancing problem. They used simulated annealing and a multi-objective optimizer to solve the uncertainty of products that cause disassembly failures. Nallusamy and Adil Ahamed [12] analyzed the current process layout for identifying and removing non-valued steps. They utilized lean tools like 5S, value-stream mapping, and line balancing, conducting a virtual simulation to verify and validate the existing situation. Bagher et al. [13] introduced a hybrid evolutionary algorithm to solve U-type assembly line balancing problems. They adjusted the algorithm parameters using the Taguchi method and examined the algorithm's performance over benchmarks from the literature to validate it.

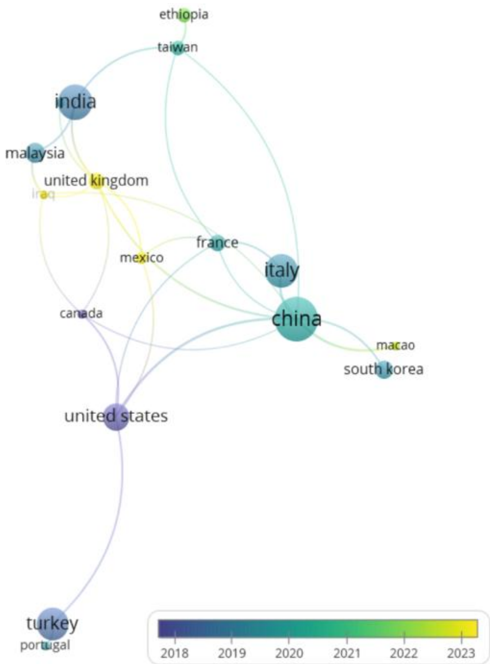

Fig. 3 The countries relationships by a timeline.

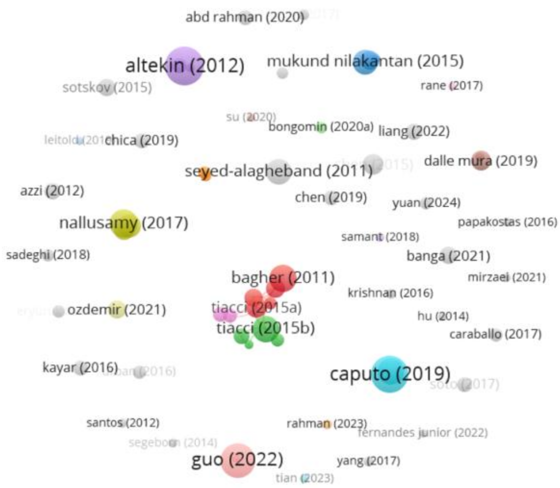

Fig. 4 Most cited documents by author, each document with at least 10 citations.

Table 1. The 10 most cited documents.

Document	Citations
Altekin and Akkan [9]	127
Caputo et al. [10]	122
Guo et al. [11]	107
Nallusamy and Adil Ahamed [12]	77
Bagher et al. [13]	71
Fera et al. [14]	69
Tiacci [15]	68
Seyed-Alagheband et al. [16]	66
Mukund Nilakantan et al. [17]	60

Nallusamy [18]	55

Finally, Fera et al. [14] presented a framework based on IoT devices and DES tools to analyze and monitor the production line performance. The infrastructure used makes a continuous assessment of line balancing under a variational product demand, validating the proposal on a real manufacturing line.

III. METHODOLOGY

To perform an adequate balancing, it is practical and logical to follow the steps described below:

1. Identify the task assignment for each process. The basic tasks that each operator must perform must be determined and each must be described in an analysis from the placement of a study to a complex assembly such as routing a main harness.

2. Make an assembly diagram. For each of the basic operations, it is necessary to determine the standard time and the order in which they must be performed.

3. Establish the cycle time of the line. The fundamental purpose of line balancing is to produce the number of units required within the available production time. To ensure that this is fulfilled, it is necessary to establish the cycle time of the line. It is defined as the maximum time that a product can remain at each workstation.

To obtain the cycle time of each operation we need to apply (1):

$$\text{Cycle Time} = \frac{\text{Available Time}}{\text{Total Units}} \quad (1)$$

When the cycle time is computed, it will be used to calculate the actual cycle time on which the efficiency of the line will be based. Therefore, the calculation of this cycle time will be a reference for the cycle time limit of each workstation, but the actual cycle time will be the maximum time that the product takes at each station.

4. Calculate the minimum required number of operating stations. The theoretical number of stations is calculated by dividing the total time of the tasks by the cycle time.

Once the cycle time has been computed, it will be used to calculate the actual cycle time on which the efficiency of the line will be based.

Therefore, the calculation of this time will be a reference for the cycle time limit of each workstation, but the actual cycle time will be the maximum time that the product takes at each station. The equation (2) makes this:

$$\text{Number of stations needed} = \frac{\sum \text{Task time}}{\text{Cycle Time}} \quad (2)$$

5. Assign basic tasks to each workstation. Elementary tasks must be assigned to each workstation, respecting the logical assembly order and the maximum cycle time.

6. Calculate balancing efficiency. To calculate balancing efficiency, you must divide the total task time by the number of workstations required by the assigned (actual) cycle time of the workstation with the highest time.

$$\text{Number of stations} = \frac{\sum \text{Time for each task}}{(\text{Stations number})(\text{Cycle Time})} \quad (3)$$

In this context, the assembly of an automotive unit goes through several stages, where the case exposed referred to the Trim 1 line. For instance, *Set Sun Roof RH/LH*, *Take Off Door RH/LH*, *Set Body harness RH/LH*, *Set Engine Room Harness*, and *Set Side Sensor RH/LH*. Fig. 5 presents the current percentage workload of each stage and exhibits opportunities for stages 2,3,7,8 and 9.

Balancing automotive production lines is a crucial process in vehicle manufacturing, as it seeks to distribute tasks in a balanced manner between the workstations on the assembly line. The objective is to minimize bottlenecks, optimize efficiency, and reduce cycle times to ensure efficient and profitable production. The model must consider:

- Line downtime, defined by exponential distributions.
- Productive times based on raw material availability and station operability.

- Analysis of operator movements to detect opportunities for efficiency improvement

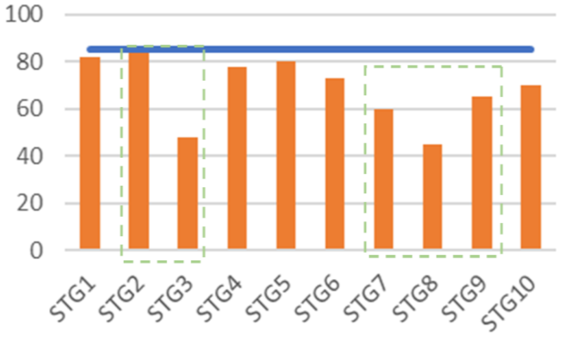

Fig. 5 The number of stages and percentage of occupation during an assembly car unit.

IV. RESULTS AND DISCUSSION

Research on assembly line balancing problems is crucial for the productivity of mass production systems. It works to maximize the throughput rate. Implementing efficient balancing in production lines brings with it multiple advantages:

- Greater operational efficiency, by reducing downtime.
- Reduction in production costs, by optimizing the distribution of resources.
- Increased productivity, thanks to better synchronization between processes.
- Improved product quality, by reducing errors due to work overload.
- Flexibility in production, allowing adaptation to variations in demand.
- Optimization of plant space, by reducing unnecessary travel and making better use of available resources.

A case study in an assembly plant in Mexico showed that, after the implementation of line-balancing strategies, the operation efficiency improved by 12 % with a downtime reduction of 20 %. It was achieved using and applying the steps described to redesign the layout of stations and optimize task assignments. Fig. 6 displays the results after using the methodology exposed for the assembly line balancing problem. The improvement has increased the percentage of work in each workstation, where tasks of stage 10 were distributed over other stations, and such stage is eliminated.

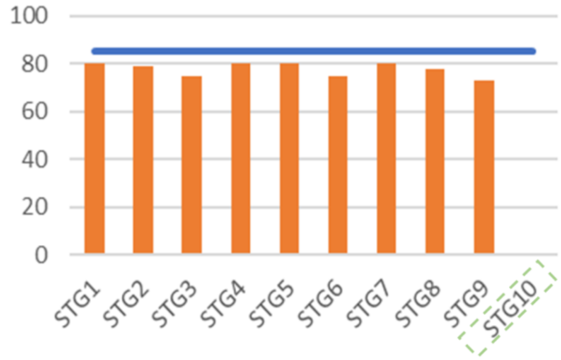

Fig. 6 The number of stages and percentage of occupation after assembly line balanced.

Another relevant example is that of an assembly plant in Germany, where collaborative robots are integrated into stations with higher workloads to reduce operator fatigue and increase production capacity without the need to extend working hours. These cases demonstrate how the application of line-balancing methodologies, supported by technological tools, can generate significant improvements in terms of productivity and costs.

V. CONCLUSION

Assembly line balancing is an essential strategy in the automotive industry to maximize efficiency, reduce costs, and improve product quality. Structured methodologies and DES models support companies in the optimization of workload distribution, minimize bottlenecks, and increase productivity.

In a highly competitive environment with a demand for greater product customization, line balancing becomes a priority for automotive companies. The combination of statistical analysis, simulation, and advanced technology will ensure that the industry continues to evolve toward more flexible and efficient production models, adapting to future challenges.

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