Chapter 5

Continuous Improvement of Bernoulli Lines

Motivation: It is not uncommon that, due to unscheduled downtime, machining lines in many industries operate at 60%-70% of their capacity. Although assembly systems are typically more efficient (often operating at 80%-90% of their capacity), the losses are still significant. In this situation, continuous improvement is a major tool for production systems management.

Typically, continuous improvement projects are developed using common sense, managerial intuition and, in some cases, discrete event simulations. Due to the “soft” nature of these approaches, they often do not result in an actual productivity improvement. The purpose of this chapter is to present analytical methods for designing continuous improvement projects in Bernoulli lines with predictable results. The development is based on the analytical method and recursive equations derived in Chapter 4.

Overview: Two approaches to design of continuous improvement projects are developed. They are referred to as constrained and unconstrained improvability.

Constrained improvability addresses the issue of improving a production system by re-allocating its limited resources, e.g., buffer capacity or workforce. The main question here is: Can or cannot a production system be improved by utilizing more efficiently its limited resources? If it is possible, the system is called improvable under constraints; otherwise, it is unimprovable. Section 5.1 presents criteria, which allow to determine whether the system is improvable and provides a characterization of unimprovable allocations.

Constrained improvability is related to optimality. Indeed, an unimprovable system is, in fact, optimal. We use, however, the term “improvable” to indicate that the goal is not necessarily to render the system optimal but rather to determine whether it can be improved and indicate actions that lead to this improvement. Moreover, given the lack of accurate information on the factory floor, the optimality may not be practically achievable, whereas continuous im-
**CHAPTER 5. IMPROVEMENT OF BERNOULLI LINES**

Improvement, being robust with respect to inaccurate information, may.

*Unconstrained improvability* addresses the issue of bottleneck identification and elimination by allocating additional resources (such as additional buffer capacity, machine improvement or replacement, etc.).

The concept of bottleneck (BN) is not well understood, and, as a result, it is not unusual that in practice an improvement or replacement of a machine, viewed as the BN, leads to no improvement of the production system as a whole. So, what is a BN? Often, BN is understood as the machine with the smallest production rate in isolation. In other cases, the machine with the largest work-in-process in front of it is viewed as the BN. It is possible to show, however, that neither may be the BN in the sense of being the most impeding for the production rate of the system. This happens because the above intuitive conceptualizations are local in nature and do not take into account the total system properties, such as the location of machines in the production line, capacity of the buffers, types of interactions among the machines and buffers, etc.

In Section 5.2, we introduce “system-based” definitions of bottleneck machines (BN-m) and bottleneck buffers (BN-b) in terms of their effect on the production rate of the line.

The main practical results of this chapter are the criteria (referred to as *indicators of improvability*), which allow factory floor personnel to determine if the system is improvable (in the constrained or unconstrained case) and define actions that must be taken to achieve this improvement. In addition, we define the notion of *buffering potency* and introduce the method of *measurement-based management* of production systems.

### 5.1 Constrained Improvability

#### 5.1.1 Resource constraints and definitions

Consider a serial production line with $M$ Bernoulli machines defined by parameters $p_i$, $i = 1, \ldots, M$, and $M - 1$ buffers with capacities $N_i$, $i = 1, \ldots, M - 1$, which operates according to conventions (a)-(e) of Subsection 4.2.1.

Assume that $N_i$'s and $p_i$'s are constrained as follows:

\[
\sum_{i=1}^{M-1} N_i = N^*, \quad (5.1)
\]

\[
\prod_{i=1}^{N} p_i = p^*, \quad (5.2)
\]

where $N^*$ and $p^*$ are positive numbers with $p^*$ satisfying $p^* < 1$. Constraint (5.1) implies that the total buffer capacity cannot exceed $N^*$. Constraint (5.2) can be interpreted as a bound on the machine efficiency or workforce. Indeed, in many systems, assignment of the workforce (both machine operators and skilled trades for repair and maintenance) defines the machine efficiency and, thus, $p_i$'s.