International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 7 Issue 12, December - 2023, Pages: 139-146

Optimization of Production, Quality Control, and Maintenance for Serial-Parallel Multistage Production Systems: A Review

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Abstract: *The study examined optimization of production, quality control, and maintenance for serial-parallel multistage production systems using a review. In the past researchers has discussed the trio of production, quality control, and maintenance. Despite the fact that there are numerous interactions and intersections between the three functions, they are highly coupled. For example, a higher production rate might hasten the equipment's deterioration process and lead to lower-quality products. Although excessive maintenance can certainly increase system quality and reliability, it also lowers production capacity and raises maintenance-related costs. The study acknowledged that Quality control is undeniably crucial in serial-parallel multistage production systems. By prioritizing quality at every stage of production, manufacturers can uphold high standards, minimize defects, and ultimately deliver superior products to their customers. It was concluded in the study that optimizing production, quality control, and maintenance for serial-parallel multistage production systems requires a holistic approach that encompasses process optimization, quality assurance, and proactive maintenance strategies.*

Keywords: Optimization, Production, Quality Control, Maintenance, Serial-Parallel Multistage

Introduction

Serial-parallel multistage production systems are complex manufacturing processes that involve a series of interconnected stages operating in parallel. Optimizing such systems involves streamlining production, ensuring high-quality output, and maintaining the equipment to minimize downtime and maximize efficiency (Cheng, & Li, 2020). An industry's efforts to increase production performance in order to sustain competitive advantages and maximize profit are essential. The three primary core functions that have the biggest effects on production performance are quality control, production control, and maintenance scheduling. Through the prediction, planning, and scheduling of production activities within the limitations of materials, equipment, costs, etc., production control seeks to achieve favorable performance (Ben-Daya, & Rahim, 2000). Systems and machines age and experience increasing wear and tear during production runs. The systems may malfunction at any time, interrupting production. Maintenance is necessary to increase system availability and ensure smooth production. This includes tasks like inspection, repair, replacement, and so forth. It is important to note that upkeep is now seen as a profit-making endeavor rather than a drawback (Pal, Sana, & Chaudhuri, 2013). The goal of quality control is to guarantee that product quality is preserved and enhanced through process control and product inspection, which can assist manufacturers in meeting customer demands while also minimizing quality loss (Fakher, Nourelfath, & Gendreau, 2018).

In the past researchers has discussed the trio of production, quality control, and maintenance. Despite the fact that there are numerous interactions and intersections between the three functions, they are highly coupled. For example, a higher production rate might hasten the equipment's deterioration process and lead to lower-quality products. Although excessive maintenance can certainly increase system quality and reliability, it also lowers production capacity and raises maintenance-related costs. Because of this, numerous researchers have looked into integrated models that couple all or some of these functions. An overview of an integrated production and maintenance model was proposed by Bouslah, Gharbi, and Pellerin, (2016). A review of the literature on the integration of production and quality control policies was given by He, Liu, Cui, Han, Zhao, Chen, Zhou, and Zhang, (2019). Early in the twenty-first century, there was writing on the subject of maintenance and quality control together (Bouslah, Gharbi, & Pellerin, 2016). The two-by-two integrations of these three functions have been the subject of in-depth research in recent decades. Nevertheless, the simultaneous integration of the three aspects has received comparatively little attention.

In an unreliable production system where both conforming and non-conforming items are produced, Cheng, Zhou, and Li (2018) investigated an integrated production-maintenance strategy. The plan connects quality, age-based maintenance policy, and EPQ (economic production quantity). Together, they maximized the size of the production lot and the age at which maintenance is carried out. The findings demonstrate that preventive maintenance can successfully lower quality losses and inventory costs. Despite being widely used in the industrial field, the traditional Economic Production Quantity (EPQ) model ignored many practical factors in actual production. Numerous academics modified the EPQ model to take into account the actual production scenario. Examples of these modifications include the use of dynamic pricing Lamas and Chevalier (2018), variable demand rate Andriolo, Battini, and Persona (2015), Massonnet, Gayon, and Rapine (2014), and adjustable productivity Ou and Feng (2019). When considering shortterm production, the aforementioned articles disregarded the objective fact of equipment deterioration in the production system. The equipment will experience wear and tear and deterioration in the real production scene (Makis & Fung, 1998). The likelihood of an equipment failure during production is high if the condition of the equipment is not taken into account. When any crucial component fails and the apparatus stops functioning, the apparatus will fail (Farahani & Tohidi, 2021). As a result, a good production maintenance plan should take into account the equipment's deterioration and keep it operating at its best.

The maintenance and quality control model is a crucial component in avoiding equipment failure while driving. Preventive maintenance (PM) should be done prior to failure, and corrective maintenance (CM) should be done following failure (Marquez, Yin, & Liu, 2013). PM is more prevalent in current research because of the advancements in sensor technology and the fact that CM is typically far more expensive than PM. A joint maintenance strategy and quality control model for imperfect production systems with an intermediate buffer was proposed by Peng and Geert-Jan van (2016). Preventive maintenance is carried out when the percentage of defective products produced crosses a predetermined threshold. Simulated and experimental designs were combined to optimize both the buffer size and the threshold. Wang, Lu, and Ren (2020) examined an EPQ model where defects can arise in both "in-control" and "out-of-control" states. The likelihood of producing defects is what makes a difference. It goes without saying that defectives are more likely to be created in a "out-of-control" manner. Defects are reworked and maintenance is done at the conclusion of regular production. To minimize the average cost rate, the ideal values of production uptime and buffer inventory were simultaneously determined. A capacitated lot-sizing problem integrating quality and maintenance was examined by Liao, Elsayed, and Ling-Yau (2006). Production runs may randomly transition from a state of "in-control" to "out-of-control," at which point certain non-conforming items may be produced. Together, they enhanced both the preventive maintenance level and the production plan. Subsequently, Lin and Dah-Chuan (2006) examined a multi-period, multi-product capacitated lot-sizing issue while taking quality and maintenance into account. They discovered that combining the potential for non-uniform preventive maintenance levels with non-periodic inspections increases overall profit.

In order to obtain optimal parameters for production and maintenance plans, Cassady and Kutanoglu (2005) studied the production scheduling and PM decision-making process of a single piece of equipment, finding the optimal production sequence and PM interval. Liao and Sheu (2011) and Wang, C. (2006) established a joint model of regular PM and mass production. Several scholars proposed multi-objective models that allow policymakers to seek optimal solutions between production and equipment maintenance objectives (Liao, Chen, & Yang, 2017; Zandieh, Sajadi, & Behnoud, 2017; Zhang, Xia, Pan, & Li, 2022). Later, after production equipment was upgraded, the component structure became complicated, making it more meaningful to study more practical equipment. Tian and Liao (2011) examined the financial reliance of maintaining multiple units in a system and suggested a numerical method to precisely determine the expenses. In the analysis of multi-component system maintenance operations, each unit is subject to both structural and economic dependencies. Van, Barros, Bérenguer, Bouvard, and Brissaud (2013) presented a grouping maintenance strategy that takes structural dependency into account for multi-component systems. Vu, Do, and Barros (2016) calculated the significance of each component in the system structure using Birnbaum's importance, based on Van et al. (2013). Nguyen, Do, and Grall (2014) investigated how complex systems' condition-based maintenance decisions take structural and financial dependency into account. Cheng, Zhou, and Li (2017) investigated the cooperative optimization of multi-component series-parallel system production and maintenance. The aforementioned articles demonstrate that multi-unit system research is on the rise and that a key element influencing the maintenance plan is the arrangement of the system's units.

Serial-Parallel Multistage Production Systems

Serial-Parallel Multistage Production Systems (SPMS) are manufacturing systems that combine both serial and parallel production processes to optimize efficiency and productivity. This type of system is commonly used in the automotive, electronics, and aerospace industries, among others. In this essay, we will discuss the models and diagram interpretations of SPMS, as well as the benefits and challenges associated with its implementation (Bouslah, et. al. 2016). There are several models used to describe and analyze SPMS, with the most common being the FMS-SPMS (Flexible Manufacturing System - Serial-Parallel Multistage Production System) model. This model consists of two main components: the FMS and the SPMS. The FMS is a computer-integrated manufacturing system that uses flexible automation and computer numerical control (CNC) machines to perform various tasks. The SPMS, on the other hand, is a production system that combines serial and parallel production processes to achieve higher efficiency and productivity (Liu, 2008).

The FMS-SPMS model can be further broken down into sub-models, such as the modular cell model and the flow-shop model. The modular cell model consists of individual modules or cells, each performing a specific task (Ajay, & Rajan, 2013). These modules can be arranged in various configurations depending on the specific requirements of the production process. The flow-shop model, on the other hand, is a more linear production system where each workstation performs a specific operation in a sequential manner (Ajay, et.al., 2013).

Optimization of Production

Production optimization is the process of maximizing efficiency and productivity in manufacturing operations. It involves identifying and implementing strategies to improve various aspects of production, such as reducing costs, increasing output, minimizing waste, and enhancing overall performance. By optimizing production processes, companies can achieve higher profitability, competitive advantage, and customer satisfaction (Cheng, et. al., 2020). There are various benefits of production optimization which are: Cost Reduction: One of the primary goals of production optimization is to minimize costs associated with manufacturing processes. By identifying inefficiencies and implementing improvements, companies can reduce expenses related to labor, raw materials, energy consumption, maintenance, and waste management. Increased Output: Production optimization aims to increase the output of goods or services without compromising quality (Bouslah, et. al. 2016). By streamlining processes, eliminating bottlenecks, and improving resource allocation, companies can achieve higher production volumes within the same timeframe. Enhanced Quality: Optimization techniques focus on improving product quality by minimizing defects and variations. Through the use of statistical process control (SPC) methods, companies can monitor production parameters and implement corrective actions to ensure consistent quality standards. Reduced Lead Time: By optimizing production processes, companies can reduce lead times and improve order fulfillment rates. This allows for faster delivery to customers, resulting in increased customer satisfaction and loyalty. Minimized Waste: Production optimization involves identifying areas of waste generation and implementing strategies to minimize them. This includes reducing scrap materials, rework, unnecessary downtime, and excess inventory levels. Improved Flexibility (Gallego-García, Sergio, & García-García, 2021). Optimized production systems are more adaptable to changes in demand or product variations. By implementing lean manufacturing principles and agile methodologies, companies can quickly adjust production levels or switch between different products to meet market demands effectively. Better Resource Utilization: Optimization techniques help companies make better use of their available resources by analyzing capacity utilization rates, scheduling efficiency, and equipment effectiveness (Gallego-García, et.al., 2021). This leads to improved resource allocation and reduced idle time. Enhanced Safety: Production optimization also considers safety aspects by identifying potential hazards and implementing measures to mitigate risks. By ensuring a safe working environment, companies can protect their employees and avoid costly accidents or disruptions in production ((Cheng, et. al., 2020).

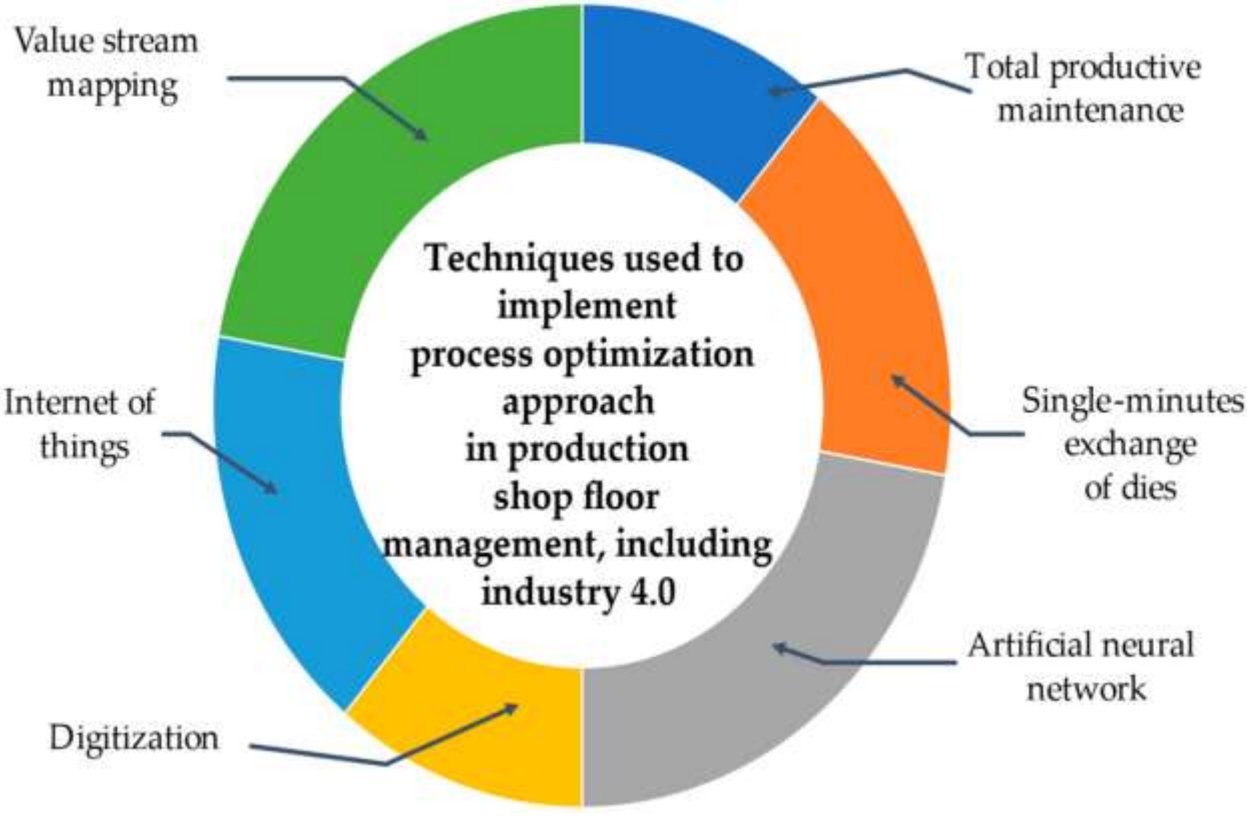

Figure 1: Illustration of Optimization of Production

Quality Control in Serial-Parallel Multistage Production Systems

Quality control is indeed paramount in serial-parallel multistage production systems. These systems involve a combination of serial and parallel processes to manufacture products. In such complex production systems, maintaining high-quality standards is crucial to ensure that the final output meets the required specifications and satisfies customer expectations (Gallego-García, Sergio,

& García-García, 2021). One of the primary challenges in multistage production systems is ensuring consistent quality throughout the entire process. As the product moves through various stages, any defects or deviations from the desired specifications can accumulate and result in significant quality issues in the final output. Identifying and addressing these issues at each stage of production is essential to prevent them from compounding and affecting the overall quality of the product (Gallego-García, Sergio, & García-García, 2021). According to Ajay, et.al., (2013) there are risk of quality control, even though quality control plays a pivotal role in mitigating these challenges. It involves a series of proactive measures and processes aimed at monitoring, maintaining, and improving the quality of products throughout the production cycle. By implementing robust quality control mechanisms, manufacturers can identify potential issues early, rectify them promptly, and ultimately deliver products that meet or exceed customer expectations. Ajay, et.al., (2013) mention some of the key aspects of quality control in multistage production systems to include the following:

1. Process Monitoring: Continuous monitoring of each stage in the production process is essential for identifying any deviations from the specified quality parameters. This may involve real-time data collection, automated inspections, and regular quality checks to ensure that each sub-process meets the required standards.
2. Defect Detection and Correction: Quality control measures should include mechanisms for detecting defects or non-conformities at an early stage. Once identified, corrective actions must be taken promptly to rectify the issues and prevent them from propagating through subsequent stages.
3. Standardization and Documentation: Establishing clear quality standards for each stage of production and documenting these standards is crucial for consistency and traceability. Standard operating procedures (SOPs) help ensure that all processes are carried out according to predefined criteria, reducing variability and enhancing overall quality.
4. Quality Assurance Testing: Incorporating comprehensive testing protocols at different stages can help validate the quality of intermediate products before they proceed to subsequent stages. This proactive approach minimizes the risk of producing defective components or assemblies further down the line.
5. Continuous Improvement: Quality control should not be static; it should be part of a continuous improvement process. Analyzing data, soliciting feedback from workers, and implementing corrective actions based on performance metrics are essential for refining processes and enhancing overall quality.

Consequent upon the risk of implementing robust quality control measures in serial-parallel multistage production systems there abide also some several benefits according to Fakher, et.at., (2018). Which includes Enhanced Product Quality: Consistent adherence to quality standards results in higher-quality products with fewer defects. Cost Savings: By detecting and addressing issues early, manufacturers can minimize rework, scrap, and warranty claims, leading to cost savings. Customer Satisfaction: Delivering high-quality products consistently enhances customer satisfaction and loyalty. Compliance: Meeting regulatory requirements and industry standards is facilitated by effective quality control practices.

Quality control is undeniably crucial in serial-parallel multistage production systems. By prioritizing quality at every stage of production, manufacturers can uphold high standards, minimize defects, and ultimately deliver superior products to their customers.

Maintenance Optimization of Serial-Parallel Multistage Production Systems

Maintenance optimization is crucial for the efficient operation of serial-parallel multistage production systems. These systems consist of multiple stages connected in series and parallel configurations (Shen, Zhang, & Shi, 2022). The optimization of maintenance in such systems involves minimizing downtime, reducing maintenance costs, and improving overall efficiency. Several factors contribute to the effectiveness of maintenance optimization in serial-parallel multistage production systems, including preventive maintenance, predictive maintenance, condition-based maintenance, and reliability-centered maintenance (Shen, et. al. 2022).

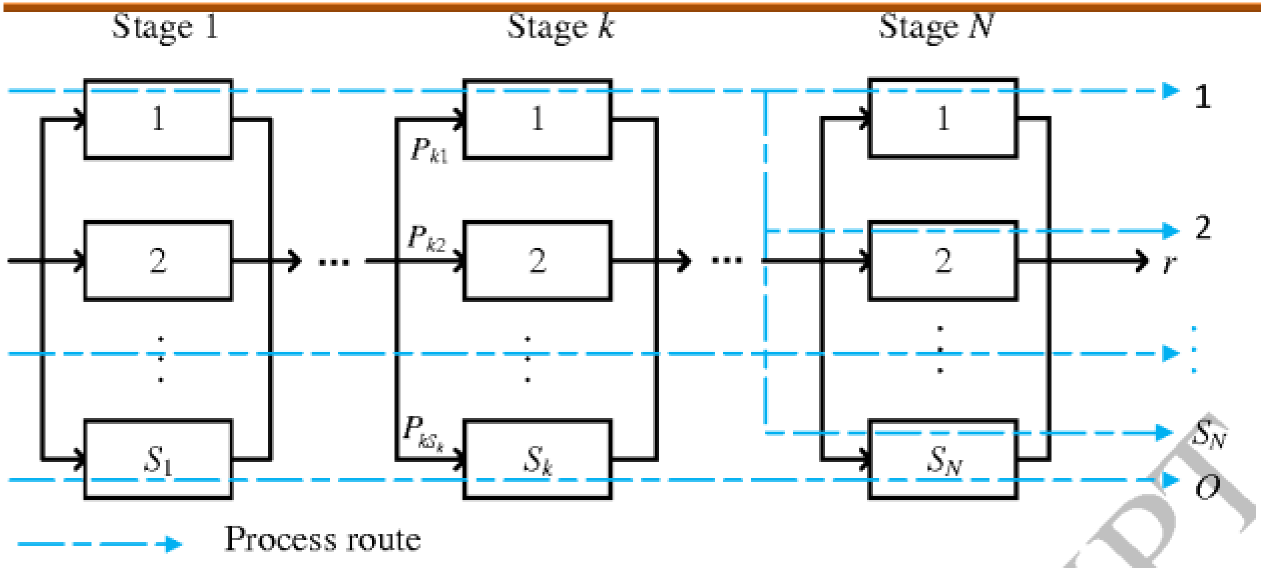

Figure 2: Maintenance Optimization Production Systems

Preventive maintenance involves scheduling routine inspections, cleaning, and repairs to prevent potential issue s before they occur. This approach ensures that the equipment remains in good working condition and reduces the likelihood of unexpected breakdowns. Predictive maintenance, on the other hand, relies on advanced technologies such as sensors, machine learning algorithms, and data analytics to predict equipment failures before they occur (Shen, et. al., 2022; Patil, Anand, Ravinder, Mohammad, Mohsen, & Seepana, 2022). This allows for proactive maintenance and minimizes downtime. Condition-based maintenance is another important factor in maintenance optimization. This approach involves monitoring the condition of equipment in real-time and performing maintenance only when necessary. This can be achieved through the use of sensors, vibration analysis, and other diagnostic tools. By focusing on the actual needs of the equipment, condition-based maintenance can reduce maintenance costs and improve overall system performance. Reliability-centered maintenance is a comprehensive approach to maintenance optimization that takes into account the specific needs and characteristics of each piece of equipment in the production system (Patil, et. al., 2022). This approach involves analyzing the failure modes and critical components of each piece of equipment to develop a customized maintenance plan. By focusing on the most critical components and failure modes, reliability-centered maintenance can maximize system availability and minimize maintenance costs. In addition to these maintenance strategies, the optimization of maintenance in serial-parallel multistage production systems also requires effective planning, scheduling, and coordination of maintenance activities (Patil, et. al., 2022). This includes prioritizing maintenance tasks based on their impact on system performance, minimizing the time required for maintenance activities, and ensuring that maintenance resources are allocated efficiently.

Integration of Advanced Technologies of Serial-Parallel Multistage Production Systems

Serial-parallel multistage production systems are complex manufacturing systems that involve a combination of serial and parallel processes to optimize production efficiency. Integrating advanced technologies into these systems is crucial for enhancing productivity, reducing lead times, and improving overall operational performance (Patil, et. al., 2022). This integration involves the incorporation of cutting-edge technologies such as automation, robotics, artificial intelligence, Internet of Things (IoT), and advanced data analytics. These technologies play a pivotal role in streamlining operations, minimizing downtime, and enabling real-time monitoring and control of the production processes. Integrating advanced technologies into serial-parallel multistage production systems presents several challenges. According to Soori, Arezoo, and Dastres, (2023). one of the primary challenges is the interoperability of different technologies. Ensuring seamless communication and data exchange between diverse technological components is essential for achieving a cohesive and efficient production system. Additionally, the complexity of integrating multiple advanced technologies while maintaining system reliability and safety is a significant challenge that requires careful planning and implementation.

In addition, the automation plays a critical role in serial-parallel multistage production systems by reducing manual intervention, increasing precision, and accelerating production cycles. Robotics, including collaborative robots (cobots) and autonomous mobile robots (AMRs), are increasingly being integrated into these systems to handle repetitive tasks, material handling, and assembly operations (Soori, et. al., 2023; Elahi, Afolaranmi, Martinez-Lastra, 2023). The use of advanced robotic systems enhances flexibility and adaptability within the production environment, allowing for rapid reconfiguration to accommodate changing product requirements. The integration of AI and machine learning technologies enables predictive maintenance, quality control, and adaptive process optimization within serial-parallel multistage production systems. AI algorithms analyze vast amounts of data from sensors, equipment, and production processes to identify patterns, anomalies, and potential issues in real time. This proactive approach to maintenance and quality assurance minimizes unplanned downtime and ensures consistent product quality (Elahi, et. al., 2023).

Conclusion

Optimizing production, quality control, and maintenance for serial-parallel multistage production systems requires a holistic approach that encompasses process optimization, quality assurance, and proactive maintenance strategies. By leveraging advanced technologies and best practices in manufacturing management, organizations can achieve higher efficiency, improved product quality, and reduced downtime in these complex production environments. The integration of advanced technologies into serial-parallel multistage production systems is essential for achieving operational excellence in modern manufacturing environments. By addressing challenges related to interoperability, complexity, and reliability, manufacturers can harness the full potential of automation, robotics, AI, IoT, and advanced data analytics to drive efficiency, agility, and competitiveness in their production operations.

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