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Research Opportunities in Workforce Management

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Abstract

In this paper, we review a subset of the labor scheduling literature and discuss areas where additional research is warranted. The review, while not exhaustive, concludes that there are still rich research opportunities to contribute to an already large field. The areas that are still most attractive are those which provide models that solve more than one phase of the workforce management problem in an integrative fashion as has been called for by many researchers. We also present an example of an integrative model found in the literature. In addition, an application area for workforce management that has received much attention but still provides promising research opportunities is the area of nurse staffing. With continued nursing shortages, managers are faced with a difficult task of providing quality care while still maintaining costs.

Key words : *Nurse scheduling, Labor scheduling*

1. Introduction:

Workforce management techniques have been studied in the literature for many years. The abundance of research is the result of numerous settings where this research is applicable. This paper provides a brief overview of existing literature relevant to each phase of the workforce management process in Figure 1. The main focus of each section of this paper will be the literature that deals specifically with the planning, scheduling, and allocation/ adjustment decisions studied in this research. The review will show that there are still many areas for opportunity to study workforce management. In addition, the assignment of heterogeneous employees to a set of shifts remains an attractive research stream, with limited attention in the literature. Lastly, there has been almost no research that integrates models across the decision phases of the workforce management process.

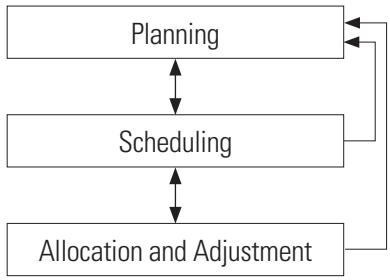

Figure 1 : Workforce Management Framework

The decisions that make up workforce management can be categorized as in Figure 1. This figure represents an adaptation of a three-phase workforce management framework seen in Campbell (1999) and Abernathy et al. (1973). There are several decisions made in each phase of the process and each is dependent on earlier phases. In addition, each of these decisions is based on forecasted demand for the services that the employees provide. The arrows in Figure 1 represent information flows. The planning and scheduling phases contain decisions made before the time of service, while the allocation and adjustment phase contains decisions made at the time of service.

In the planning phase, the manager makes decisions such as: how many employees to hire, what level of cross-training each should achieve, how many to dedicate to each unit of the company, and how many employees to schedule for each shift over the planning horizon. The number of employees needed for each shift is referred to as the *employee requirements*.

In the scheduling phase, the manager develops a schedule which shows when each employee works over the planning horizon. The scheduling model developed in this research accommodates employees that are heterogeneous in terms of skill, availability, and preference while minimizing schedule cost and undesirable shifts. As will be discussed later, some recent research identifies a tradeoff analysis between the cost and undesirable shifts objectives of the tour assignment model.

The allocation and adjustment phase deals with real-time schedule adjustment in order to accommodate actual demand. Allocation and adjustment can be accomplished by assigning cross-trained employees to particular units and transferring employees from one unit to another when necessary.

2. Planning Literature

2.1 Determining the Workforce Size

The size of the workforce (i.e., the number of employees on the payroll) must be determined based on anticipated demand. This decision is based on having enough manpower to cover the expected employee requirements for each shift over the planning horizon. Other scheduling policies may place limitations on the number and/or composition of the shifts each employee is allowed to work. Several researchers have studied this problem and presented algorithms that determine the optimal size of the workforce under various scheduling policies (Burns and Carter 1985, Burns and Koop 1987, Dijkstra et al., 1994, Hung 1994, Ikem and Reisman 1990, Koop 1988).

2.2 Determining Employee Requirements

Approaches to generating requirements have dominated most research dealing with the planning phase of the workforce management process. The approach used is dependent on the individual characteristics and objectives of the company. Service-based and economic-based approaches are most common in the literature. Previous literature is classified by their approach in Table 1. Service-based approaches seek to minimize the employee requirements subject to some minimum service level. Queueing and discrete-event simulation methods are most common for this type of approach. Those that involve queueing commonly use one of Erlang's models, e.g. M/M/c/∞ delay model or M/M/N/N loss model. Call centers have been a favorite area for this research (Agnihhothri and Taylor 1991; Gaballa and Pearce 1979; Hueter and Swart 1998; Segal 1974; Sze 1984). Thompson (1993) addresses multi-period impacts of service to develop employee requirements. Easton and Rossin (1996) allow for variable service levels by using a stochastic goal program to determine requirements. More complicated service systems for which analytical results are too difficult to obtain are typically simulated. For instance, Mason et al. (1998) simulated passenger behavior for two distinct groups, one for departing flights and one for arriving flights, which were served by the same staff. These service based approaches are limited because customer service in a hospital is based not so much on waiting time but rather on quality of service. Service based studies that focus on recent legislation regarding nurse to patient ratios and overtime have recently appeared in the literature (Wright, et al. (2006).

Economic-based models for determining requirements also appear in the literature. This approach generates employee requirements based on calculated opportunity

costs associated with differences between capacity and demand. Costs for understaffing and overstaffing must be readily available for this type of model. Mabert (1979) used economic criteria in the context of check encoding operations. These same criteria are used in a call center environment in Andrews and Parsons (1989, 1993) and Quinn et al. (1991). Thompson (1995) used a net present value (NPV) approach to determine the marginal benefit of adding an additional worker to the requirements.

Approach	Reference
Service-based	Agnihhothri and Taylor (1991)
	Gaballa and Pearce (1979)
	Easton and Rossin (1996)
	Heuter and Swart (1998)
	Mason et al., (1998)
	Segal (1974)
	Sze (1984)
	Thompson (1993, 1997a)
	Wright et al. (2006)
Economic-based	Andrews and Parsons (1989, 1993)
	Mabert (1979)
	Quinn et al. (1991)
	Thompson (1995)

Table 1 Classification of Employee Requirements Literature

3. Scheduling Literature

3.1 Shift/Tour Scheduling

Employee requirements, as determined during the planning phase, are typically used as inputs for the development of the schedule. Schedule development involves creating a set of shifts (tours) for the workforce while complying with various scheduling policies that may exist. The decision variables in the tour scheduling problem indicate how many workers to schedule for each period. Therefore, the tour scheduling problem assumes that labor resources are in infinite supply, which differs from the tour assignment problem discussed in the next section. The earliest formulation of the tour scheduling problem can be seen in Dantzig (1954). This seminal work involved a set covering formulation that satisfied the employee requirements for each shift at the lowest cost. Keith (1979) presented a model which allowed but penalized deviations from the target employee requirements. The models presented in these two works provide the basis for most scheduling research in the literature. A subset of this literature can be seen in Table 2 categorized by the type of formulation. Minimization of the wage cost of the schedule is the predominant performance measure for tour scheduling research. In addition, some authors include a specific consideration for employee preferences (Miller et al., 1976, Warner 1976). Because of the large scale of most tour scheduling problems, heuristic methods have been most frequent. Heuristics range from local search (Henderson and Berry 1976, Keith 1979, Krajewski et al., 1980, Showalter and Mabert 1988, Easton and Rossin 1991a), working subset (Mabert and Watts 1982, Bechtold and Brusco 1994, 1995, Easton and Rossin 1991b), and construction/improvement (Bechtold and Showalter 1987, Buffa et al., 1976). A review of several tour scheduling methodologies can be seen in Bechtold et al. (1991).

Type of Formulation*	Reference
Set Covering (Dantzig 1954)	Henderson and Berry (1976,1977)
	Bechtold and Showalter (1987)
	Easton and Rossin (1991a, 1991b)
	Dantzig (1954)
	Mason, Ryan and Panton (1998)
Penalty functions for deviations from target staffing level (Keith 1979)	Bailey (1985)
	Buffa, Cosgrove and Luce (1976)
	Keith (1979)
	Krajewski, Ritzman and McKenzie (1980)
	Mabert (1979)
	Mabert and Watts (1982)
	Thompson (1990, 1995)
	Warner and Prawda (1972)

Table 2 Classification of Shift/Tour Scheduling Literature

* References are categorized by the formulation that is most similar

3.2 Shift/Tour Assignment

The tour assignment problem is an area of the labor scheduling research that has not been given as much attention. In a labor-constrained environment, the workforce is fixed and each individual must be assigned a set of shifts for the given scheduling horizon. The particular setting in which the tour assignment problem is implemented may include homogeneous (identical) or non-homogeneous employees (non-identical). When employees can be categorized into groups with the same characteristics, a separate assignment problem can be easily solved for each group. This was the case with Ritzman et al. (1976) who assigned postal workers to shifts. They considered different skill levels, but all employees within each skill group were interchangeable. When employees have differences, i.e., are not completely interchangeable, the assignment problem is more difficult to solve. Heterogeneous tour assignment has been given limited attention in the literature.

Developing tour assignments for a heterogeneous workforce requires special consideration for each of its employees. Heterogeneous employees can be unique in terms of skill level, availability, shift preferences, et cetera. Only a few papers that consider heterogeneous employees appear in the literature. Loucks and Jacobs (1991) presented a construction/improvement heuristic to assign workers to tasks within a fast food environment. Love and Hoey (1990) also studied a fast food scheduling system. They presented two network subproblems of an integer goal programming formulation, one that determines employee requirements and one that assigns heterogeneous employees to shifts. Thompson (1997a) assigned telephone operators to shifts based on seniority and preference using a goal programming formulation. Thompson (1990) studied employees that had limited availability. Past research dealing with tour assignment is summarized in Table 3. The first three columns indicate the inclusion of schedule cost, the use of heterogeneous employees, and employee preferences. The last column represents research that integrates more than one phase of the workforce management process. Wright et al. (2006) and Wright and Bretthauer (2009) considered wage cost, heterogeneous employees, employee preference, and also integrated decisions across multiple phases of the workforce management process.

Reference	Cost Objective	Heterogeneous Employees	Employee Preference	Integrate Multiple Phases
Ritzman, et al. (1976)	*			
Malhorta and Ritzman (1994)				
Loucks and Jacobs (1991)	*	*		
Thompson (1990)				
Thompson (1997a)	*	*	*	
Love and Hoey (1990)				
Wright, et al. (2006)	*	*	*	*
Wright and Bretthauer (2009)				

Table 3 Classification of Tour Assignment Literature

Another characteristic that can make employees unique is their level of training outside of their normal department or station. Cross-training, as it is referred to, introduces flexibility into the scheduling environment. Cross-training literature will be reviewed in the following section.

4. Allocation and Adjustment Literature

4.1 Allocation of Cross-Trained Workers

Cross-training is a tactic that managers have used to increase the amount of scheduling flexibility. When workers are trained in multiple areas, it increases the number of options that a manager has to create the schedule. Several researchers have explored the use of cross-training in various settings. A common result in most studies showed that marginal benefits associated with cross-training can be high initially, but diminishing returns sets in relatively quickly.

Brusco and Johns (1998) evaluated several cross-training policies in the context of workers in a paper mill. Campbell (1999) studied various cross-training policies for use in a multi-department service environment.

Workers were assigned to departments at the beginning of a shift. Campbell and Diaby (2002) developed a heuristic for allocating cross-trained staff with non-linear departmental objective functions. Brusco et al. (1998) examined the impact of cross-training on the size of the workforce. In a multi-location environment, Brusco & Showalter (1993) presented several staffing models which allowed cross-trained workers to be transferred to other locations for which they are trained. Pinker and Shumsky (2000) caution that efficiencies gained by the use of cross-trained staff may be offset by decreases in service quality. They incorporate learning, length of employment, and cross-trained servers in their system and show that cross-trained employees may not achieve sufficient experience to provide acceptable levels of customer service. They concluded that some mixture of cross-trained and specialized workers is best. Hopp and Van Oyen (2004) discuss cross-training in the context of coordination. Finally, the use of cross-training in the context of a nurse float pool also appears in the literature. Hershey et al. (1974) evaluated fixed staffing policies versus variable staffing policies that included the use of a cross-trained nurse float pool. Trivedi and Warner (1976) used patient acuity levels at the beginning of a shift to determine departmental needs.

4.2 Real-Time Schedule Adjustment

The Real-Time Work Schedule Adjustment (RTWSA) problem was introduced by Hur et al. (2002). Very little work concerning RTWSA has appeared in the literature. The relevant decision is to modify the planned schedule in real time when the initially scheduled service capacity becomes asynchronous with forecasted demand. Modifications may be required as a result of worker absenteeism, tardiness, or unforeseen variability in customer demand. Vaughan (1995, 1996) suggested the use of on-call employees to alleviate understaffing. These on-call employees were paid a much smaller wage unless they were called to work. Berman and Larson (1994) advocated the use of temporary employees to help cover understaffing. These employees are called only when needed but are guaranteed a minimum number of shifts each month. On-call and temporary employees are short term responses to differences in forecasted and actual demand. Easton and Goodale (2002) studied the importance of planning in advance for turnover and absenteeism. Their method suggested an increase in employee requirements to create additional buffer capacity. Each of these papers presented methods that involved planning in advance for real time adjustment of the schedule. Easton and Goodale (2005) focused on service recovery when absenteeism is encountered. Thompson (1999) suggested more sophisticated methods of monitoring demand and the use of many "action times" (starting or ending time of shifts and breaks) to better prepare for real-time adjustment. Hur et al. (2002) explored a variety of options that could be exercised in real time in the event of both understaffing and overstaffing. These included modification of shift start or end times, cancellation or addition of shifts, reassignment after initial work station assignments, and changes to employee break schedules.

5. Nursing Specific Literature

The nurse scheduling problem has been a favorite area that has been addressed by several authors over the past 30 years. Nurse scheduling, among other service environments, presents a special case of the scheduling problem because of the need for workers on a 24-hour basis. In addition, demand must not be backlogged and there must be a high level of customer service. Nursing is also facing a crisis worldwide (Buerhaus et al. 2008). Table 4 shows past research dealing with nursing. Each article is categorized by the phase of the workforce management process it concerns. Much like the general scheduling literature, the nurse scheduling literature is also dominated by the use of homogenous employees. Early nurse scheduling research explored fixed (Stimson and Stimson 1972) and variable (Hershey, et al. 1974) staffing policies. Fixed staffing only considered full time employees that worked the same time each day. Variable staffing allowed for part-time employees. Kao and Tung (1981) assessed the need for permanent staff, overtime pay, and temporary personnel. Warner and Prawda (1972) presented a mixed-integer programming model that determines the number of each skill class to be scheduled for each unit and shift. Bordoloi and Weatherby (1999) studied the implications of staff skill mix. Easton et al.

(1992) evaluated several nurse scheduling policies used at eight medical and surgical units to reduce turnover. Huarng (1999) used employee preference as a criterion in a binary goal-programming model to determine work tours for nurses. Other academic research dealing with nurse planning (Brusco et al., 1993; Brusco and Showalter 1993; Kao and Queryanne 1985; Needleman et al., 2002; Siferd and Benton 1992; Venkataramanan and Brusco 1996), scheduling (Warner and Prawda 1972; Ozkarahan and Bailey 1988; Downsland 1998; Jaumard et al., 1998; Miller et al., 1976; Warner 1976) and allocation/adjustment (Trivedi and Warner 1976; Hershey et al., 1974) can be seen in Table 4.

In addition to the literature found in academic journals, numerous articles have appeared in practitioner-focused journals. Many of these articles discuss current and troubling issues regarding nurse staffing and scheduling (Aiken et al., 2001, 2002, Graham 1995, Hung 1991, Lanser 2001, Lovern 2002, Marchionno 1987, Schaffner & Ludwig-Beymer 2003, Staff Writer 2002, Tieman 2001a, 2001b, 2002a, 2002b, Jones 2005, 2007). For example, in a series of articles, Tieman discusses developments on the legislature's intervention in nurse staffing issues by instituting mandatory nurse to patient ratios. In fact, 28 state governments plan to consider nurse to patient ratios in the 2004 legislative session. These actions motivate: (1) an evaluation of how the nurse to patient ratios impact scheduling cost and the desirability of the schedule and (2) new methods for determining employee requirements based on controlling the amount of work assigned to each employee.

6. Integrative Literature

There have been a few studies in the literature that claim integrative approaches to planning and scheduling. Venkataraman and Brusco (1996) present an iterative procedure that alternates between planning and scheduling modules until a suitable solution to both problems is found. Easton et al. (1992) also discuss both a staffing and a scheduling model but do not solve them simultaneously. Thompson (1997b) develops two service level approaches for the planning problem and then solves the scheduling problem. Abernathy et al. (1976) present a three-stage model for the nurse-staffing process. Love and Hoey (1990) treat both problems, but do so separately. Each of the authors discuss and provide insights into two problems in the same paper, however, they still solves each phase independently. Although these researchers indicate integrative or simultaneous approaches, they do not meet the level of integration provided by Wright et al. (2006) and Wright & Bretthauer (2009) where the integrative model has the ability to solve both problems simultaneously with decision variables for each phase.

Example of an Integrative Model

This section presents an example of an integrative model that is a scaled down formulation of the model found in Wright et al. (2006). The model coordinates across two problems that are typically treated independently:

Planning	Scheduling	Allocation and Adjustment
Brusco et al. (1993)	Huarng (1999)	Trivedi and Warner (1976)
Brusco and Showalter (1993)	Easton et al. (1992)	Hershey et al. (1974)
Bordoloi and Weatherby (1999)	Warner and Prawda (1972)	Wright and Bretthauer (2009)
Kao and Queryanne (1985)	Ozkarahan and Bailey (1988)	
Needleman et al. (2002)	Downsland (1998)	
Siferd and Benton (1992)	Jaumard et al. (1998)	
Stimson and Stimson (1972)	Miller et al. (1976)	
Venkataramanan and Brusco (1996)	Warner (1976)	
Wright, et al. (2006)	Wright, et al. (2006)	
Wright and Mahar (2009)	Wright and Bretthauer (2009)	
	Wright and Mahar (2009)	

Table 4 Classification of Nursing Specific Literature

planning and scheduling. This integrative model determines how many employees are needed to work on each shift at the same time creates the schedule. The benefits of this integrative model are that it can substantially reduce scheduling cost. The particular model was constructed for a nursing environment and is formulated as a non-linear, bi-criteria integer programming problem.

Sets

N = the set of all nurses
N_{kj} = the set of nurses of type k available for shift j
K = the set of all nurse types
S = the set of shifts
T = the set of weeks in the scheduling horizon
SA^i = the set of shifts that nurse i is available to work
S^{it} = the set of shifts that nurse i is available to work in week t

Subscripts

i : nurse i k: nurse type k
j : shift j
t : week t

Decision Variables

x_{ij} = 1 if nurse i works shift j at regular time wages, 0 otherwise.
y_{ij} = 1 if nurse i works shift j at overtime wages, 0 otherwise.
b_{jk} = the number of nurses of type k required for shift j

Parameters

w = the number of weeks in the scheduling horizon
c_{ij} = regular time wages if nurse i works shift j
d_{ij} = overtime wages if nurse i works shift j
$\overline{n_i}$ = maximum number of shifts each week for nurse i
$\underline{n_i}$ = minimum number of shifts each week for nurse i
$\overline{l_i}$ = upper limit on the number of overtime shifts assigned to nurse i
R_k = the number of patients per nurse type k as determined by the nurse-to-patient ratio
λ_j = mean patient arrival rate during shift j
μ_j = mean unit service rate during shift j
$P_h(\lambda_j, \mu_j)$ = probability of h occupied beds during shift j
u_k = upper limit on the single shift service level for nurse type k
v_k = upper limit on the average service level for nurse type k over the planning horizon
s = number of beds (servers) on a unit
M = a large number

$$\text{Min} \quad \sum_{i\in N}\sum_{j\in SA^i} c_{ij}x_{ij} + \sum_{i\in N}\sum_{j\in SA^i} d_{ij}y_{ij} \tag{1}$$

$$\text{st} \sum_{i\in N^{kj}} x_{ij} + \sum_{i\in N^{kj}} y_{ij} \geq b_{jk},\ j \in S,\ k \in K \tag{2}$$

$$\sum_{h=R_k\cdot b_{jk}+1}^{s} P_h(\lambda_j, \mu_j) \leq u_k,\ j \in S, k \in K \tag{3}$$

$$\left(\sum_{j\in S}\sum_{h=R_k\cdot b_{jk}+1}^{s} P_h(\lambda_j, \mu_j)\right) / |S| \leq v_k, k \in K \tag{4}$$

$$\underline{n_i} \leq \sum_{j\in S^{it}} x_{ij} \leq \overline{n_i},\ \ i \in N, t \in T \tag{5}$$

$$\sum_{j\in SA^i} y_{ij} \leq l_i, i \in N \tag{6}$$

$$(x_{ij} + y_{ij}) + (x_{i(j+1)} + y_{i(j+1)}) + (x_{i(j+2)} + y_{i(j+2)}) \leq 1, i \in N, j \in SA^i \tag{7}$$

$$x_{ij} \in \{0,1\}, y_{ij} \in \{0,1\},\ \ i \in N, j \in SA^i \tag{8}$$

$$b_{jk} \geq 0 \text{ and integer}, j \in S, \text{ and } k \in K \tag{9}$$

where

$$P_h(\lambda_j, \mu_j) = \frac{(\lambda_j/\mu_j)^h / h!}{\sum_{g=0}^{s} (\lambda_j/\mu_j)^g / g!} \qquad i = 0, 1, \ldots, s \tag{10}$$

Having specific decision variables for both the planning and scheduling phases of the workforce management process accomplishes the integration in the above model. The planning decisions come from the b_{jks} in constraint (2) which are determined by constraints (3) and (4). The scheduling decisions are made with decision variables x_{ij} and y_{ij}. Objective (1) minimizes regular time and overtime wage costs for each nurse over the scheduling horizon. Constraint (2) enforces the requirements for each nurse type for each shift. These requirements are determined from constraints (3) and (4) which enforce service levels. Constraint (3) determines per shift service levels and (4) enforces average service levels over the entire planning horizon. Constraint (5) forces each nurse to be scheduled for a minimum and maximum number of shifts per week according to hospital policy. Constraint (6) sets limits to how much overtime can be scheduled for each nurse. Constraint (7) specifies that each nurse must not be scheduled within 24 hours before the previously assigned shift. Constraints (8)-(9) force integer, binary,

and non-negative conditions as appropriate. Expression (10) calculates the probability of any number of beds being occupied on a unit. It is used to enforce service quality in constraints (3) and (4) (see Wright et al. 2006 for more details). Any number of additional constraints could be added. For instance, a manager may want to limit the number of weekend shifts worked by nurses that do not want to work weekends. In addition, as was done in Wright et al. (2006), undesirable shifts may be reduced by adding an objective that minimizes undesirable shifts. This type of objective is important for employee satisfaction and morale.

7. Summary

Three areas of the literature stand out as needing further attention. First, integrative approaches to workforce management, as described above, have just begun to appear in the literature. Many researchers have noted the need for integrative workforce management but only one published paper (Wright et al. (2006)) exists. Because of the complexity of the three-phase staffing problem, integrative models are difficult. However, they are a necessity for the models to be consistent with all of the issues of a practicing manager. Campbell (1999) argues that integrative models that can handle both the scheduling and allocation/adjustment phases of the scheduling process would be particularly useful. Brusco and Johns (1998) describe an example of an "interesting and challenging extension" that is very similar to the integrative approaches developed in this research. Second, the earlier discussion indicates that the tour assignment problem has not been the focus of the workforce management literature, especially with respect to heterogeneous employees. Tour assignment models that also have treatment of employee preferences are particularly useful and attractive to managers. And third, there is a wealth of opportunity in the nurse scheduling area particularly in light of many new laws that pertain to staffing of nurses. Although we have not covered all literature in this review, we have certainly proposed some issues that need to be addressed that are lacking in the literature.

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