Proceedings of the 2025 Winter Simulation Conference
E. Azar, A. Djanatliev, A. Harper, C. Kogler, V. Ramamohan, A. Anagnostou, and S. J. E. Taylor, eds.

DYNAMIC RISK CONTROL IN SERIAL PRODUCTION SYSTEMS UNDER QUEUE TIME CONSTRAINTS

Yen-Tzu Huang [1], Cheng-Hung Wu [1,2]

[1]Inst. of Industrial Eng., National Taiwan Univ., Taipei, TAIWAN
[2]Dept. of Business Admin., Dept. of Mech. Eng., National Taiwan Univ., Taipei, TAIWAN

ABSTRACT

This research introduces a dynamic risk control framework for a two-stage production system with downstream queue time constraints. Queue time constraints are critical in semiconductor manufacturing, as their violations lead to quality degradation and production losses. To reduce the risk of violating queue time constraints, a key principle in queue time constraint management is controlling upstream production when downstream queue times exceed critical thresholds. Traditional control methods face challenges in accurately responding to dynamic manufacturing conditions. Our approach develops a dynamic admission control method that predicts queue times by estimating the real-time downstream processing capacity and the number of preceding jobs. We implement a two-stage system combining upstream admission control with downstream priority dispatching. Through simulation experiments in multi-machine, multi-product systems, we evaluate performance across various utilization rates and capacity configurations. Results show that our approach reduces total costs, including scrap and inventory holding costs, while maintaining optimal throughput.

1 INTRODUCTION

In semiconductor manufacturing industries, queue time constraints represent a critical factor in maintaining product quality. These constraints define maximum allowable waiting times between process steps, and violations result in quality deterioration and costly scrap losses. Managing these constraints presents substantial challenges due to uncertain production environments that face random disruptions including machine failures, processing time variations, and unplanned inspections. Previous research has addressed time constraints through different approaches. Klemmt et al. (2012) tackled scheduling problems with nested time constraints in flexible flow shops using mixed integer programming decomposition methods, while Wu et al. (2010) developed Markov decision models for dynamic production control in two-station tandem systems with process queue time constraints. However, existing approaches have limitations in handling complex multi-stage systems with varying system conditions and real-time queue states.

Our research addresses these limitations through a novel dynamic framework that integrates upstream admission control with downstream priority dispatching. The key innovation lies in developing adaptive control policies that respond to complex system dynamics and enable coordinated decision-making across different production stages through dynamic programming and admission control methodologies. We validate our approach through comprehensive simulation studies that model stochastic production environments, enabling systematic evaluation of the proposed framework under diverse operational scenarios and uncertainty conditions.

2 METHODOLOGY

The fundamental challenge addressed by this research is queue time control in serial production systems where upstream and downstream workstations contain multiple parallel machines processing diverse product types. The system operates under significant uncertainty, with stochastic product arrivals, variable processing times, and random machine health deterioration. Products exceeding their queue time limits in downstream queues must be scrapped, making effective time management crucial for cost reduction.

Our proposed framework implements a hierarchical risk control strategy through two coordinated components.

- The upstream component uses a dynamic admission control method that estimates queue waiting times by analyzing the number of preceding jobs with shorter remaining queue times in the downstream queue and calculating capacity of downstream process in real-time. This approach incorporates a risk coefficient parameter that determines admission thresholds based on the trade-off between production cycle time and scrapping risk. The admission decision compares predicted waiting time against a fraction of the queue time limit determined by the risk coefficient.
- The downstream component implements a dynamic priority control mechanism that monitors remaining allowable queue times of all jobs and current system states. Products with remaining queue times below critical thresholds automatically enter a priority queue, where they are processed in the order of remaining queue time. This prioritization mechanism ensures queue time compliance while maintaining efficient resource utilization across the production system.

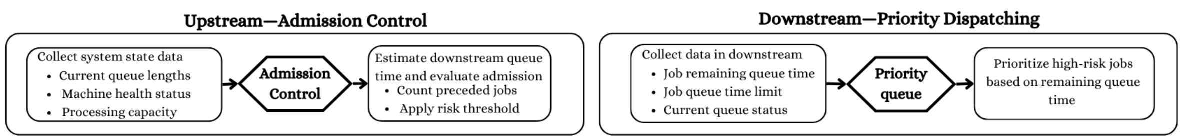

Figure 1: Risk control architecture.

This hierarchical risk control architecture achieves effective queue time management through coordinated upstream prediction and downstream prioritization. By synchronizing admission decisions with processing priorities, the system maintains precise control over queue times while optimizing throughput.

3 RESULTS

The simulation results demonstrate the effectiveness of our dynamic admission control approach across nine different combinations of utilization rates (0.7, 0.8, 0.9) and upstream-downstream capacity ratios (0.8, 1.0, 1.2). Table 1 shows our method significantly outperforms traditional approaches. Compared to the $C\mu$ method(Baras et al., 1985) , our approach reduces cycle time by 11%, total costs by 77%, and scrap counts by over 99%. Against First-Come-First-Serve (FCFS) scheduling, our method achieves even greater improvements with 91% cycle time reduction, 93% cost reduction, and over 99% scrap count reduction.

Table 1: Normalized performance comparison of different control methods.

	Our method	$C\mu$	FCFS
Cycle Time	1.000	1.129	11.717
Scrap Count	1.000	120.298	126.160
Total Cost	1.000	4.360	13.914

Future research will focus on extending the model's capability to more complex manufacturing configurations while enhancing its real-time optimization performance.

REFERENCES

Baras, J., Ma, D.-J., & Makowski, A. (1985). K competing queues with geometric service requirements and linear costs: The μc-rule is always optimal. *Systems & control letters*, *6*(3), 173-180.

Klemmt, A., & Mönch, L. (2012). Scheduling jobs with time constraints between consecutive process steps in semiconductor manufacturing. Proceedings of the 2012 winter simulation conference (WSC),

Wu, C.-H., Lin, J. T., & Chien, W.-C. (2010). Dynamic production control in a serial line with process queue time constraint. *International Journal of Production Research*, *48*(13), 3823-3843.