



Operations Research Methods Applied to Workflow in a Medical Records Department

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Abstract. Transcribing medical documents accurately into pre-defined formats and within certain time frames is vital for administrative and medical purposes in any hospital. This paper describes quantitative models incorporating available data to represent transcription activities of a medical records department. We forecasted the workload of the department, determined the optimal worker schedule and designed a simulation model to represent the workflow of the transcription function of a medical record department. The findings provided insight into the workflow, staffing and performance of the department.

Keywords: Arena, integer programming, ARIMA, scheduling, optimization, simulation, forecasting, workflow, medical records

1. Overview

This paper is a demonstration and comparison of the value of both deterministic and stochastic models in the analysis of a hospital information system. Using traditional quantitative methods, we were able to model and analyze the transcription workflow of the Medical Records and Word Processing (MR & WP) Department at the Madonna Rehabilitation Hospital (MRH) in Lincoln, Nebraska. By workflow, we refer to the way jobs (medical information pertaining to a patient's health status) arrive into the department and the process in which they are transcribed.

The medical record administrator from MRH voiced a need for quantitative models which could incorporate available data to represent the workflow of the MR & WP Department. At times, the department was overwhelmed with jobs that needed processing. The quantitative models developed would provide insight to the workflow of the department. We first applied an integer programming model to determine the minimal staffing pattern necessary to provide acceptable service and to perform sensitivity analysis on the resources avail-

able. The data and modeling suggested that the workflow is quite variable, but an aggregate model smoothing out the variability showed that staffing and scheduling are on average adequate. The aggregate linear programming model does not address stochastic variability so we next developed simulation and forecasting models in order to characterize and predict the variability. We used simulation to test alternative work schedules for the existing personnel and the forecasting models to infer weekly patterns in the workload and predict workload in future weeks.

From all three models that we developed, we were able to answer some questions that were of interest to our client such as:

- What is the optimal worker schedule in aggregate?
- What resources are the limiting factors affecting job completion?
- How would a change in resources or workload affect the job completion time?
- Is it possible to accurately predict the weekly transcription workload so that more efficient scheduling can be carried out?

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1.1. Madonna Rehabilitation Hospital

Madonna Rehabilitation Hospital in Lincoln, Nebraska, is a comprehensive medical rehabilitation facility for children and adults with physical disabilities. A 252-bed facility, Madonna provides many different services and programs, including inpatient and outpatient rehabilitation, aquatic programs, adult day services and occupational health services.

1.2. The reporting process

Upon registration, a new inpatient of MRH is admitted into one of four programs. These are Acute Rehabilitation, Subacute Rehabilitation, Special Needs and Complex Medical. On the day of the patient's admission, a physician performs a physical examination of the patient. The physician then dictates observations in a *history and physical* report (all reports are dictated). Various therapists evaluate the patient within 2 days of admission. Within 72 hours of the patient's admission, the physician and the therapists meet with a case manager to discuss the patient's condition and treatment. The synopsis of this meeting is dictated and is referred to as an *initial evaluation*. The attending physician monitors the patient's condition daily from Monday to Friday and reports it in a *progress note*. The patient's progress is discussed in a weekly meeting attended by the case manager, therapists and the physician. The summary of the meeting is reported as a *re-evaluation* by the case manager. Two *discharge summaries* are written when the patient is discharged. The physician summarizes the patient's stay while the case manager describes the status of the patient's goals, education provided, equipment issued and the patient's destination after being discharged. In the case of an outpatient, the examining physician only needs to dictate a *clinic note* describing the outpatient's conditions, prescribed treatment and follow-up plans. Several other reports and materials are dictated for special circumstances including *letters*, *telephone conversations*, *independent medical examinations*, *disability evaluations*, *family conferences*, *consultations* and *discharge medications*.

Each day, physicians and case managers call into a digital dictation telephone system where they dictate information regarding their patient's medical status. These dictation jobs can be any one of the fourteen work types in table 1. These dictated reports are displayed on the dictation system monitor. At the MR & WP Department, transcriptionists review the dictation system monitor daily for the list of jobs that are "Ready" to be transcribed. They would then work on these dictation jobs according to the jobs' priorities. The following information about the dictation job can be obtained from the system monitor:

1. The time and date when the dictation job was first put into the system.
2. A number representing the physician or case manager who dictated the information and a number representing the transcriptionist who transcribed the job.
3. The length of the dictation job in tenths of minutes.

Table 1
Description of dictation jobs and their priorities.

| Job type | Description | Priority |
|----------|----------------------------------|----------|
| 1 | Progress note | 1 |
| 2 | History and physical | 2 |
| 3 | Discharge summary (physician) | 3 |
| 4 | Outpatient clinic notes | 3 |
| 5 | Letter | 2 |
| 6 | Telephone conversations | 3 |
| 7 | Independent medical examination | 3 |
| 8 | Disability evaluation | 3 |
| 9 | Initial evaluation | 3 |
| 10 | Re-evaluation | 3 |
| 11 | Family conference | 3 |
| 12 | Consultation | 2 |
| 13 | Discharge medications | 1 |
| 14 | Discharge summary (case manager) | 3 |

Table 2
Resource schedule.

| Resources | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Sun. |
|--------------|------|-------|------|--------|------|------|------|
| 8-hour shift | 3 | 4 | 4 | 4 | 4 | 1 | 0 |
| 7-hour shift | 2 | 2 | 2 | 2 | 2 | 0 | 0 |

4. The time and date when the dictation job was transcribed.

The resource strength of the MR & WP consists of *four* medical transcriptionists (8-hour shift), *two* case manager transcriptionists (7-hour shift) and *one* on-call transcriptionist. The schedule of the transcriptionists is in table 2. Each medical transcriptionist takes turns to work on Saturday once a month. From table 2, notice that only three of the medical transcriptionists work on Monday. This is because the case manager transcriptionist who works on Saturday will get Monday off. The on-call transcriptionist will fill in the Saturday when no other medical transcriptionists are scheduled to work.

Transcriptionists refer to the system log file to view the list of jobs available and their priorities. They then schedule their time and work on jobs that need to be transcribed in order to meet deadlines.

2. Data analysis and queueing models

The transcription workload system is a queueing system. There are two queues in this system. Queue one comprises priority 1 (transcribed within *same day* of arrival) and 2 (transcribed within *24 hours* of arrival) jobs while queue two contains priority 3 (transcribed within *three days* of arrival) jobs only. The medical transcriptionists work on dictation jobs from both queues. The case manager transcriptionists work only on jobs from queue two. When both priority 1 and 2 jobs are due to be transcribed, we assumed that the medical transcriptionist chooses a priority 1 job over a priority 2 job. Refer to figure 1 for the conceptual system representation of the way jobs arrived into the system and were then transcribed by transcriptionists before they were printed and archived. For the purpose of this simulation, if no jobs are

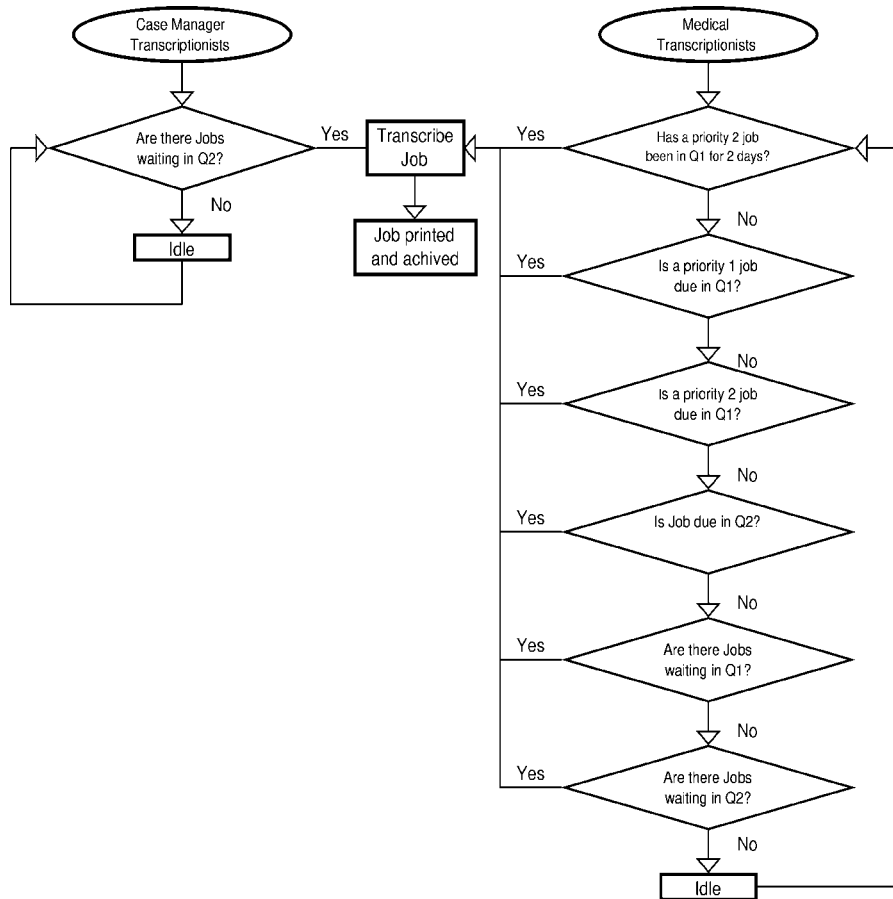


Figure 1. Representation of the way work flows at the MR & WP Department.

waiting in the queue, we will assume that transcriptionists stay idle even though in reality transcriptionists are seldom idle because they are also responsible for other non-medical word processing duties.

The most natural way of modeling the transcription workload system is as a queueing network with non-preemptive priority [4]. In a priority queue discipline, customers with higher priorities are selected for service over customers with lower priorities, independent of their time of arrival into the system. By non-preemptive we mean that transcriptionists will not be interrupted at any time even when a higher priority job arrives in the system. Since we wanted to model a queueing system, we needed the distribution of the interarrival times and the distribution of service times. With three different priority job types, we would need an interarrival and service time probability distribution for each job type.

Due to its many mathematically agreeable properties, in many queueing models it is assumed that interarrival times and service times obey the exponential distribution or equivalently that the arrival and service completions are Poisson processes [4]. Even though such assumptions, particularly for the arrival process, would have greatly simplified our analysis, we could not apply the models since the data did not fit exponential assumptions. However, these simplifying assumptions are not important if we are doing a simulation. We first

considered the interarrival time data that could be easily extracted from the data provided to us. About a year's worth of data were used for this analysis.

Many different paths were explored to generate sets of data that were required for our analysis, including splitting data between morning and afternoon, truncating data that were out of the meaningful range, grouping data according to their relevancy and others [3]. The Expertfit [7] software package was used to conduct such a data fit. Expertfit compares real data against named probability distribution functions. The comparisons are made using the goodness-of-fit tests. The default test used in this package is the Anderson–Darling test [1]. Other goodness-of-fit tests including Kolmogorov–Smirnov and Pearson's chi-square tests [2] are available for further verifications. Unfortunately, no analytically tractable distribution was found to fit the data satisfactorily. The closest, but still not satisfactory, representative named distribution was a Weibull distribution. Its high coefficient of variation indicated the presence of a large amount of variability in the analyzed data. We identified three reasons why mathematical queueing theory could not be used in our analysis [4]:

1. A queueing system would be analyzed with a system of coupled (or simultaneous) differential equations. Such a set of coupled differential equations can be difficult to solve, even numerically.

2. A queueing system with priority and which is non-preemptive is even harder to solve.
3. The interarrival distributions did not fit exponential assumptions. Therefore, it is difficult to derive a closed form of mathematical solutions.

Nevertheless, the queueing network modeling process helped us to understand the system. In particular, we found that interarrival times exhibited very high variability. It is well known that variability in queueing systems causes additional congestion and delays beyond what would be predicted by average arrival and service rates. The data analysis results motivated us to try computer simulation (see section 4) in addition to deterministic modeling and provided the correct empirical distributions to use.

3. Scheduling

The next component of our analysis was to use linear integer programming [5] as the method for examining the scheduling of the workers of the MR & WP Department. The objective was to minimize the staffing required to complete the workload. With linear programming, we identified optimal worker scheduling and we used sensitivity analysis to identify critical factors.

Since our purpose was to minimize the total number of person-days in the weekly staffing pattern of the MR & WP Department, we needed an objective function z that reflected this goal. This objective function was expressed in terms of the decision variables – the days worked each week by the four medical transcriptionists and the 4-hour work periods worked each week by two case manager transcriptionists and one on-call transcriptionist. The four medical transcriptionists were denoted by the letters A, B, C and D. The two case manager transcriptionists were denoted by letters E and F, while the on-call transcriptionist was denoted by the letter G. Thus the binary variable x_{ij} represented the work status of transcriptionist i ($i = A, B, \dots, G$) during work period j ($j = 1, 2, \dots, 12$) or work day j ($j = I, II, III, IV, V, VI$):

$$x_{ij} = \begin{cases} 1 & \text{if transcriptionist } i \text{ is working during} \\ & \text{period/day } j, \\ 0 & \text{otherwise.} \end{cases}$$

The objective function constructed from the x_{ij} had to reflect the following requirements:

1. Medical transcriptionists are scheduled in 8-hour days Monday through Saturday
2. Case manager transcriptionists are scheduled in 4-hour shifts Monday through Friday. (In this case, we simplified the model by assuming that the case manager transcriptionists work 8 hours from Monday to Friday instead of 7 hours as assumed previously.)
3. The on-call transcriptionist works only either Saturday mornings or afternoons

Table 3
Labeling of work period.

| Work period time | Work period number | Work day numeral |
|---------------------|--------------------|------------------|
| Monday morning | 1 | I |
| Monday afternoon | 2 | I |
| Tuesday morning | 3 | II |
| Tuesday afternoon | 4 | II |
| Wednesday morning | 5 | III |
| Wednesday afternoon | 6 | III |
| Thursday morning | 7 | IV |
| Thursday afternoon | 8 | IV |
| Friday morning | 9 | V |
| Friday afternoon | 10 | V |
| Saturday morning | 11 | VI |
| Saturday afternoon | 12 | VI |

The parameters of the objective function represented work periods – definite units of time, not figures derived from data. The coefficient of a medical transcriptionist-work day is 1, while the coefficient of a case manager transcriptionist-half-day is 0.5. The objective function z of 46 decision variables (which represents the weekly total number of transcriptionist-days to be minimized) is:

$$z = \sum_{i=A}^D \sum_{j=1}^{VI} x_{ij} + 0.5 \sum_{i=E}^F \sum_{j=1}^{10} x_{ij} + \sum_{j=11}^{12} x_{Gj}.$$

With an objective function in place, four constraint sets were developed:

1. Work time constraints

$$\begin{aligned} \sum_{j=1}^{VI} x_{ij} &\leq 5 \quad \text{for } i = A, B, C, D, \\ \sum_{j=1}^{10} x_{ij} &\leq 10 \quad \text{for } i = E, F, \\ \sum_{j=11}^{12} x_{ij} &\leq 1 \quad \text{for } i = G. \end{aligned}$$

The model has the aim of avoiding overtime compensation. Medical transcriptionists (A, B, C and D) work 5 out of the 6 possible working days, case-manager transcriptionists (E, F) work on weekdays and the on-call transcriptionist (G) works on either Saturday morning or afternoon. Note that the second inequality cannot be violated, but we include the constraint for post-solution sensitivity analysis.

2. Work space constraints

$$\begin{aligned} \sum_{i=A}^D x_{ij} + \sum_{m=E}^F x_{mn} &\leq 6 \quad \text{for } j = I, n = 1, 2; \\ & \quad j = II, n = 3, 4; j = III, n = 5, 6; \\ & \quad j = IV, n = 7, 8; j = V, n = 9, 10; \\ \sum_{i=A}^D x_{ij} &\leq 1 \quad \text{for } j = 6. \end{aligned}$$

Taking the number of workstations available in the department into consideration (i.e., 6), the “Monday through Friday” space constraints could never be violated. The second inequality considers the case where only one medical transcriptionist works on Saturday.

3. Work load constraints

$$2 * w \left[\sum_{i=A}^D x_{ij} \right] \geq \text{med}_j \quad \text{for } j = I, \dots, V,$$

$$2 * w \left[\sum_{i=A}^D x_{i6} \right] + w \left[\sum_{j=11}^{12} x_{Gj} \right] \geq \text{med}_{VI},$$

$$(w + 5) \left[\sum_{i=E}^F x_{ij} \right] \geq \text{cmgr}_j \quad \text{for } j = 1, \dots, 10.$$

In this case, we assume that work is performed according to the “deadline hypothesis” which specifies that a dictation is transcribed just before its deadline. The deadline hypothesis provides the specification necessary to assign jobs to certain work periods. Here, med_j (for $j = I, \dots, V$) and cmgr_j (for $j = 1, \dots, 10$) represent the Monday–Friday workload quota for medical and case manager transcriptionists, respectively, derived from system data using the deadline hypothesis. On Saturdays, a single medical transcriptionist and the on-call transcriptionist have a work load quota to meet as well, denoted by med_{VI} . The minutes of dictation that can be transcribed by a transcriptionist every four hours is denoted by w . According to efficiency data supplied by the medical record administrator who derived the information from the dictation log, in bulk average 30 minutes of dictation can be transcribed every 4 hours [10]. Therefore $w = 30$ (minutes). Hence, the coefficient $(w + 5)$ indicates that case manager transcriptionists transcribes 35 minutes of dictation every 4 hours.

4. Non-negative and binary constraints

Since we are viewing our x_{ij} binary variable as a “decision” whether to employ transcriptionist i during work period j , $x_{ij} \geq 0$; x_{ij} must be an integer, in fact, either 0 or 1 for all $i = A, \dots, G$ and $j = 1, \dots, 10$ or $j = I, \dots, VI$.

3.1. Findings/discussions

We constructed seven models using six monthly workload data sets and one six-month average workload data set and found that in most cases, the linear programs were infeasible. This was due to the fact that for each month the workload resulted in more than the available work time for particular days. That is, using the notion of workload constraints, the workload med_j or cmgr_j derived from the data exceeded the amount of available worker time in at least one of the work load constraints. For five of the six monthly workload linear programming models a different workload constraint was violated, for two of the models there was too much medical dictation to be transcribed over the course of a week. For more details, see [10]. This variety of infeasibilities indicates

a variability in the data which works against deterministic modeling.

The six-month average workload model was feasible. The subsequent integer linear programming formulation produced solutions that agreed with the actual scheduling practice. This agreement showed that the MR & WP Department was operating near optimal staffing pattern. With this result establishing confidence in the model, the linear programming model was used to provide foresight on managerial decisions about staffing or workload. While an infeasible linear program may not result in a final answer, post-optimality analysis from the feasible model can provide insight on the constraints facing the MR & WP Department.

For our particular model, the sensitivity of the objective function coefficients was not helpful since the coefficients are either 1’s or 0.5 representing a full work day or half a work day. These coefficients are definite – not parameters estimated from data that are subject to change. The sensitivity of the optimal staffing pattern to the staffing resources available, that is, the right-hand sides for the constraints, was of interest though. To measure the effect of an increase in a right-hand side of a constraint, *shadow prices* were computed. For our model, the shadow prices indirectly or directly answer the questions:

1. What would be the benefit of allowing transcriptionists to work overtime?
2. What would be the benefit of constructing another transcriptionist work station?
3. What would be the effect of an increase in the weekly workload?

Using LINDO [11] software, sensitivity analysis for the feasible integer program was computed. The shadow prices for all 35 functional constraints were zero, implying that the optimal staffing of $z = 29.5$ work days is the lowest that the MR & WP Department can employ and still complete the required dictation work load. Note that maximum staffing is 30.5 work days per week. Management tactics such as allowing overtime or constructing a new transcriptionist work station would have no effect on the optimal staffing pattern for system dictation.

At the optimal solution, almost all of the work load constraints resulted in “slack” between the left-hand sides and the right-hand sides of the constraints (thus resulting in the zero shadow prices). This “slack” represents time that a transcriptionist is working on non-system dictation. By adding up all the slack times from the work load constraints, it was determined that about 4.67 transcriptionist-work days is available per week to do these other tasks. If 4.67 transcriptionist-work days is not sufficient to perform these duties, another transcriptionist work period must be employed.

Even though the aggregate LP model showed that the MR & WP Department should be able to meet its workload with available resources, the infeasibility of the individual months’ models showed the importance of considering stochastic variability before making any final recommendations. See [10] for further discussions and results.

4. Simulation

As an alternative to mathematically modeling the system, and to incorporate variability and uncertainty, we used computer simulation. The main aim of our simulation was to determine the effect of a change in worker schedule on the number and timeliness of job completions. In our case, we used the Arena [6] simulation software package.

4.1. Model development

The aim of our model was to simulate the number of jobs which arrive and are either completed or accumulated on the queue over a month. We were also interested in the amount of time that a job would take for completion. We could run the model with a variety of worker schedules to see the effects on the job completion. Since a month is the usual performance reporting period of the MR & WP Department, this model simulates the reports that would be turned in for a typical period.

In our model, dictation jobs arrive from 7:30 AM in the morning to 7:30 PM in the evening [3]. Hence, the run length of our model is 720 minutes per day. With a time horizon of 28 days, the total run length of the model is 20160 minutes. Even though no existing named probability distribution functions represent all our data sets, Expertfit plots a histogram for the data and converts it into an empirical continuous probability distribution. On top of that, the Expertfit software package has the capability of converting this information into a format that is accepted by Arena, see [7]. We ran the model for 30 replications. By using classical confidence intervals across replications for the average time each priority job type stays in the system, we obtained the output of our model as a confidence interval for the average length of time a job took to be completed and the average number of jobs completed in one reporting period.

4.2. Model analysis

We tested the model to determine if the time in the system for each priority type of job would change when the 7-hour shift transcriptionists were upgraded to 8-hour shift workers. Four cases were considered. They were:

1. We simulated the model with the assumption that both 7-hour shift transcriptionists work eight hour shifts from Tuesday to Saturday.
2. We considered the case where both 7-hour shift transcriptionists work eight hour shifts but one of them works from Monday to Friday while the other works from Tuesday to Saturday.
3. We also tested the model with both 7-hour shift transcriptionists working eight hour shifts from Monday to Friday.
4. In the last case, we changed the work schedule of only one of the 7-hour shift transcriptionists from seven hours to eight hours and assumed that the transcriptionist works from Monday to Friday.

Table 4

95% confidence intervals of average time in the system in minutes, for each type of job priority under various worker schedules.

| Priority type | Status quo | Case 1 | Case 2 | Case 3 | Case 4 |
|---------------|------------|-----------|-----------|-----------|-----------|
| 1 | 441 ± 9 | 469 ± 9 | 458 ± 9 | 430 ± 10 | 438 ± 10 |
| 2 | 1130 ± 15 | 1150 ± 20 | 1160 ± 20 | 1105 ± 15 | 1110 ± 15 |
| 3 | 5050 ± 50 | 5170 ± 50 | 4950 ± 50 | 4790 ± 50 | 4870 ± 50 |

4.3. Findings/discussion

Refer to table 4 for the results. From the results obtained in case 1, we deduced that a Tuesday to Saturday work schedule did not improve the overall performance of the department, even when both case manager transcriptionists work an extra hour each day. This agrees with the results found in section 5. Since more work is anticipated in the Monday to Friday work week rather than the weekends, reducing the number of workers during the weekday will affect job waiting time in the system. Cases 2 and 3 consider 8 hour schedules for both case manager transcriptionists. The significant reduction in the average time in the system for case 3 as compared to case 2 suggest that a Monday to Friday schedule is more viable than a Tuesday to Saturday schedule. This agrees with our observation in case 1. Cases 3 and 4 look at the situation where the case manager transcriptionists retain their Monday to Friday work schedule. In both cases, the average time in the system was found to be less than the time for the original resource schedule. See [3] for further discussions and results. Besides a data summary, one can also obtain output distributions from the simulation. This information can then be used to address other relevant questions. For example, the administrator may be interested to find out the proportion of jobs that take longer than 24, 48, and 72 hours, for various priorities.

5. Forecasting

One of our objectives was to predict the workload of the department so that more efficient scheduling could be carried out. In addition, we wanted to be able to deduce when to hire more transcriptionists, if required, before work accumulated. Changing resources without anticipating the change of workload may be an acceptable trial and error approach, however, this approach can be costly and may even be an unpleasant experience for those involved. To find the best forecasting model, we conducted model comparisons among several forecasting methods. The different forecasting methods compared were ARIMA and Simple Exponential Smoothing with additive or multiplicative adjustment [9]. We used the *Statgraphics* software package [8] to perform the model comparison. Three criteria were used to check for forecast accuracy. They were the following:

1. The residual is the difference between the fitted value and the observed value. If the model is appropriate, then the autocorrelations of the residuals should not differ significantly from 0. In *Statgraphics*, the Box–Pierce test is based on the sum of squares for the first 24 autocorrela-

tion coefficients. If the p -value is greater than 0.1, then we do not reject the forecast model.

2. The forecasting method that produces the lowest mean square error is favored.
3. The last week of data was ‘held back’ as a validation period so that we could compare it to the forecast obtained using candidate forecasting methods. The forecast that has the smallest mean square deviation during the validation period is preferred.

We extracted information about the number of dictation jobs and the total length of dictations in minutes for each priority type. A program was written to extract this information from the dictation log using the Perl [12] software package. Since there are 3 priority job types of dictation and models for the number and length of jobs, this gave us six models altogether. In all models, ARIMA [9] was found to be most favorable. The general form of a multiplicative seasonal autoregressive integrated moving average model of order $(p, d, q) \times (P, D, Q)_s$ is

$$\Phi_p(B)\Lambda_P(B^s)\nabla^d\nabla_s^D x_t = \Theta_q(B)\Gamma_Q(B^s)a_t,$$

where x_t and a_t represent the data and the white noise process, respectively, and ∇ and B are the difference and backward shift operators, respectively, and $\Theta_q(B)$ and $\Gamma_Q(B^s)$ are polynomial combinations of these operators [9].

Once the forecasting models were constructed, we tested each model. The six multiplicative seasonal autoregressive integrated moving average forecasting models are:

1. *Daily number of arrivals for priority 1 jobs is*

$$\begin{aligned} \nabla^1 \nabla_7^1 x_t &= \Theta_1(B)\Gamma_2(B^7)a_t, \\ (1-B)(1-B^7)x_t &= (1+0.976B) \\ &\quad \times (1-1.064B^7-0.102B^{14})a_t. \end{aligned}$$

2. *Total length of time for priority 1 jobs is*

$$\begin{aligned} \nabla_7^1 x_t &= \Theta_2(B)\Gamma_1(B^7)a_t + b, \\ (1-B^7)x_t &= (1+0.273B+0.106B^2) \\ &\quad \times (1-0.961B^7)a_t + 0.204. \end{aligned}$$

3. *Daily number of arrivals for priority 2 jobs is*

$$\begin{aligned} \nabla_7^1 x_t &= \Theta_1(B)\Gamma_1(B^7)a_t, \\ (1-B^7)x_t &= (1+0.082B)(1-0.970B^7)a_t. \end{aligned}$$

4. *Total length of time for priority 2 jobs is*

$$\begin{aligned} \nabla_7^1 x_t &= \Gamma_1(B^7)a_t, \\ (1-B^7)x_t &= (1-0.970B^7)a_t. \end{aligned}$$

5. *Daily number of arrivals for priority 3 jobs is*

$$\begin{aligned} \nabla_7 x_t &= \Theta_1(B)\Gamma_1(B^7)a_t, \\ (1-B^7)x_t &= (1-0.105B)(1-0.907B^7)a_t. \end{aligned}$$

6. *Total length of time for priority 3 jobs is*

$$\begin{aligned} \nabla_7^1 x_t &= \Gamma_2(B^7)a_t, \\ (1-B^7)x_t &= (1-0.868B^7-0.099B^{14})a_t. \end{aligned}$$

For each model, we compared a one week look-ahead forecast, calculated using the respective forecasting models for each data set, with the observed data value. Results showed that for all six models, the actual value in the test week fell close to the forecast and well within the prediction interval. See [3] for further discussion. Figure 2 shows the length of dictations (in minutes), a one-step look ahead forecast and residuals of priority 1 jobs using $ARIMA(0, 0, 2) \times (0, 1, 1)_7$ with constant. This is the forecasting model for the *total length of time for priority 1 jobs*.

It shows that for instance the workload on a Monday is related to the workload on the previous Monday, together with ‘‘random shocks’’ experienced on the previous two Mondays. This is indicated by the letter ‘‘m’’ on the figure. The forecasting model ‘‘smooths out’’ the random variation. The forecasting model also shows that daily workload has a fairly consistent pattern, for example larger number of priority 1 jobs occur during the early part of the week. This finding confirms the conclusion from simulation that it is better to provide more staffing on Mondays.

6. Conclusion

The medical records and medical transcription department of a modern hospital is fruitful ground for simulation modeling because quantitative information is readily available and plentiful. The volume of information made mathematical modeling, forecasting and analysis possible and successful. On the other hand, although it is possible to formulate the models and conceive the framework mathematically, the mathematical models themselves are usually not tractable with elementary closed form solutions. In the present study, the models did not satisfy standard simplifying assumptions, so that we needed computer methods, including simulation. However, readily available software was well-adapted to the models, simulations and methods required.

It is possible to forecast the daily workload of the MR & WP Department both for the number of jobs and the total length of jobs using standard forecasting software and readily available data. The forecasting models revealed considerable weekly ‘‘seasonality’’ which was expected, but had not previously been quantified.

The data collection process and the subsequent integer linear programming formulation produced optimal scheduling solutions that agreed with the real-world scheduling practice. This agreement showed that the MR & WP Department is currently operating near a minimal staffing pattern. This was important managerial information which influenced subsequent staffing decision making.

We constructed the integer linear programming model to be fairly general. The integer programming analysis showed

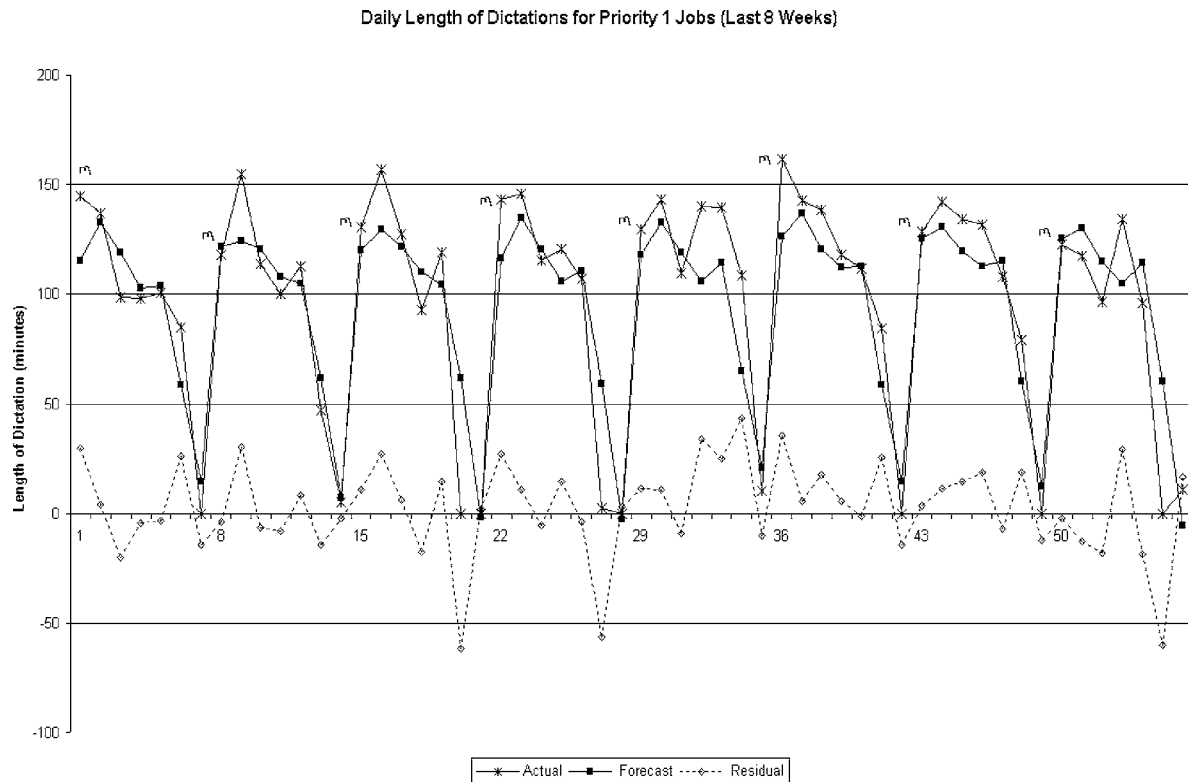


Figure 2. Historical data, a one-step look ahead forecast and residual for the last eight weeks of the daily length of dictations (in minutes) for priority 1 jobs.

that the department was operating near capacity and quantified the amounts by which additional workload or new workstation investment would affect the staffing. For example, the effect of adding an extra physician on transcription workload could be projected. Therefore the models have utility beyond the immediate modeling process. With good confidence, the linear program can provide foresight (via simulation) on managerial decisions that affect the MR & WP Department.

It is possible to easily forecast the daily activity of the MR & WP Department both for the number of jobs and the total length of jobs using standard forecasting software and readily available data. The simulation model was constructed to be quite general. With good confidence, the simulation model can provide foresight on managerial decisions that affect the MR & WP Department. The simulation results in statistical data which has important consequences for future staffing decision making. For example, having all transcriptionists work on an 8-hour Monday through Friday schedule results in a significant reduction in the average time that a transcription job spends in the system.

The various types of analysis used in the study can complement and supplement each other. For example, forecasting the total length of jobs for each day of the week can be used as the work load quota of the integer programming model work load constraints. Then the staffing for each week can be projected and adjusted using the combination of the two methods. The simulation models provide insights on the dynamics of workload accumulation in the department that are not readily made available from the static in-

teger programming models and forecasting models. Together the combination of all methods provides insights on the department which are valuable for management decision making.

The present mathematical and simulation models could benefit from additional study and fewer simplifying assumptions. The present study was done in a cooperative arrangement between a local hospital and university, so it is possible to continue the study and simulations with additional student work, resulting in benefits to both the hospital management and the students.

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