

# Flow shop manufacturing layout as low carbon approach for application in bonding wire drawing industry

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**Abstract.** Modern manufacturing environments are yet to fulfil the ever-growing competitive supply and demand due to the limitation of conventional production approaches. A low-carbon approach incorporating the change from process to product-centric manufacturing systems could conserve energy while fulfilling supply and demand requirements in a competitive market. Current study had conducted a case study in a bonding wire factory that operates on process-oriented system with job shop layout. Preliminary data collection had assessed the existing practices on the factory's shop floor, and simulation model using WITNESS software was developed using this data. A job shop to flow shop conversion framework was developed with the integration of factors such as shop floor layout, order release, and dispatch rule play crucial roles in the conversion process of the production system. Based on the application of the conversion framework encompassing six future production system models, CL-SPT model which uses flow shop as layout, CONLOAD as order release and shortest processing time as the dispatch rule is selected as the best performing and economical production system. This model enhanced the output and average flow time by 2.7% and 27.7%, respectively, in tandem with low-carbon requisites while retaining machine utilization performance equivalent to the conventional system.

## 1 Introduction

A process-oriented production system is a manufacturing facility designed with great flexibility to manufacture diverse products and to carry out customizable production [1] while product-oriented production system is a form of facility setup where the machines or workstations are arranged in a serial line and all the jobs flow along the same route [2]. Both these systems perform best to their function in their respective manufacturing environment. However, product-oriented production system is superior in terms of machine utilization, lead time, material handling cost and Work-in-Process (WIP) control [3]. This is due to the

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continuous production and minimal waiting time between adjacent processes in product-oriented production system [4].

Conversion of process-oriented production system to product-oriented production system is not possible without addressing and solving certain challenges, such as dispatch rule, order release, shop floor layout and cost of changeover. Both production system is operable with number of dispatch rules, and several are compatible with both production systems [5]. However, there are several dispatch rules that are not interchangeable because of the different function of the dispatch rules that may yield different behaviour of the production systems [6]. The instruction from Material Requirements Planning (MRP) to release orders acts as the only instruction for process-oriented production system, whereas for product-oriented production system it acts as the first instruction [7].

In job shop layout, the job movements on the shop floor are flexible which leads to multiple job routing. Whereas in flow shop layout, the movement of the jobs are fixed with no unnecessary movements on the shop floor. Releasing jobs with multiple routings on flow shop layout would cause the production system to collapse as it will extend the lead time and WIP build up will become uncontrollable. Hence, group technology (GT) method need to be employed to scrutinize the non-value-added activities and identify the part families before adapting to the flow shop layout.

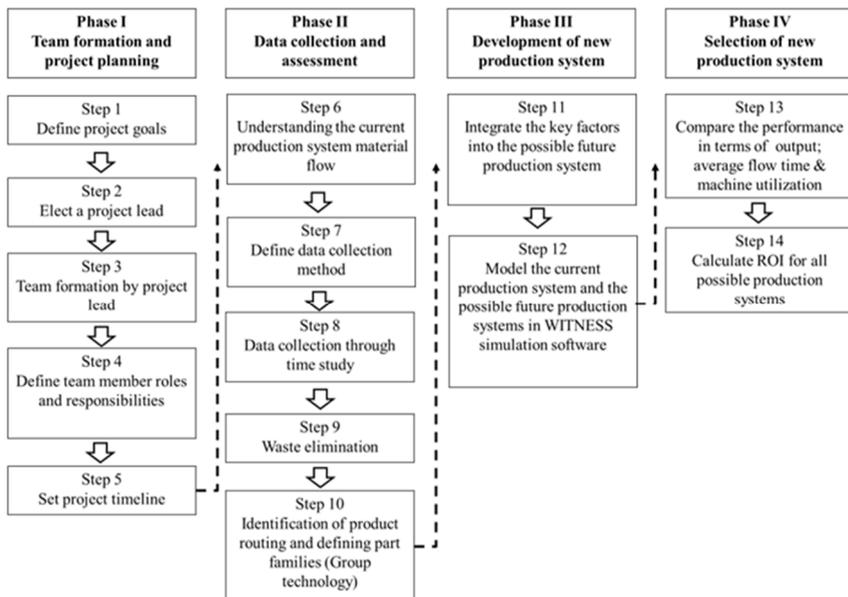
Current research aims to establish the transition from a process-oriented production system utilizing a job shop layout to a product-oriented production system employing a flow shop layout. Previous conversion studies have predominantly focused on transforming process-oriented production systems using job shop layouts into product-oriented systems [8]. This research serves as a pioneering effort in the conversion of process-oriented production systems with job shop layouts to product-oriented production systems with flow shop layouts in bonding wire drawing industry.

Low carbon economy spotlights the overall efficiency of source allocation and decreasing carbon emissions by enhancing energy intensity [9]. A framework for the conversion of the production system is introduced in this research, which drives a structured conversion process in achieving optimized production performances and at the same time sustainable production system through low carbon economy approach in an organization.

The case study for this research was conducted at a company based in Kulai, Johor, Malaysia. The company, established in 2008, possesses excellent facilities and cutting-edge technologies for manufacturing copper wires. This company provides several packages of manufacturing processes tailored to meet customer requirements and standards. This company also produces many items in the form of thin drawn wires. These wires are extensively utilized in the electronics industry, particularly in printed circuit boards (PCBs). This company is operating on a process-oriented production system in job shop environment.

## **2 Methodology**

The focus of this framework is to convert process-oriented production system working on job shop layout to product-oriented production system with flow shop layout. This framework consists of four phases, which are, Phase I, Team formation and project planning; Phase II, Data collection and assessment; Phase III, Development of new production system; and, Phase IV, Selection of new production system. The flow of the framework is shown in the Figure 1.



**Fig. 1.** Job shop to flow shop conversion framework.

Phase I of the framework consist of five steps. First step is to define project and the goals by the project manager. Second step is to elect a project lead, which lead to the third step where the team lead will form the team. In the fourth step, the roles and responsibilities of each team members will be defined. As the last step, project timeline will be set.

The objective of phase II is to understand the current production system, eliminate non-value-added activities and to identify the number of process flows (routings) on the shop floor. To aid the objective achievement for this phase, the data collection and assessment approach is proposed. Each of the 5 step carries its respective objective, and at the end of the phase as the objectives are achieved the production flow would be effective and productive.

Phase III of this framework discusses the steps in developing the new production system. This phase comprised of two steps. The first step provides insight on the integration of the three key factors chosen from literature review in generating possible future production systems. The second step provides guidance on simulating the current production system and the future production systems generated in the previous step.

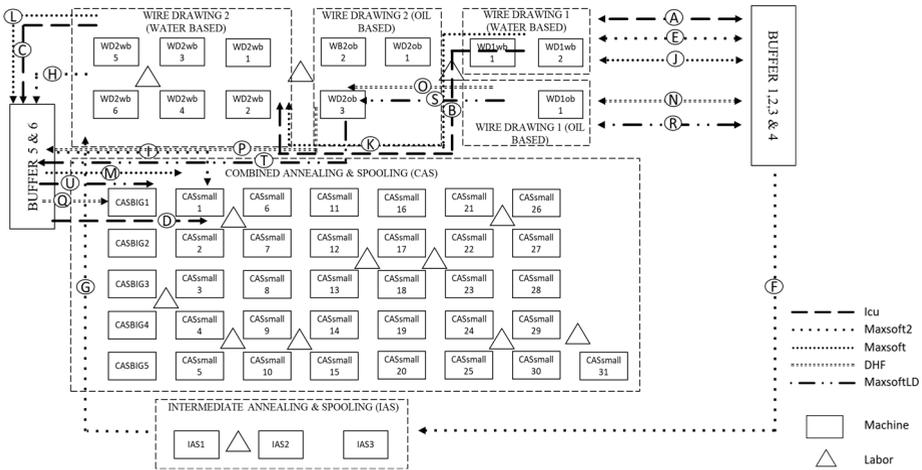
In phase IV, the best performing future production system would be chosen based on its performance in terms of output, average flow time and machine utilization. The objective of this phase is to choose best performing and economically feasible future production system. The first step compares the performance, whereas the second step provides the guidance to calculate the cost of conversion for each production system and compares the cost efficiency of each production system by using return on investment (ROI) calculation.

### 3 Results

Phase I involved the case study company's relevant department personnel forming the team. The 3-month project timetable was set. As per phase II, the production system is examined, and data collection conducted for evaluation. The analysis found that the existing process-oriented production system has four primary processes: Wire Drawing 1 (WD1), Wire Drawing 2 (WD2), Intermediate Annealing and Spooling (IAS), and Combined

Annealing and Spooling (CAS). Current production flows are water-based and oil-based. This wire drawing process uses water and oil as lubricants; hence machines are identified by lubricant use. Variations in machine identifications affect manufacturing flow.

The shopfloor has five main products: Icu, Maxsoft, Maxsoft 2, DHF, and MaxsoftLD. Figure 2 shows the current process-oriented production system's job shop structure and five primary product material flows on the shop floor. Icu and Maxsoft follows water-based flow from buffer station 1 to WD1, then to WD2 and staged at buffer station 2 before reaching CAS small machines. Maxsoft2 follows similar flow, but it flows through IAS in between WD1 and WD2. DHF and MaxsoftLD follows oil-based flow from buffer station 1 to WD1, then to WD2, and stage at buffer station 2 before proceeding to CAS big or CAS small machines based on lot diameter variation.



**Fig. 2.** Current production system with job shop layout and the product flow.

Multiple material moves in this process-oriented production system make routing and job traceability inefficient. Processing time variations cause long waiting times, extra WIP inventory, and underutilized or overworked machines and labor. Due to its long average processing time, WD2 appears to be the bottleneck despite its high resource allocation. Inefficiencies like repeated material transport between workstations increase lead and flow times. Step 8 of the framework involves a rigorous time study to identify and eliminate non-value-adding production activities, optimizing flow and production efficiency.

In accordance with step 10, implementation of a combined time and labor analysis alongside group technology principles yielded significant improvements in production efficiency. The analysis identified two distinct product families (PF): PF1 (DHF and Maxsoft LD) and PF2 (Maxsoft, Maxsoft 2, and ICu). The PF1 and PF2 are defined into flow lines called Line 1 and Line 2, respectively. As a result of line 1 and line 2 introduction, the workforce was optimized, reducing personnel from 13 to 11. Additionally, a detailed time study facilitated the elimination of non-value-adding (NVA) activities, achieving a commendable 10.9% reduction in setup times.

The completion of phase I drives the research into phase III, where six possible future product-oriented production systems through the incorporation of the three key factors developed in WITNESS simulation software. All 6 future models adopted the flow shop layout. As for the order release push (PH) and CONLOAD (CL) systems are deployed. First in first out (FIFO), shortest processing time (SPT) and earliest due date (EDD) are the three dispatch rules selected for these future models. The details on the combination of these three key factors for each future models are tabulated in Table 1.

**Table 1.** Current and possible future production systems.

Production system	Layout	Order release	Dispatch rule	Modelling name
Current model	Job shop	PH	FIFO	Current
Future model 1	Flow shop	CL	FIFO	CL-FIFO
Future model 2		CL	SPT	CL-SPT
Future model 3		CL	EDD	CL-EDD
Future model 4		PH	FIFO	PH-FIFO
Future model 5		PH	SPT	PH-SPT
Future model 6		PH	EDD	PH-EDD

## 4 Discussion

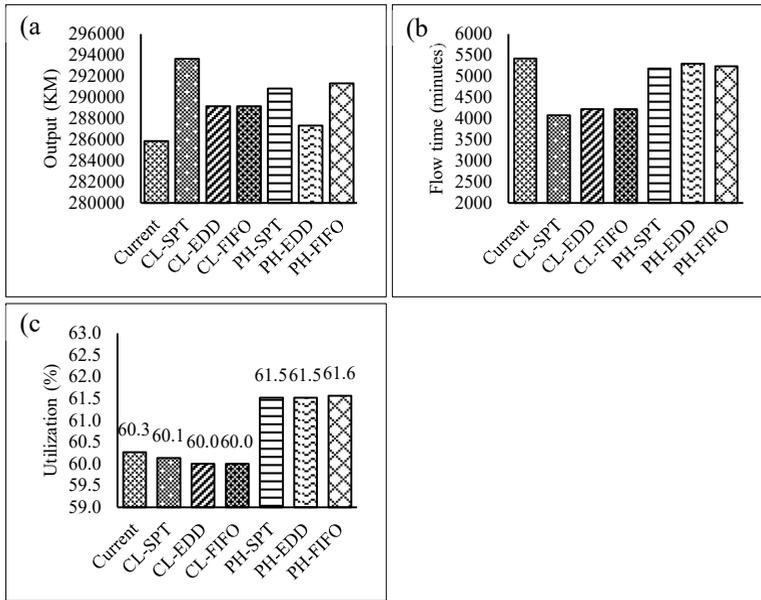
The implementation of this framework, designed to conversion from a job shop to a flow shop layout, yielded demonstrably positive results across several key production metrics. A meticulous time study was conducted, enabling the identification and elimination of non-value-adding activities. This resulted in a commendable 10.9% reduction in setup times, directly aligning with the streamlined production flow characteristic of a flow shop layout. Consequently, lead times for products traversing the production line were significantly reduced.

Furthermore, capitalization on the inherent repetitive nature of tasks within a flow shop environment reduced the workforce from 13 to 11 personnel, without jeopardizing the product quality. This streamlining has the potential to translate to a reduction in overall labor costs. Finally, the shift towards standardized products, a hallmark of flow shops, yielded significant improvements in inventory management. The organized movement of material through the production line enhanced visibility and predictability, leading to a more efficient approach to inventory control. These combined benefits serve as a testament to the practical efficacy of this framework in optimizing production within a flow shop layout.

Traditionally, production system analysis has prioritized maximizing output, minimizing flow time, and achieving high machine utilization. However, the transition towards a low-carbon economy necessitates a more comprehensive evaluation that considers these metrics alongside their environmental impact. This research examines various production systems through this lens, highlighting the importance of identifying an optimal balance between efficiency and sustainability.

As shown in Figure 3(a)(b), CL-SPT stands out as a promising contender, demonstrating an increase in output (+2.7%) and a substantial reduction in flow time (+24.7%), in comparison to the current job shop production system. In contrast, a study converting job shop to cellular manufacturing showed a flow time improvement of 15.97% [10]. Another comparison study between job shop and virtual manufacturing (VCM) using SPT as the dispatch rule showed that despite setup time reductions, job shop layout performed better in average flow time [11]. These findings collectively highlight that this study by converting job shop to flow shop achieved exceptional optimization of flow time efficiency. These improvements suggest enhanced production efficiency, potentially leading to higher throughput and reduced lead times. On the other hand, the output decline observed in CL-EDD and CL-FIFO suggests potential trade-offs that warrant further investigation.

Interestingly, PH systems, while exhibiting impressive machine utilization exceeding 61% as can be seen from Figure 3(c), might not be the most sustainable option. High machine utilization doesn't necessarily equate to an environmentally friendly system. In the context of a low-carbon economy, production efficiency must be balanced with environmental impact. CL systems, with their potential for lower energy consumption due to potentially streamlined processes and less reliance on machines, could be a more sustainable alternative. Additionally, their shorter flow times might indicate reduced energy use throughout production cycles.



**Fig. 3.** (a) Performance comparison in terms of output. (b) Performance comparison in terms of average flow time. (c) Performance comparison in terms of average machine utilization.

## 5 Conclusion

A holistic approach that considers both production efficiency and environmental impact is paramount for manufacturers in a low-carbon economy. This approach ensures long-term business success while safeguarding the environment for future generations. From the production efficiency aspect, the findings of this research highlighted the importance of three key factors: shop floor layout, order release, and dispatch rules. These factors have a profound impact on the overall performance of a production system. Current study identified the CL-SPT production system as the most favourable, cost-effective, and sustainable option. This model utilizes a flow shop layout, CONLOAD order release, and shortest processing time dispatch rule, offering numerous benefits. It minimized material movement and optimized the flow of production, resulting in improved efficiency and reduced lead times. By aligning the order release with the production capacity, bottlenecks and resource underutilization are minimized, leading to increased throughput and overall productivity. This model goes beyond just efficient production; it prioritizes reducing greenhouse gas emissions and fostering a healthier ambience. It is crucial to note that the conclusions drawn from this research are based on the specific analysis and data provided in the preceding discussions. However, it is essential to conduct a comprehensive assessment that considers additional factors, such as potential risks, organizational constraints, and specific industry

dynamics, before finalizing the decision to convert to the CL-SPT production system. Furthermore, exploring alternative energy sources like solar or wind power to power these production systems, and integrating energy-efficient technologies within the chosen system, can further contribute to environmental sustainability.

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