Multi-period technician scheduling with experience-based service times and stochastic customers

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\begin{abstract}
This paper introduces the multi-period technician scheduling problem with experience-based service times and stochastic customers. In the problem, a manager must assign tasks of different types that are revealed at the start of each day to technicians who must complete the tasks that same day. As a technician gains experience with a type of task, the time that it takes to serve future tasks of that type is reduced (often referred to as experiential learning). As such, while the problem could be modeled as a single-period problem (i.e. focusing solely on the current day’s tasks), we instead choose to model it as a multi-period problem and thus capture that daily decisions should recognize the long-term effects of learning. Specifically, we model the problem as a Markov decision process and introduce an approximate dynamic programming-based solution approach. The model can be adapted to handle cases of worker attrition and new task types. The solution approach relies on an approximation of the cost-to-go that uses forecasts of the next day’s assignments for each technician and the resulting estimated time it will take to service those assignments given current period decisions. Using an extensive computational study, we demonstrate the value of our approach versus a myopic solution approach that views the problem as a single-period problem.
\end{abstract}

\section{Introduction}
As the global economy recovers, there is growing pressure in the skilled labour markets. According to the Hays Global Skills Index 2014, a statistics-based study designed to assess the dynamics of skilled labor markets across 31 countries, this pressure continues to rise, particularly in economies that are returning to pre-crisis levels such as United States, Germany, and the United Kingdom [1]. Maintaining growth in a pressured labor market requires that companies use their expensive and limited labor resources to their greatest potential. One opportunity is for companies to take advantage of the capacity that is gained as employees learn by experience. Matching the right employee with the right job cannot only help a company meet its current needs, but also build capacity for meeting future demand growth as well as build the flexibility needed to buffer against demand uncertainty. Further, the ability to account for each individual employee’s ability to learn allows companies to best deploy workers in the face of strategic growth opportunities giving companies the agility that [2] calls essential to surviving in the volatile modern business environment.

In this paper, we explore the issue of how companies can use immediate employee job assignments to meet current demand and build capacity for the future. We focus on service workers, particularly service technicians. The problem discussed in this paper is a variant of the technician and task scheduling problem (TTSP). In the TTSP, a set of technicians serves a set of customer requests. Customers are associated with certain tasks and different tasks have different skills associated with them. In our version of the problem, technicians have different service times depending on their experience in performing a task as well as each technician’s ability to transform that experience into improved productivity. We measure experience in the number of times that the technician has performed the task.

The fact that technician productivity, and really all workers productivity, is linked to experience suggests that what could be modeled as a single-period problem (i.e. focusing solely on making assignments to serve the current day’s tasks) should instead be modeled as a multi-period problem. As such, we consider the multi-period technician scheduling problem that accounts for the fact that productivity increases (or service time decreases) as...
technicians gain experience. These increases in productivity are
often referred to as "learning". We assume that the time that it
takes a technician to complete a task depends on the technician's
experience in the skill associated with the task and how quickly
the technician learns. How quickly a technician learns is known
as the technician's learning rate. We assume that we have a set
of heterogeneous technicians whose learning rates and initial
experience are known. The service time depends on the amount
of experience the worker has with the skill required by the task.

We assume that daily demand is not revealed until the day
of service. Each day, the technicians serve the day's demand. In
this work, we seek to minimize the expected sum of each day's
total service times over a finite horizon. Reflecting what are often
tight labor market conditions for technicians (a job definition that
can span multiple industries, including home appliance repair, lab
technician, and home health care), we choose an objective that
seeks to maximize the capacity of an existing workforce. We call
our problem variant the multi-period technician scheduling prob-
lem with experience-based service times and stochastic customers
(MTSP-ESTSC).

To solve the problem, we propose an approximate dynamic
programming (ADP) approach that, at each stage, solves a mixed
integer program (MIP) to assign technicians to tasks. In addition
to recognizing the resulting service times in the current period,
the MIP approximates the impact of those assignments on future
technician service times (the "cost-to-go") with a forecast of each
technician's task assignments in the next period. Assignment de-
cisions in the next period are partially driven by each technician's
service times on each type of task, which are in turn driven by
their experience level on each type of task. To capture this fact,
the forecasting model embedded in the MIP is a function of the
assignment decisions in the current period.

One of the challenges associated with solving optimization
models that recognize that humans learn is that the quantitative
models of human learning proposed by the psychology community
are non-linear. As a result, to solve a MIP at each stage of the ADP,
we adapt an exact reformulation method from the literature that
relies on the fact that the function we use to map experience to
service time has a finite domain.

In this study, we make the following research contributions.
First, we present the first model that explicitly models the impact
of individualized, experience-based learning on the technician
scheduling problem. Such a model will facilitate organizational
productivity improvement by allowing for more effective work-
force management. Further, we discuss how the presented Markov
decision process (MDP) model can be adapted to handle cases
of worker attrition and new task types. Second, we introduce a
method for approximating the future value of today's work-
force assignments. With the addition of technician learning to
the model, decisions today affect tomorrow's productivity. Thus,
the approximation method allows us to do so. Third, using the
approximation, we demonstrate how the approximate Bellman
equation can be transformed into a linear, mixed integer program.
This transformation is significant because the nonlinearity of
the learning functions naturally lead to a nonlinear integer pro-
gramming formulation. Our formulation allows the approximate
Bellman equation to be solved by a standard implementation of
a commercial integer programming solver.

We demonstrate the value of the proposed solution approach
with three experiments. In one experiment, the set of technicians
and the set of task types remain the same over the problem
horizon. In the second, we introduce a workforce disruption in the
middle of the horizon in which one technician leaves the
workforce and a new technician is added. The third variant adds
an additional task type in the middle of the horizon. For each of
the three problem variants, we compare the proposed solution
approach to a myopic solution approach that views the problem as
a single-period problem, ignoring the impact of current period de-
cisions on future service times. Our comparisons demonstrate that
the proposed solution approach leads to higher-quality solutions
by better positioning technicians to meet future demands.

The remainder of this paper is organized as follows. Section
2 reviews the literature related to the MTSP-ESTSC. Section
3 presents a model for the problem. Section 4 describes
the solution approach. Section 5 discuss the design of the ex-
periments, and Section 6 presents our computational results.
Finally, Section 7 concludes this work and suggests areas of future
research.

2. Literature review

We review the literature of technician scheduling and routing
problems as well as for experience-based learning.

2.1. Individual learning and its applications

That humans learn as they gain experience, "learning-by-doing" is
a well known phenomenon. The learning effect was first exam-
inined on a scientific basis by [3], who quantified learning curves
with the observation that in the aircraft industry the working
costs per unit declined with an increasing production output.
Subsequent empirical studies confirmed the existence and im-
portance of learning effects (see for example [4–7]). In 2016, the
concept has become mainstream enough that it is now included
in textbooks on operations management ([8,9]).

The mathematical descriptions of learning are often called
learning curves. Reviews of the literature on learning curves can
be found in [10–13]. Because of the availability of distributions
from which to generate workforces, in this research, we use the
hyperbolic learning model described in [14]. We note that, while
we employ the hyperbolic learning model, most learning
curves have similar shapes and would support conclusions similar
to those discussed in Section 6. We note that there also exists
an extensive literature focusing on organizational learning [15],
provides an excellent reference.

Work that explicitly models individual learning and the
associated heterogeneity of the workforce demonstrates the value
of capturing learning [16], shows that simply modeling worker
heterogeneity without considering learning improves system
performance versus assuming uniform workforce productivity in
flow-line production. [17] extend the analysis of [16] to demon-
strate the impact of heterogeneous learning and forgetting curves
on system productivity in an assembly-line setting [18], confirms
the results of [17] for technician routing. In addition to flow lines,
assembly lines, and technician routing, the value of modeling
learning has also been found in call centers ([19]), departmental
assignment ([20]), machine routing (see [21] for a review),
project selection ([22,23]), and vehicle routing ([24]).

One of the challenges of much of the workforce planning lit-
erature that models individual learning is that the nonlinearity
of the learning curves creates challenges. For this reason, work such
as [19] and [25], simplify the model of individual learning to avoid
the nonlinearities. Work such as [26] exploits structural proper-
ties of the optimal solution to increase the size of the problem
that can be solved. However, such approaches do not generalize.
Work such as [27–29] are limited to solving small problems [30],
introduce a linear and integer reformulation of the learning curve
that takes advantage of the fact that most work is assigned in time
intervals. The reformulation allows much larger problems to be
solved than had been previously. We take advantage of the refor-
mulation in this work as well. Other examples of the reformulation
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