Title	組み立てラインにおける作業者再配置のための需要指向数理計画モデル
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Abstract

Assembly lines (ALs) are of great importance in most actual production systems and thus continue attracting strong research interest. In fact, assembly line balancing (ALB) continues to be an active area of optimization research in industrial engineering, operations management, operations research, and related fields. We address a real industry scenario where the aim of the line is to target a production output that meets, as much as possible, a given demand forecast. To the best of our knowledge, the existing literature has not tackled this problem, and we denominated it the *demand-driven assembly line rebalancing problem* (DDALRP). In this work, we define the DDALRP, provide a classification framework for the problem variants, developed two non-linear, multi-objective, combinatorial optimization models, and tested the models in the straight assembly line, providing useful insights about the dynamics of worker reallocation.

In a nutshell

Purpose: Introduce the *demand-driven assembly line rebalancing problem* (DDALRP).
Academic implication: This paper contributes to the body of knowledge in the field of assembly line balancing (ALB) / rebalancing (ALR) by introducing a new family of problems (DDALRP).
Originality/value: The rebalancing mechanism: We rebalance an assembly line (AL) over a planning horizon (multi-period rebalancing) via worker reallocation, taking into consideration a demand forecast, as well as workers' learning and forgetting (L&F) curves.
Method: Non-linear, multi-objective, combinatorial optimization model solved by means of a genetic algorithm (GA).
Findings: The results of the numerical experiments reveal insights about the dynamic of worker reallocation over the planning horizon (the length of the demand forecast), under different scenarios: optimistic, most-likely, pessimistic L&F coefficients; experienced and inexperienced workers; and different demand scenarios.
Practical implications:
1) With this method, it is possible to adjust the production output of the AL without the need of reengineering the line; i.e., without modifying the original assignment of tasks to stations.
2) Worker reallocation implies job rotation, which leads to job enrichment and multi-skilled, motivated workers.
Limitations: This model is limited to manual ALs organized in straight layout (I-shaped configuration). The investigation of the DDALRP in ALs having other types of layout (U-shaped ALs, two-sided ALs, ALs with parallel stations, etc.) is part of the upcoming research agenda.

Research content

Ford's assembly line at Highland Park is one of the most influential conceptualizations of a production system [1]. Formally, an assembly line is a production system where the bill-of-material parts and components are attached one by one to a unit in a sequential way by a series of workers [2]; these units or workpieces visit stations successively as they are moved along the line usually by some kind of transportation system, e.g., a conveyor belt [3, 4]. The main objective of an assembly system is to increase production efficiency by maximizing the ratio between throughput and cost [5].

The extensive literature on assembly line balancing (ALB) has focused on maximizing line efficiency, overlooking strategic use or neglecting the organization's overall operations effectiveness [1]. Wilson [6, 7] argues that Ford's assembly lines were optimized both 'locally' as individual production systems; and also 'globally' as constituent sub-systems of Ford's larger, vertically integrated supply chain system. Wilson [1] also reveals with data that, in fact, Ford's operations were adaptable to strongly increasing and highly variable demand.

Needless to say, the importance of matching supply with demand is universally recognized [8, 9, 10, 11, 12]. However, to our surprise, demand fluctuations still have not been explicitly considered to perform task assignment and/or worker allocation (to stations) in the assembly line balancing problem (ALBP).

This research introduces the *demand-driven assembly line rebalancing problem* (DDALRP). The proposed models aim to balance and rebalance an assembly system over a planning period, adjusting the production output of the line as much as possible to the forecast market demand, by means of worker allocation and reallocation. At the same time, our models aim to achieve smooth production flow by minimizing the standard deviation of the number of units processed by the stations and minimizing total overproduction or production excess.

Experimental results provided useful insights to understand the dynamic of worker reallocation under different scenarios: (1) optimistic, most-likely, and pessimistic learning and forgetting coefficients; (2) experienced workers (e.g., workers with some initial skill inventory) and inexperienced workers (e.g., workers with no initial skill inventory); (3) different demand forecast trends (increasing, seasonally increasing, and erratic patterns); and (4) different levels of difficulty of the demand forecast (attainable and challenging).

Because our model takes into account the learning curve, due to the learning effect, eventually, all workers will achieve 100% efficiency in all assembly tasks, after several reallocations. When this point is reached, any worker allocation to stations would yield nearly the same number of units of production output from the line. So, the proposed model should be particularly useful during *production ramp-up*, the period from completed initial product development to maximum capacity utilization. The core idea in this research is to assertively match learning curve improvements with variable (changing) demand.

Research purpose

Previous research in ALB has focused solely on maximizing the efficiency of the assembly line, without taking into consideration the number of units that are actually needed, orders placed by customers, or any kind of demand forecast.

The originality standing points of this work consists of a balancing mechanism of the assembly line that aims at both, achieving high efficiency, and adapting the production output of the assembly line to some given demand forecast. As a consequence, this work addresses by the first time a problem that we have named DDALRP.

Different from other balancing methods, which attempt to evenly distribute workload among the stations of the line by performing a *one-time* assignment of *tasks to stations*, our balancing mechanism is performed repeatedly (*multi-period*) by allocating and re-allocating *workers* (to stations) over some planning horizon (the length of the forecast horizon), considering dynamic processing times of tasks due to the learning and forgetting curves of workers.

We hope that the DDALRP will become an important research topic within the field of assembly line balancing (ALB) / rebalancing (ALR).

Keywords

- Assembly line rebalancing
- Demand forecast
- Learning and forgetting curves
- Non-linear, multi-objective, combinatorial optimization model
- Worker reallocation