Optimizing Group Waiting Time in Service System with Learning Effect

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ABSTRACT

This paper deals with service lines that serve groups of customers that differ in their service processes, but have similarities regarding the service capabilities of the specific servers. This paper optimizes the problem of allocating work elements with various learning slopes to servers to minimize the system waiting time of customers in such a line. The customer groups have a large variety of service needs. The service is organized in tandem, and the service repetitions in each group causes learning effect, but due to the nature of work, server’s learning slopes can vary. The authors propose a two stage optimization methodology: the first stage is an optimization based on a non-linear formulation for work allocation with some constraints relaxation; the second stage drops the relaxations and finds a solution that is the closest to the unconstrained solution found in the first stage. The authors show that in the presence of learning, the optimal system waiting time requires assigning different workloads to different servers. This difference depends on the number of cycles of a customer group, the server’s learning slope, and the server’s location along the line. The savings in the optimal system waiting time due to the imbalanced loading of work over the balanced load case are demonstrated.

KEYWORDS

Group Service, Job Design, Learning Curve, Learning, Servers, Service Line, Service Load, Work Allocation

INTRODUCTION

This paper considers system waiting time minimization of a customer-group processed sequentially on a mostly manual service system whose work servers have different learning slopes. The situation of processing customer groups in line configuration can typically be found in international tourist services for organized groups and in treating organized groups of students, or dealing with organized groups within passport security and customs control. Practical instances of this setting are presented in many papers (e.g., (Borkman, 1976; Menor, Roth, & Mason, 2001; Whitt, 1999). In addition, similar situation is well known in the production arena (Arditi, Tokdemir, & Suh, 2001; Cohen & Dar-El, 1998, 1998; Cohen, Vitner, & Sarin, 2006; Dar-El, 2013).

Although there is a bounty of literature on system balancing, and on the learning phenomenon, the literature on the intersection of both subjects is scarce. Especially, the literature on optimizing work allocation in service lines with learning effect is very limited. Since we will show that balancing policy is not optimal the introduction will concentrate on presenting the setting and assumptions of the model, the importance of industrial learning to the model and presenting relevant background in learning calculations.
Setting and Assumptions of the Model

The service process is composed of many tasks, each with estimated standard time, learning slope and precedence constraints. Each server is assigned a combination of these tasks. A study (Cohen & Dar-El, 1998) presented a specific instance of line balancing in the production arena where all the servers have the same learning slope. Another study (Cohen et al., 2006) showed that even under homogeneous learning, allocating the same amount of work to each server is not optimal. In this paper the service operators may have different learning slopes based on their work content. We also assume that the number of servers, \( L \), is known a priori. A method to compute optimal \( L \) is given in (Cohen & Dar-El, 1998).

Since maximizing the simultaneous workload of all operators minimizes the system waiting time, and since simultaneous work is best achieved when the learning slopes of all servers are the same, it would be ideal to have the same learning slope at all servers (Cohen & Dar-El, 1998). In reality, however, learning slopes may vary considerably between servers. This may be due to highly constrained networks, or segregated tasks with very dissimilar learning slopes. In this paper, we show that the optimal workload assignment to servers is considerably affected by the learning phenomenon that induces variability between servers.

Theoretical Background

According to the mathematical form of the classical power learning curve (since Wright, 1936), the cycle time reduces by a constant percentage (\( \phi \)) every time the quantity produced is doubled (\( \phi \) is called the learning slope). We define cycle time to be the time taken to process the work allocated to a server. If \( t_1 \) is the execution time of the first cycle, and \( t_n \) is the execution time of the \( n \)th cycle, then the learning curve can be expressed as follows:

\[
t_n = t_1 \cdot \phi \log_2 2^{(n)} \quad (1)
\]

A more prevalent form of Equation (1) is based on the classic learning constant (\( b \)) (Yelle (1979)):

\[
b = - \log_2 (\phi) \quad (2)
\]

to give:

\[
t_n = t_1 \cdot n^{-b} \quad (3)
\]

A prevalent approximation of the time for the first \( n \) cycles of a learning curve is derived by taking the integral of equation 3 as shown in equation 4:

\[
T_n = \frac{t_1}{1 - b} \cdot n^{(1-b)} \quad (4)
\]