Managing Learning and Turnover in Employee Staffing*

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Call Center Operations

call routing and CSR scheduling algorithms

customer population

CTI resources

CSR population
CSR Plans Are Made at 3 Levels

• Moment-by-moment
  • on-the-fly adjustments of call routing, overtime, lunch, breaks

• Week-by-week
  • assignment of CSRs to schedules

• Monthly, quarterly
  • target staffing levels set and hiring plans made
Our Hierarchical Approach

• Focus on high level staffing problem
  • formulate as discrete-time dynamic program
• Embed lower level scheduling and call routing problems
  • scheduling software
Related Literature

- Aggregate Planning
  - HMMS Model (1960)
  - Orrbeck, Schuette, and Thompson (1968)
  - Grinold and Stanford (1974)
  - Ebert (1976)
  - Khoshnevis and Wolfe (1986)
  - Gerchak, Parlar, and Sengupta (1990)

- Human Resources
  - Bartholomew, Forbes, and McClean (1991)
Related Literature

• Inventory Theory
  • Arrow, Karlin and Scarf (1958)
  • Veinott (1965)
  • Iglehart and Jacquett (1969)
  • Karlin (1960) and Zipkin (1989)
  • Gerchak and Wang (1994)

• Call Center

......
Staffing Problem Description

• Stochastic non-stationary service requirement
• Uncertain service capacity: people's service capacities change
  • Random learning
  • Random turnover
• Long hiring/training leadtime
Service Requirement ...

... Varies by

- Time of day
- Day of week / month
- Month of year
- Promotion
- Special events
Learning

Fig. 3. Proficiency acquisition curves for Directory Assistance Operators

Source: Gustafson, 1982
Turnover

• Call centers have high turnover rates
• Turnover decreases with job tenure
  • Empirical evidence
    • National Longitudinal surveys (Light and Ureda 1990)
    • AT&T service representatives (Gustafson 1982)
  • Theoretical explanations
    • longer tenure implies better "fit" (Jovanovic 1979)
    • repeated searches for a better job (Parsons 1973)
Outline

- Model
- Structural Properties of The Optimal Policy
- Model Details
- Numerical Analysis
Model: Dynamics

• Indices
  • $i = 1, 2, \ldots, m$: employee type
  • $t = 0, 1, \ldots, T$: discrete time periods

• State variables
  • $n_{i,t}$: type $i$ employee, time period $t$
    (before hiring)
  • $x_t$: type 1 employee hired, time period $t$
    (decision variable)
  • $y_t$: type 1 employee, time period $t$
    (after hiring)

\[ y_t = n_{1,t} + x_t \]
Model: Dynamics (contd)

• Transition variables

- $\tilde{q}_{i,t}(n_{i,t})$ : type-$i$ employees who turn over, out of $n_{i,t}$ random variable

\[ \tilde{q}_{i,t}(n_{i,t}) = n_{i,t} \cdot \tilde{q}_{i,t} \]

- $\tilde{l}_{i,t}(n_{i,t})$ : type-$i$ employees who learn, out of $n_{i,t}$ random variable

\[ \tilde{l}_{i,t}(n_{i,t}) = n_{i,t} \cdot (1 - \tilde{q}_{i,t}) \cdot \tilde{l}_{i,t} \]
Model: Costs

- \( \alpha \): discount factor
- \( h \): unit hiring cost
- \( W_i \): per stage wage cost, type \( i \) employee
- \( O_t(y_t, n_{2,t}, ..., n_{m,t}; D_t) \): operating cost including overtime and outsourcing costs
  - jointly convex in \((y_t, n_{2,t}, ..., n_{m,t})\)
Dynamic Programming Model

\[ V_t(n_{1,t}, \ldots, n_{m,t}) \]

\[
= \min_{x_t \geq 0} \left\{ \begin{align*}
&hx_t + W_1(n_{1,t} + x_t) + \sum_{i=2}^{m} W_i n_{i,t} \\
&+ O_t(n_{1,t} + x_t, n_{2,t}, \ldots, n_{m,t}) \\
&+ \alpha E_{\{\tilde{q}_1,t, \ldots, \tilde{q}_m,t, \tilde{i}_1,t, \ldots, \tilde{i}_{m-1},t\}} \left\{ V_{t+1}(n_{1,t+1}, \ldots, n_{m,t+1}) \right\}
\end{align*} \right\}
\]
Constraints

• Subject to the system dynamics:

\[ y_t = n_{1,t} + x_t \]

\[ n_{1,t+1} = y_t - \tilde{q}_{1,t}(y_t) - \tilde{l}_{1,t}(y_t) \]

\[ n_{i,t+1} = n_{i,t} - \tilde{q}_{i,t}(n_{i,t}) - \tilde{l}_{i,t}(n_{i,t}) + \tilde{l}_{i-1,t}(n_{i-1,t}) \]

\[ \forall 1 < i \leq m. \]
System Dynamics Illustrated

demand and costs realize

\[ n_{i,t} - \tilde{q}_{i,t}(n_{i,t}) - \tilde{l}_{i,t}(n_{i,t}) + \tilde{l}_{i-1,t}(n_{i-1,t}) \]

learning and turnover

\[ y_t - \tilde{q}_{1,t}(y_t) - \tilde{l}_{1,t}(y_t) \]
Optimality of “Base-Level” Policy

• Base-Level Policy: there exist state-dependent base-levels $y^*_t(n_{2,t},\ldots,n_{m,t})$ such that the optimal number to hire is

$$x^*_t = \begin{cases} 
  y^*_t(n_{2,t},\ldots,n_{m,t}) - n_{1,t} & \text{if } n_{1,t} < y^*_t(n_{2,t},\ldots,n_{m,t}) \\
  0 & \text{otherwise}
\end{cases}$$
Proof Idea

Convexity of one-period cost function propagates

\[ V_t(n_{1,t},...,n_{m,t}) = \min_{y_t \geq n_{1,t}} \left\{ (h + W_1)y_t + O_t(y_t,...,n_{m,t}) \right\} - h n_{1,t} + \sum_{i=2}^{m} W_i n_{i,t} \]

where

\[ n_{1,t+1} = (1 - \tilde{q}_{1,t})(1 - \tilde{l}_{1,t})y_t \]

\[ \ldots \]

\[ n_{i,t+1} = (1 - \tilde{q}_{i,t})(1 - \tilde{l}_{i,t})n_{i,t} + \tilde{l}_{i-1,t}n_{i-1,t} \]

\[ \ldots \]

\[ n_{m,t+1} = (1 - \tilde{q}_{m,t})n_{m,t} + \tilde{l}_{m-1,t}n_{m-1,t} \]
Proof Idea

**Lemma 1**

If $V_{t+1}(n_{1,t+1}, \ldots, n_{m,t+1})$ is jointly convex in $(n_{1,t+1}, \ldots, n_{m,t+1})$
and $n_{i,t+1}(i = 1, \ldots, m)$ are linear functions of $(y_t, \ldots, n_{m,t})$,
then $V_{t+1}(n_{1,t+1}, \ldots, n_{m,t+1})$ is jointly convex in $(y_t, \ldots, n_{m,t})$.

**Lemma 2**

Let $f(n_1, n_2, \ldots, n_m) = \inf_{y \geq n_1} \{h(y, n_2, \ldots, n_m)\}$. If
$h(y, n_2, \ldots, n_m)$ is jointly convex in $(y, n_2, \ldots, n_m)$,
then $f(n_1, n_2, \ldots, n_m)$ is jointly convex in $(n_1, n_2, \ldots, n_m)$.
Model Details (I): Operating Cost Function

\[ O_t(y_t \cdots n_{m,t} ; D_t) \]

Sub-interval: \[ 1 \quad 2 \quad 3 \quad \cdots \quad s \quad \cdots \quad S \]

\[ D_t = \begin{bmatrix} D_1 & D_2 & D_3 \end{bmatrix} \]

\[ w = \text{work schedule } 1 \]

Type-1 (42)

\[ I(w,s) = 0 \]

Type-2 (26)

\[ w = \text{work schedule } w \]

Type-3 (15)

\[ I(w,s) = 1 \]

Type-4 (9)

\[ w = \text{work schedule } WS \]
Operating Cost Function $O(t)$

- $s = 1, \ldots, S$: sub-intervals in any hiring period $t$
- $w = 1, \ldots, WS$: work schedules ($I(w,s) = 1$ if $w$ requires working in sub-interval $s$, 0 otherwise).
- $x_{i,w}$: the number of type-$i$ employees assigned to work schedule $w$
- $z_s$: the amount of work to be outsourced in sub-interval $s$
Operating Cost Function $O(t)$

$$O_t(y_t, n_2, ..., n_m, \vec{D}_t) = \min_{x_{iw}, z_s} \sum_{i=1}^{m} \sum_{w=1}^{WS} C_{iw} x_{iw} + \sum_{s=1}^{S} OS_s z_s$$

s.t. $$\sum_{i=1}^{m} \sum_{w: I(w, s) = 1} \mu_i x_{iw} + z_s \geq D_s \ \forall s \quad (1)$$

$$\sum_{w=1}^{WS} x_{1w} \leq y_t$$

$$\sum_{w=1}^{WS} x_{iw} \leq n_{i,t} \ \forall 1 < i \leq m$$

$$x_{iw}, \ z_s \geq 0 \ \forall i, w, s$$

More General $O(t)$

$$O_t(y_t, n_{2,t}, \ldots, n_{m,t}; \vec{D}_t) = \min_{x_{iw}, z_{sj}} \sum_{i=1}^{m} \sum_{w=1}^{WS} C_{iw}(x_{iw}) + \sum_{s=1}^{S} \sum_{j=1}^{J} OS_{sj}(z_{sj})$$

s.t.  \[ f(x_{11}, \ldots, x_{m WS}, z_{11}, \ldots, z_{SJ}; \vec{D}_t) \geq 0 \]  \hspace{1cm} (2)

$$\sum_{w=1}^{WS} x_{1w} \leq y_t$$

$$\sum_{w=1}^{WS} x_{iw} \leq n_{i,t} \quad \forall 1 \leq i \leq m$$

$$x_{iw}, z_{sj} \geq 0 \quad \forall i, w, s, j$$

Example of (2): $P\{\text{waiting in queue} \geq U\} \leq a\%$. 
Model Details (II): Hiring/Training Lead Time

• Hiring/training lead time $\lambda > 0$ modeled by adding employee types
  • $m > \lambda$
  • $i = 1, \ldots, \lambda$ indicate hiring/training stages

• Hiring lead time
  • $\mu_i = 0$
  • $W_i$ may be 0

• Training lead time
  • $\mu_i$ may be 0
  • $W_i > 0$
Numerical Analysis

• Modeling of different CSR classes
• Modeling of the stochastic elements

Compare

• Optimal policy: state-dependent
  • recognize different employees have different capacities
  • take into account the stochastic elements

• Heuristic: headcount policy
  • check only the total number of employees
  • assume everyone has the same (average) capacity
  • take into account the stochastic elements

• Heuristic: LP-based
  • recognize different employees have different capacities
  • use average learning and turnover rates
Example Problem: Slow and Fast CSRs

• CSR turnover
  • slow CSRs: 48% yearly (15% per quarter)
  • fast CSRs: 34% yearly (10% per quarter)

• CSR learning: slow and fast CSRs
  • CSR becomes fast after one quarter of experience
  • % speedup with learning: 20%, 40%, 60%, 80%

• Call volume
  • Demand: 250,000 per quarter
  • CSR capacity: 10,000 per quarter on average
  • Overtime as % of regular time: 10%, 20%, 30%
Costs Used for Examples

Wage is capacity neutral, for an avg. capacity of 10,000 per quarter:

- Base wage: $4,500, benefits: $1,000 (22.2%)
- Overtime: 1.5 times base wage rate
- Outsource cost: 1.8, 18, 36, 91, 182 times base wage rate
Optimal v.s. Headcount: Ample Overtime

Average Annual Cost ($000's)

- HC 20%
- OPT 20%
- HC 40%
- OPT 40%
- HC 60%
- OPT 60%
- HC 80%
- OPT 80%

% cost increase

OT+OS
Hiring
Wage

policy, % learning
Optimal vs Headcount: Limited Overtime

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<td>454</td>
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<td>554</td>
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<td>704</td>
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<td>HC 80%</td>
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<tr>
<td>OPT 80%</td>
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% cost increase

Policy, % learning

OT+OS
Hiring
Wage
Cost Variability

Average Cost +/- 1 Standard Deviation

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Call Centre Workshop, Centre de Recherches Mathematiques, Universite de Montreal, 07/25/2004
Optimal vs. Headcount

Distribution of Regular Time Capacity

30% overtime

10% overtime

capacity below which outsourcing required

service requirement

headcount policy

optimal policy

Capacity (1,000 calls / quarter)
Our Findings

• When spare capacity is cheap
  • simpler hiring schemes do well
  • less need to track employees carefully
  \[\Rightarrow\] heuristics that ignore learning

• When spare capacity is tight
  • simpler hiring schemes can do poorly
  • value to tracking employees carefully
  \[\Rightarrow\] more complex approaches: DP, IPA
Optimal vs. LP Heuristic

• W/O training LT: LP does very well

• When there is a one-period leadtime: LP capacity often falls short
Our Findings

• LP heuristic performs well, when …
  • … training is fast -- LP can wait to observe the number of employees available and hire accordingly
  • … training takes time, but overtime is ample, or OS (or service failure) is cheap -- OT and OS can cover capacity shortfall when turnover is higher than average
  • The optimal “base level” structure simplifies calculation

• LP performs poorly, when …
  • … overtime is limited and OS (or service failure) is expensive
  • If MDP is too complicated to use, then at least add some “buffer capacity” in conjunction with LP
Summary

• A new framework to study employee staffing problems
  • DP approach, allows randomness in the system
  • Natural incorporation of the scheduling and routing problem
  • Optimal policy and structural properties
• Numerical results show when it is worthwhile to more carefully monitor system capacity