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Process Flexibility: A Distribution-Free Approach to Long Chain Resilience

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Process flexibility has been a well-established supply chain strategy in both theory and practice that enhances responsiveness to demand uncertainty. In this study, we expand the scope of this strategy to supply disruption mitigation by analyzing a long chain system. Specifically, we investigate the effectiveness of long chains in the face of random supply disruptions and demand uncertainty. Our study derives a closed-form, tight bound on the ratio of expected sales under supply disruption for a long chain relative to that of a fully flexible system, thereby providing a service level guarantee. Our analysis provides a concrete analytical result demonstrating that the fraction of benefits a long chain can achieve relative to full flexibility increases in the disruption probability when designed capacity equals expected demand. Also, the long chain demonstrates superior resilience by withstanding a non-negligible fraction of the supply disruption due to its relatively sparse structure compared to a fully flexible system.

To generalize the analysis, we introduce a moment decomposition approach that readily adapts to general piecewise polynomial performance metrics and allows the capacity to differ from the expected demand. This approach encompasses the traditional type-II service metric (expected sales) as well as the type-I metric (probability of meeting full demand), with the latter representing a novel contribution to the existing literature. Our approach can also incorporate higher-moment information (such as skewness and kurtosis) on the random demand while maintaining tractability through a semidefinite program (SDP). We apply this approach to study the capacity configuration problem. Our study reveals that, in the absence of supply disruption, attaining a specific service level requires a capacity level close to that of a fully flexible system, even when the demand distribution is only partially characterized. In contrast, a notable increase in capacity is required under supply disruption. Yet, the long chain significantly outperforms a dedicated system in capacity requirement. Our findings underscore the remarkable resilience demonstrated by long chains and the importance of adapting capacity configuration decisions to supply disruption.

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