Modeling and prediction of surgical procedure times

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Abstract

Accurate prediction of medical operation times is of crucial importance for cost efficient operation room planning in hospitals. This paper investigates the possible dependence of procedure times on surgeon factors like age, experience, gender, and team composition. The effect of these factors is estimated for over 30 different types of medical operations in two hospitals, by means of ANOVA models for logarithmic case durations. The estimation data set contains about 30,000 observations from 2005 till 2008. The relevance of surgeon factors depends on the type of operation. The factors found most often to be significant are team composition, experience, and daytime. Contrary to widespread opinions among surgeons, gender has nearly never a significant effect. By incorporating surgeon factors, the accuracy of out-of-sample prediction of case durations of about 1,250 surgical operations in 2009 is improved by up to more than 15 percent as compared to current planning procedures.

Keywords and phrases

Operation room, surgeon factors, lognormal distribution, ANOVA model, planning, European hospital, health care management, current procedure terminology (CPT)

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1 Introduction

Operating rooms (OR's) are among the most expensive surgical resources in hospitals (Vissers and Beech, 2005). In an era of cost-constrained health care, efficiency increases if a larger number of surgical operations can be performed within the available OR time (Stepaniak et al, 2009b). The OR management of medical institutions needs to balance the costs of reserving too much time, with resulting idle time of the OR, against the costs of reserving too little time. In the last case, the OR schedule must be modified, resulting in an increased demand for anesthesiologists, nurses, and support staff. Therefore, accurate prediction of case durations helps in effective OR scheduling, it reduces waiting times for patients and idle times of medical and other staff, and thereby it improves the quality of health care delivered in other services throughout the hospital.

Surgical procedure times are inherently unpredictable, and the amount of uncertainty varies greatly among different types of operations. Hospitals employ standard classifications of operations, in terms of so-called current procedure terminologies (CPT's). Apart from the CPT, surgeon factors are the primary source of variation in case durations, as shown in Strum et al (2000a, 2000b).

The purpose of this paper is to quantify the effect of surgeon factors on case durations and to exploit these factors to improve case duration predictions. The empirical analysis is based on extensive data bases of surgical operations in two teaching hospitals in The Netherlands. The OR management in these two hospitals often receives arguments brought forward by surgeons, anesthetists, and OR staff, as to why surgical cases should be planned shorter or longer than usual due to a range of factors. The factors mentioned most frequently to slow down procedure times are the following: composition of the surgical team (presence of residents, that is, physicians receiving specialized clinical training), lack of experience (low recent work rate for this CPT), gender (female surgeons would be more precise and more careful, and hence slower), age (younger surgeons are less experienced), and time of the day (fatigue in the afternoon). Some of these factors have been analyzed before for hospitals in the US, for instance, in Strum et al (2000b). As labor regulations and working habits are quite different in Europe, it is of interest to study the effect of these factors within a European setting.

The main results are the following. For several CPT's, some of the factors contribute significantly (at the 1% significance level) to operation times. This holds true most notably for relatively complex surgical operations, for instance, those involving endoscopic and laparoscopic procedures. Team composition, work rate, and daytime are the most commonly relevant factors. Age matters only for two CPT's, and gender for none of the CPT's (and at the 5% significance level only for a single CPT, cataract in hospital A, where female surgeons work faster than their male colleagues). The practical relevance of these factors is demonstrated by improved out-of-sample prediction of case durations for 2009. As compared to current OR planning procedures, which are based on the last ten cases of each CPT, the accuracy is improved by 10-15%. Even if the more advanced three-parameter lognormal model for case durations is taken as benchmark, incorporation of significant surgeon factors leads to improvements of the same order of magnitude.

The paper has the following structure. Section 2 presents the data, and Section 3 discusses the statistical model for case durations. The results in terms of relevant factors and the gains in predictive accuracy are described in Section 4, and Section 5 concludes.

2 Data

2.1 Surgical procedure times

The data are obtained from surgical databases of two large teaching hospitals in The Netherlands, covering about 100,000 operations in the period from January 2005 till August 2009. The data from 2005 till 2008 are used in estimation, leaving out the data of 2009 for predictive evaluation purposes. The two hospitals, that will be labeled as A and B, differ in several aspects, such as covered specializations, organizational structure, OR protocols, OR logistics, and intensity of teaching. Therefore, the two hospitals will be analyzed separately, but with similar methods.

For each operation, the database contains information on the type of operation (the CPT-anesthesia combination), on the procedure and surgical times, and on several surgeon factors (as will be discussed in the next subsection). The procedure time is defined as the time passing from entry into the operating suite until leaving the OR, This includes the surgical time, that is, the time passing from incision to closure of the wound. The attention will be focused on procedure times, as these are the relevant durations for OR planning. These times will also be denoted as surgical procedure times, indicating that these times include the surgical operation itself as well as the required OR procedures preceding and following the operation.

For the period 2005 till 2008, the database of hospital A contains over 44,000 cases for nearly 1,200 CPT-anesthesia combinations, with total OR time of about 50,000 hours. For various reasons, the actually employed dataset is much smaller and contains 17,516 cases for 29 CPT-anesthesia combinations and a total OR time of about 20,000 hours. The main reason for this data reduction is that CPT's are excluded if they occur relatively infrequently or if they are always performed under similar circumstances. More precisely, in order to be included in the analysis, a CPT-anesthesia combination should exhibit sufficient variation in surgeon factors to allow for an analysis of the effect of these factors. Therefore, for every CPT-anesthesia combination, the imposed minimal requirements are at least 150 cases in total and at least 25 cases for every surgeon involved. Further, about 15% of the cases consist of composite operations involving multiple CPT's. These operations are excluded to avoid possible confounding factors, following Strum et al (2000a). Composite operations do not only occur rather infrequently in a fixed composition, but other factors such as the order of the operations may also affect the composite case durations. Minor other reasons for exclusion are operations with incomplete data (less than 1%), and special operations like donor procedures and operations not started or not completed (less than 0.1%).

A similar data selection strategy is followed for hospital B. This database contains about 42,000 cases for about 1,000 CPT-anesthesia combinations, with total OR time of about 45,000 hours. The actually employed dataset, after applying the selection strategy discussed before, contains 12,030 cases for 25 CPT-anesthesia combinations and a total OR time of about 16,000 hours.

The total number of included CPT-anesthesia combinations in hospitals A and B is 32, with 22 common ones for hospitals A and B, 7 for hospital A alone, and 3 for hospital B alone. Table 1 shows the included CPT's and contains information on the procedure times. The last four columns show the total number of surgeons and residents involved in each CPT, as well as the number of cases performed in the morning and in the afternoon.

<< Table 1 to be included around here >>

2.2 Surgical factors

The literature review of Dexter et al (2008) identifies 48 papers reporting significant factors affecting the perioperative time, that is, the total time required for a patient's surgical procedure, including ward admission, anesthesia, surgery, and recovery. There are multiple reports of the effects on OR times of operative procedures, perioperative team composition including primary surgeon, type of anesthetic, and patient characteristics, in this sequence of importance. Strum et al (2000a, 2000b) mention surgeon factors as the single most important source of variability in surgical procedure times. Other, secondary sources of variability mentioned in their study are the type of anesthesia, age and gender of the patient, and American Society of Anesthesiologists risk class. The age of the surgeon is mentioned in Van Houdenhoven (2007).

As described in the Introduction, several of these surgeon factors were also brought forward by surgeons, anesthetists, and OR managers in hospitals A and B. In total, the following five factors will be taken into account.

Gender

A popular belief is that female surgeons are more precise and more careful in performing operations, resulting in longer case durations. The gender of the surgeon is indicated by the dummy variable 'Female' (with value 1 for females and 0 for males). For the CPT's of Table 1, the total numbers of female and male surgeons in hospital A are respectively 7 and 23, and in hospital B these numbers are respectively 7 and 18.

Age

In general, older surgeons are more experienced and they may therefore work more efficiently. This effect is mentioned, for instance, in Van Houdenhoven (2007). It could also be that surgeons work fastest in the middle period of their career, as older surgeons may become tired more quickly. However, because of the limited number of surgeons, a distinction in two age categories is preferred. The age of surgeons who are active in hospitals A and B ranges between 30 and 60 years. The two age groups are indicated by the dummy variable ‘Age’, with value 1 if 45 or above and 0 if younger than 45. For the CPT’s of Table 1, the total numbers of surgeons above and below 45 years of age are respectively 14 and 16 in hospital A, and in hospital B these numbers are respectively 13 and 12. For a team of surgeons performing an operation, the age is defined as the age of the oldest surgeon in the team.

Workrate

For a given CPT and surgeon, the work rate is related to the number of similar operations that this surgeon has performed in the recent past. A higher work rate means that the surgeon is more experienced in this kind of operation and that case durations may become shorter (Strum et al, 2000a). Again, because of the limited number of surgeons, a distinction in two classes of work rate is preferred. The work rate is defined to be high if the surgeon performed a similar CPT at most three weeks ago, and it is defined to be low if this was more than three weeks ago. This rate is indicated by the dummy variable ‘Work rate’, with value 1 for a high rate and 0 for a low rate. For the CPT’s of Table 1, the percentage of operations with a high work rate is 81 for hospital A and 84 for hospital B. For a team of surgeons performing an operation, the work rate is defined as work rate of the leading surgeon of the team.

Team

For all procedures of Table 1, the OR surgeon team always consists of a surgeon who is assisted by at least one other surgeon or a resident. Residents are surgeons who receive specialized clinical training in the hospital. It is common belief that the presence of a resident has an increasing effect on case durations, because the resident receives on the job training during the operation. The team composition is indicated by the dummy variable 'Team', with value 1 if the team consists of surgeons only and 0 if a resident is part of the team.

Daytime

Some people work better in the morning, others in the afternoon, in the evening, or at night. A recent study (Tamm et al, 2009) shows differences in brain excitability, that is, people who say that they feel best during a certain part of the day tend to have a brain that is most easily excitable during that part of the day. As an operation is a team effort of the involved surgeons and assisting staff, it is not easy to combine the daytime effect for each individual in a joint team effect. Still, it is of interest to know whether the time of the day has an effect on case durations. The time of an operation is indicated by the dummy variable 'Daytime", with value 1 for the afternoon (operations starting at 12.00 PM or later) and 0 for the morning (operations starting before 12.00 PM). It might be that case durations are longer in the evening and at night, due to less availability of surgeons and staff. However, such operations are very rare in the two hospitals under consideration, and there is insufficient information to test for separate evening and night effects. Therefore, operations taking place during the evening or at night are excluded due to insufficient data.

3 Model for surgical procedure durations

3.1 Distribution of case durations

The literature on surgical procedure times deals nearly exclusively with the situation in the US. Early results report a lognormal distribution for OR waiting times (Rossiter and Reynolds, 1963) and a normal (Barnoon and Wolfe, 1968) or lognormal (Hancock et al, 1988) distribution for OR case durations. Insight in the distribution of case durations has advanced markedly in the past decade (Strum et al, 2000a, 2000b, 2003, May et al, 2000, Spangler et al, 2004). The empirical study of Strum et al (2000a) indicates a lognormal distribution of surgical procedure times. Strum et al (2003) consider composite operations consisting of two different surgical procedures and conclude that the lognormal distribution fits such case durations better than the normal distribution.

As surgical procedures require a positive start-up time, the shifted lognormal distribution (also called the three-parameter lognormal, written as 3-logN) is used in Strum et al (2000a) and, within an European context, in Stepaniak et al (2009a). For the far majority of CPT's, this distribution provides a better fit than the normal and lognormal distributions. Let the procedure time (in minutes) of a given CPT be denoted by T, then the 3-logN distribution for can be written as

$$\log(T - \alpha) = \beta + \varepsilon \text{ , } \varepsilon \sim N(0, \sigma^2).$$

Here $\alpha > 0$ is the shift parameter, and ε denotes an unobserved random error term causing unpredictable variation. Stated otherwise, after shifting by α, the logarithmic procedure times are normally distributed with mean β and standard deviation σ. The procedure time is always larger than α, and the median is equal to $\alpha + \exp(\beta)$.

The effect of surgeon factors on case durations is modeled by replacing β in the above model by parameters depending on the factors, similar to what is done in analysis of variance (ANOVA) models. If all five factors discussed in Section 2.2 are included, the model becomes

$$\log(T - \alpha) = \beta_{PT} + \varepsilon \text{ , } \varepsilon \sim N(0, \sigma^2),$$

$$\beta_{PT} = \beta_0 + \beta_1 \times \text{Gender} + \beta_2 \times \text{Age} + \beta_3 \times \text{Workrate} + \beta_4 \times \text{Team} + \beta_5 \times \text{Daytime}.$$

We call this the ANOVA model. This model is estimated for each CPT and each hospital separately, allowing for different surgeon factor effects according to the hospital and the type of surgical procedure. Although it may be possible to cluster some of the CPT's in Table 1 in groups with identical parameters, this will not be pursued here, because the OR planning system is based on individual CPT's. For a given CPT and hospital, the error terms associated with all corresponding case durations in the database are assumed to be independent and identically distributed.

The various hypotheses on surgeon factors discussed in Section 2.2 can be expressed in terms of the following hypotheses on the parameters of the above model:

$$\beta_1 > 0 \;,\; \beta_2 < 0,\; \beta_3 < 0 \;,\; \beta_4 < 0 \;.$$

Further, it is expected that surgeon factors become more important as the complexity of surgical procedures increases. A procedure is complex if it requires highly trained OR staff performing very specific operational procedures and if the risk of perioperative complications is larger than what is usual for routine procedures.

3.2 Estimation and prediction

For each CPT of Table 1, the ANOVA model for procedure times is estimated for both hospitals separately, using data from the period 2005-2008. Factors that do not vary are removed from the model. For instance, if all surgeons for a CPT are male, then the effect of gender can not be estimated for this CPT. To start, all factors that do vary for the CPT are included in the model. Next, backward elimination is used for stepwise removal of insignificant factors. In the end, if all remaining factors are significant, each of the other factors is tested once more for significance when added to the other factors. In addition, the significance of interaction effects between the factors is tested (as none of these interactions is significant, these results will not be reported). All tests employ the same significance level, which is 10%, 5%, or 1%.

To evaluate the practical relevance of the identified significant surgeon factors, the models that are estimated with data for 2005-2008 are used to predict the case durations in the period from January till August 2009. The prediction model is kept fixed, even though the parameters could be re-estimated after each relevant CPT operation in 2009. This choice conforms to practical planning constraints, which demand that models are kept fixed, for instance, for periods of twelve months. The forecast study is restricted to the CPT's for which at least one factor is significant at the 1% significance level.

Three prediction methods are compared. The first is the method that is currently employed in the OR management of both hospitals. The predicted time is simply the average of the ten most recent durations of this CPT. The second method predicts the procedure time to be the median of the 3-logN distribution (without factors), that is, $\alpha + \exp(\beta)$. The third method predicts the case duration to be equal to the median of the ANOVA model, that is, $\alpha + \exp(\beta_0 + \sum_j \beta_j F_j)$, including only those factors F_j for which the estimate of β_j is significant (at the 1% level). Predicted case durations are compared with the actual procedure times, and the accuracy is evaluated in terms of absolute prediction errors (in minutes). The significance of the difference in mean absolute errors of two methods is tested by the paired t- test.

4 Results

4.1 Surgeon factors

For each hospital and CPT, the significant surgeon factors are obtained by the backward selection strategy described in Section 3.2. The results are summarized in Table 2, which shows how often each factor is found to be significant for significance levels of 10%, 5%, and 1%. For instance, in hospital A, the effect of the factor 'Gender' can be analyzed for 22 CPT's, as for the other 7 CPT's the gender does not vary among the surgeons. The gender effect is significant (and negative) for 3 CPT's at the 10% level (with a median effect of -1.8%), for 1 CPT at the 5% level (with a median effect of -8.2%), and never at the 1% level. In hospital B, gender is never found to be significant, not even at the 10% level. This means that there is no support whatsoever for the commonly expressed opinion that female surgeons would work slower. The gender effect is very weak, and at most it indicates faster work of female surgeons.

Age effects are found to be often significant at the 5% level, mostly with faster work of older surgeons, but the effect is significant at the 1% level only for two CPT's (with a time reduction of about 10% for older surgeons). Work rate effects are significant in several cases, with varying sign at levels of 10% and 5%, but with a consistent time saving effect at the 1% level (of about 5%) for high work rates. The team composition is significant in many cases, and in the far majority of cases the presence of a resident in the team causes longer procedure times (of about 15%, at the 1% level). Daytime effects are significant in many cases, mostly with slower work in the afternoon.

<< Table 2 to be included around here >>

Table 3 shows the estimated surgeon factor effects for each CPT separately, 29 for hospital A and 25 for hospital B. The effects are shown only if they are significant at the 10% level. The number of significant factors varies among CPT's. For each of the 22 CPT's that are performed at both hospitals, the sign and size of the effects are often quite the same in both hospitals, even though the effects of some factors cannot be estimated at both hospitals, that is, if the factor does not vary for the CPT under consideration. For instance, for the CPT ablatio mamma, the age affect in hospitals A and B is respectively -1.9% and -3.5%, the team effect is -12.9% and -12.5%, the daytime effect is 8.6% and 7.4%, and the work rate effect is significant only for hospital A (at the 5% level) and not for hospital B (at the 10% level).

Age and Daytime are the factors found most often to be significant. Work rate and team composition are also significant in many cases, and the largest percentage effects are found for these two factors. Gender is nearly never of any importance. The only significant gender effect at the 5% level is for cataract in hospital A, where female surgeons work 8% faster than male surgeons. The CPT's that have at least two significant factors at the 1% level correspond to relatively complicated surgical procedures requiring special skills: ablatio mamma, open appendectomy, endoscopic appendectomy, endoscopic total prostatectomy, laparoscopic cholestectomy, and laparoscopic sterilization. For many of these complicated procedures, the work rate and team composition effects on procedure times are considerable, up to 20%. As compared to less demanding CPT's, complex procedures require more time both for on the job training of residents and for activating specialized skills if the surgeon did not practice these skills within the preceding three weeks.

<< Table 3 to be included around here >>

Summarizing, the largest effects are obtained for work rate and team composition for complicated CPT's. In most cases (and at the 1% level always), procedure times are relatively shorter for older surgeons, for a high work rate, and for teams without resident. Gender has hardly any effect. In most cases, procedure times are shorter in the morning than in the afternoon, but for some CPT's this effect is reversed.

The mixed daytime effect can be due to the fact that this effect is measured jointly for the full OR team involved in the operation and without information on the time preference of the members of the team. A small-scale study was performed to investigate this further. Ten surgeons of hospital A and also ten surgeons of hospital B were asked whether they have any preference for performing operations in the morning or in the afternoon. Of these 20 surgeons, 9 prefer the morning, 10 the afternoon, and one surgeon has no preference. In total, the 19 surgeons with a preference are active in 64 CPT's. For each surgeon and CPT, the average case duration in the morning is compared with that in the afternoon. Of the 64 surgeon-CPT combinations, the fastest work was delivered in 48 cases in the preferred daytime and in 16 cases in the non-preferred daytime. This effect of preferred daytime on case durations is significant (the p-value according to the binomial distribution with a success probability of 50% is smaller than 0.01%). For hospital A (B), the fastest work was delivered in 23 (25) cases in the preferred daytime and in 7 (9) cases in the non-preferred daytime, corresponding to a p-value for the absence of daytime effects of less than 1% in both cases.

As daytime preferences are not known for many of the surgeons involved in the CPT's of Table 1, this factor could not be incorporated in the analysis of surgeon factor effects in Tables 2 and 3. However, the small-scale study indicates that it may help to incorporate surgeon preferences in OR planning.

4.2 Prediction

In order to evaluate the practical usefulness of surgeon factors in predicting case durations, the attention is restricted to CPT's for which at least one surgeon factor is significant at the 1% level. This holds true for eight CPT's in hospital A and seven CPT's in hospital B, five of which occur at both hospitals. The ANOVA models, estimated with the data of 2005-2008 and with the estimated factor effects of Table 3 that are significant at the 1% level, are used to predict the procedure times for the period from January till August 2009. The total number of predicted case durations is 683 for hospital A and 575 for hospital B.

Table 4 summarizes the results of three prediction methods, that is, the current method (average of last ten cases), the three-parameter lognormal model without factors (3-logN), and the ANOVA model. The table shows the mean and standard deviation of the absolute prediction errors, that is, the differences between the predicted time and the actual case duration. The differences in mean absolute prediction errors of the three methods are evaluated both in absolute terms (in minutes) and in relative terms (as percentage of the median procedure time for each CPT over the prediction period).

As an illustration, Figure 1 shows the absolute prediction errors and the differences of these errors of the three prediction methods for the 71 endoscopic appendectomy operations that took place in hospital A between January and August 2009. The current method predicts the procedure time as the average of the last ten case durations of this CPT, and this estimate is updated after each operation in 2009. The 3-logN predictions are obtained from the ANOVA model without factors, estimated with data from 2005 till 2008 and with fixed parameters for 2009. Finally, the ANOVA predictions are also obtained from a model estimated with data from 2005 till 2008 and with fixed parameters for 2009. This model includes factors only if they are significant at the 1% level. Table 3 shows that the included factors are work rate (with coefficient -0.073) and team composition (with coefficient -0.137). Figure 1 shows that the smallest prediction errors are obtained for ANOVA, and that 3-logN is second-best. The predictions of ANOVA are better than the current method in 67 out of 71 cases, and they are better than 3-logN in 53 out of 71 cases. The differences in absolute forecast errors of the three methods are all significant (at the 5% level) when tested by the paired t-test.

<< Figure 1 to be included around here >>

Table 4 shows that, in all of the considered 15 CPT's in hospitals A and B, the 3-logN predictions are more accurate than the currently employed method. The same holds true for the ANOVA predictions, except for transurethral resection of the prostate in hospital A. As compared to the current method, the forecast improvements of 3-logN are up to 10%, and those of ANOVA are up to 18%. The ANOVA predictions are better than the 3-logN predictions in the far majority of cases (11 out of 15), with gains of up to 15%. For three CPT's in hospital B, 3-logN is slightly better than ANOVA (up to 2%), and for one CPT in hospital A, 3-logN is 6% better than ANOVA. The paired t-test finds that, for hospital A, ANOVA improves significantly on 3-logN (at the 5% level) for 7 out of 8 CPT's, and the reverse holds true for the remaining CPT. For hospital B, ANOVA is significantly better than 3-logN for 4 out of 7 CPT's, and the difference is not significant for the other 3 CPT's.

When averaged over the eight considered CPT's in hospital A, the gain in prediction accuracy is 5 minutes (5%) for 3-logN as compared to the current method, 10 minutes (11%) for ANOVA as compared to the current method, and 5 minutes (7%) for ANOVA as compared to 3-logN. For hospital B, the prediction gains are 4 minutes (4%) for 3-logN as compared to the current method, 8 minutes (8%) for ANOVA as compared to the current method, and 4 minutes (4%) for ANOVA as compared to 3-logN. On average, the standard deviation of the prediction errors is smallest for ANOVA (3.7 minutes in hospital A and 4.1 minutes in hospital B), as compared to 3-logN (4.7 in A and 4.5 in B) and the current method (5.9 in A and 5.2 in B). Although these differences are not large, reduction of uncertainty is important in OR planning. It is a nice finding that the improved prediction accuracy of ANOVA, which is based on more elaborate models involving surgeon factors, is combined with reduced forecast uncertainty. Stated otherwise, the smaller prediction bias of ANOVA comes without any cost of increased variance.

<< Table 4 to be included around here >>

5 Conclusion

Depending on the type of operation (CPT) and on the hospital, procedure times may depend on several surgeon factors. In particular, for complex operations, factors like relevant work rate experience of the surgeon and composition of the surgical team may have large effects. The effect of team composition goes up to 20%, and when combined with work rate, the total effect goes up to 30%. Other relevant factors are age of the surgeon and time of the day. Gender has nearly never any effect, and the only effect that is significant (at the 5% level) is found for cataract, where female surgeons work 8% faster than male surgeons. A predictive out-of-sample analysis for case durations in 2009 shows that surgeon factors help in predicting case durations. As compared to the methodology currently employed in both hospitals, mean absolute prediction errors are reduced by up to 18 minutes and up to 18% of the median procedure time.

The most significant gains are obtained for relatively complex CPT's, especially those involving endoscopic and laparoscopic procedures. As the complexity of surgical procedures shows an ever increasing trend, surgeon factors may become even more important in the future.

The practical implementation of (ANOVA or other) prediction models is done best after consultation of surgeons, OR management, and other staff involved in the operation room activities. As hospitals differ widely in aspects like surgical experience with different specializations, organizational structure, OR protocols and OR logistics, the effect of surgeon factors will differ among hospitals. Therefore, it may be best to estimate separate models for each hospital. The results of this paper show several differences between the two considered hospitals, although the type of effect is quite the same in many cases, especially for complex procedures.

The achieved improved forecast accuracy can be of great help for operation room planning. Reduction of case duration uncertainty will have positive benefits in terms of patient health care and human resource planning in hospitals.

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Table 1.A : Data of hospital A (2005-2008)

CPT	Cases (#)	Procedure time (minutes) Mean	Median	SD	Min	Max	Surgeons (#)	Residents (#)	AM (# cases)	PM (# cases)
Ablatio mamma	152	85	73	18,5	12	198	5	7	79	73
Acetabuloplastic	675	91	83	14	26	166	5	5	286	389
Appendectomy, open	462	73	63	24	32	240	7	12	201	261
Arcomion resection	774	69	62	13	19	199	5	0	388	386
Arthroscopic knee and surgery	722	43	40	15	18	163	5	0	293	429
Arthroscopic nettoyage of the knee	417	40	35	11	20	87	5	0	183	234
Arthroscopic total or partial menisectom	1,248	41	35	12	15	147	5	0	608	640
Bi/trimalleolar fracture	189	88	91	11	7	132	6	6	77	112
Cataract	3,219	28	35	8	12	86	3	0	1537	1,682
Diagnostic D & C / Hysteroscopy	426	44	40	21	3	108	5	0	198	228
Endoscopic appendectomy	154	98	88	21	48	172	7	6	59	95
Endoscopic total prostatectomy	294	237	189	39	55	383	3	3	150	144
Femur fracture	342	67	64	9	18	99	7	11	186	156
Genisis total knee	952	73	66	31	11	131	5	0	514	438
Hemicolectomy	152	182	188	17	83	426	5	5	67	85
Hernia inguinalis	764	71	62	20	31	155	7	12	340	424
HNP lumbale	613	74	64	20	40	219	3	0	251	362
Ileus surgery	167	99	94	15	43	177	4	3	109	58
Laminectomy lumbale	340	87	76	22	40	222	2	0	171	169
Laparoscopic cholestectomy	800	123	103	35	53	340	4	11	443	357
Laparoscopic sterilisation	182	61	48	16	5	94	5	5	71	111
Mammareduction both sides	431	102	89	34	55	227	4	0	198	233
Manual placenta removal	281	40	45	22	12	236	6	4	108	173
Scopic decompresion shoulder	401	45	40	9	11	37	5	0	179	222
Sectio caesarea	961	60	54	14	26	171	6	7	393	568
Total hip arthroplasty	1,221	98	84	25	15	332	5	0	577	644
Transurethral resection of the prostate	533	69	64	23	5	121	4	0	278	255
Ureterorenoscopy	212	78	71	35	20	221	3	0	89	123
Uterus extirpation	432	98	91	19	12	154	5	2	191	241
Total	17,516						30	19	8,223	9,293

Table 1.B : Data of hospital B (2005-2008)

CPT	Cases (#)	Procedure time (minutes) Mean	Median	SD	Min	Max	Surgeons (#)	Residents (#)	AM (# cases)	PM (# cases)
Ablatio mamma	687	82	78	21	13	201	8	6	358	329
Acetablluloplastic	804	97	89	17	38	169	5	5	194	610
Appendectomy, open	547	91	80	21	4	171	8	11	202	345
Arcomion resection	678	64	60	15	13	187	7	4	498	180
Arthroscopic knee and surgery	200	40	35	18	18	4	5	0	103	97
Arthroscopic nettoyage of the knee	214	37	35	12	35	17	5	0	120	94
Arthroscopic total or partial menisector	300	47	43	15	23	103	3	0	161	139
Bi/trimalleolar fracture	156	98	88	13	6	210	7	6	90	66
Cataract	1,541	26	25	10	32	70	4	0	639	902
Cholestectomy open	1,110	87	81	15	6	198	7	6	698	412
Colon resection	430	169	150	14	10	201	4	2	199	231
Diagnostic D & C / Hysteroscopy	688	47	44	18	5	101	4	0	310	378
Endoscopic appendectomy	269	89	78	17	15	163	6	5	127	142
Endoscopic total prostatectomy	301	243	171	31	9	375	3	0	125	176
Femur fracture	298	108	95	32	8	222	5	0	129	169
Hernia inguinalis	268	75	71	22	4	124	7	10	151	117
Ileus surgery	151	108	100	17	11	191	4	8	67	84
Laminectomy lumbale	294	86	80	19	20	125	2	7	139	155
Laparascopic cholestecomy	305	120	104	25	20	218	4	6	128	177
Mammareduction both sides	564	114	100	14	12	227	4	0	291	273
Manual placenta removal	405	51	45	26	9	117	6	4	233	172
Scopic decompresion shoulder	401	45	40	9	11	137	5	0	179	222
Small bowel resection	684	101	89	21	16	242	5	3	385	299
Transurethral resection of the prostate	414	64	61	25	14	162	3	0	221	193
Uterus extirpation	321	102	96	23	19	172	5	0	140	181
Total	12,030						25	12	5,884	6,146

Table 2 : Surgeon factor effects (number of CPT's with positive and negative effect, and median percentage effect on procedure time)

	Coding	CPT's	p < 0.1			p < 0.05			p < 0.01		
	(1 / 0)	(#)	+	-	Median	+	-	Median	+	-	Median
Hospital A											
Gender	1 = Female	22	0	3	-1.8	0	1	-8.2	0	0	-
Age	1 = Older	29	3	15	-3.9	2	11	-4.1	0	1	-8.7
Work rate	1 = High	23	5	4	3.5	3	4	-2.9	0	4	-5.3
Team	1 = No resident	15	0	11	-10.6	0	9	-13.7	0	7	-15.3
Daytime	1 = PM	29	16	6	3.0	12	2	4.7	1	1	-0.5
Hospital B											
Gender	1 = Female	18	0	0	-	0	0	-	0	0	-
Age	1 = Older	25	6	15	-4.3	3	14	-5.7	0	1	-9.9
Work rate	1 = High	17	1	4	-2.1	0	2	-7.3	0	2	-7.3
Team	1 = No resident	14	2	6	-7.3	1	5	-13.2	0	4	-14.1
Daytime	1 = PM	25	17	3	3.9	14	2	5.5	3	0	7.5

Table 3.A : Percentage effect of significant surgeon factors on procedure time (hospital A)
(shown only if significant at 10%; * and ** denote significance at 5% and at 1%)

CPT	Cases (#)	Gender (1 = Female)	Age (1 = Older)	Work rate (1 = Higher)	Team (1 = No res)	Daytime (1 = PM)
Ablatio mamma	152	-	-1.9	9.2*	-12.9**	8.6 **
Acetabuloplastic	675	-	-3.2*	-	-	-7.0*
Appendectomy, open	462	-0.7	-8.7 **	-	-10.6**	2.5*
Arcomion resection	774	-	-4.1*	-	-	5.0*
Arthroscopic knee and surgery	722	-	-2.9*	-	-	1.0
Arthroscopic nettoyage of the knee	417	-	-4.1*	-	-	-3.1
Arthroscopic total or partial menisectomy	1,248	-	-	-	-	6.2*
Bi/trimalleolar fracture	189	-	-	-	-8.6	4.1*
Cataract	3,219	-8.2*	-	-	-	-
Diagnostic D & C / Hysteroscopy	426	-	-2.5	-	-	-0.4
Endoscopic appendectomy	154	-	-3.9*	-7.3**	-13.7**	8.1*
Endoscopic total prostatectomy	294	-	-	-8.9**	-20.3**	8.5*
Femur fracture	342	-	-	6.1*	-4.1	3.4
Genisis total knee	952	-	-	-	-	3.6
Hemicolectomy	152	-	3.1	-	-4.3*	2.5*
Hernia inguinalis	764	-	-6.2*	-	-3.8*	2.4
HNP lumbale	613	-	-9.2*	-	-	4.4*
Ileus surgery	167	-	-	6.3	-	1.7*
Laminectomy lumbale	340	-	-	3.5	-	6.8*
Laparoscopic cholestectomy	800	-	-7.6*	-3.2**	-19.2**	-3.3
Laparoscopic sterilisation	182	-1.8	-8.5*	-2.9**	-15.3**	-
Mammareduction both sides	431	-	-3.8	-	-16.8**	-5.3
Manual placenta removal	281	-	-	-	-	5.4*
Scopic decompresion shoulder	401	-	5.4*	-	-	-
Sectio caesarea	961	-	4.3*	-	-	-
Total hip arthroplasty	1,221	-	-2.4*	-	-	-
Transurethral resection of the prostate	533	-	-	4.1*	-	-9.6**
Ureterorenoscopy	212	-	-	-	-	-
Uterus extirpation	432	-	-9.2	-	-	-
Total / Percentage of cases with factor = 1	17,516	21.0	48.2	81.2	14.9	53.1

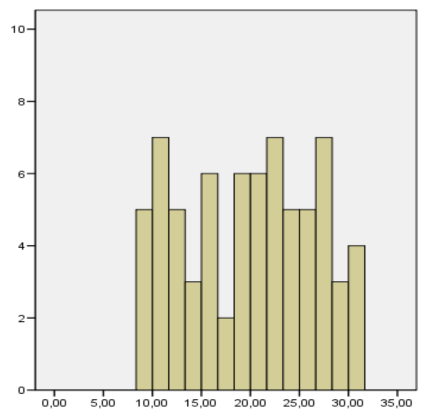
Table 3.B : Percentage effect of significant surgeon factors on procedure time (hospital B)
(shown only if significant at 10%; * and ** denote significance at 5% and at 1%)

CPT	Cases (#)	Gender (1 = Female)	Age (1 = Older)	Work rate (1 = Higher)	Team (1 = No res)	Daytime (1 = PM)
Ablatio mamma	687	-	-3.5*	-	-12.5**	7.4*
Acetabluloplastic	804	-	-5.4*	-	-	4.0*
Appendectomy, open	547	-	0.6	-	-	2.6**
Arcomion resection	678	-	-8.6*	-	-	6.0*
Arthroscopic knee and surgery	200	-	-6.5*	-	-	-
Arthroscopic nettoyage of the knee	214	-	-8.7*	-	-	7.1*
Arthroscopic total or partial menisectomy	300	-	-	-	-	1.3
Bi/trimalleolar fracture	156	-	-5.8*	-	1.2*	-
Cataract	1,541	-	6.5*	-	-	5.5*
Cholestectomy open	1,110	-	7.6*	-	-14.3**	-6.4*
Colon resection	430	-	4.8	-	-15.3**	3.80
Diagnostic D & C / Hysteroscopy	688	-	-8.5*	-	-	-4.6
Endoscopic appendectomy	269	-	5.6*	-5.8**	2.2	8.2**
Endoscopic total prostatectomy	301	-	-9.0*	-8.7**	-	8.3*
Femur fracture	298	-	-4.1*	-	-	-
Hernia inguinalis	268	-	-	-	-	2.2
Ileus surgery	151	-	2.1	-2.1	-	2.7
Laminectomy lumbale	294	-	-4.3*	-1.9	-	-
Laparascopic cholestecomy	305	-	-9.9**	-	-13.8**	7.5**
Mammareduction both sides	564	-	-5.7*	-	-	2.7*
Manual placenta removal	405	-	-	-	-2.1	3.5*
Scopic decompresion shoulder	401	-	-	-	-	-4.2*
Small bowel resection	684	-	-7.8*	-	-1.9*	6.7*
Transurethral resection of the prostate	414	-	-4.0*	2.7	-	4.8*
Uterus extirpation	321	-	-1.1	-	-	-
Total / Percentage of cases with factor = 1	12,030	10.8	52.2	84.3	18.8	51.1

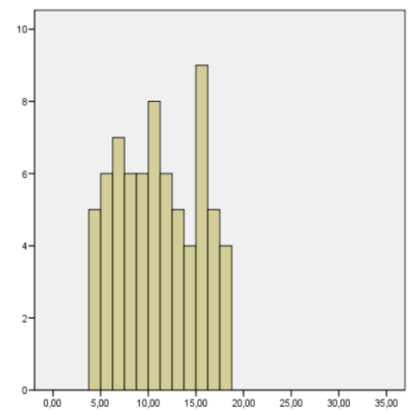
Table 4: Prediction errors of procedure times (absolute errors and differences between methods), January - August 2009

CPT	Cases	Absolute errors (minutes)						Diff (minutes)			Diff (% of median procedure time)		
	(#)	Last ten		3-logN		ANOVA		3-logN -	ANOVA -	ANOVA -	3-logN -	ANOVA -	ANOVA -
		Mean	SD	Mean	SD	Mean	SD	last 10	last 10	3-logN	last 10	last 10	3-logN
Hospital A													
Ablatio mamma	51	19.3	6.3	15.7	6.4	6.5	3.3	-3.6	-12.8	-9.2	-4.6	-17.5	-12.6
Appendectomy, open	67	16.2	5.2	12.3	4.4	7.7	2.9	-3.9	-8.5	-4.6	-6.2	-13.5	-7.3
Endoscopic appendectomy	71	19.9	6.6	11.0	4.2	7.4	3.1	-8.9	-12.5	-3.6	-10.1	-14.2	-4.1
Endoscopic total prostatectomy	71	24.6	8.2	14.2	6.4	6.6	4.5	-10.4	-18.0	-7.6	-5.5	-9.5	-4.0
Laparascopic cholestectomy	142	18.2	4.2	15.9	3.2	9.9	6.5	-2.3	-8.3	-6.0	-2.2	-8.1	-5.8
Laparoscopic sterilization	68	12.3	4.3	11.2	4.2	4.9	2.6	-1.1	-7.4	-6.3	-2.3	-15.4	-13.1
Mammareduction both sides	132	21.8	9.5	17.3	5.8	9.8	2.9	-4.5	-12.0	-7.5	-5.1	-13.5	-15.6
Transurethral resection of the prost	81	9.4	3.2	6.3	2.8	10.2	3.9	-3.1	0.8	3.9	-4.8	1.3	6.1
Total / Average	683	17.7	5.9	13.0	4.7	7.9	3.7	-4.7	-9.8	-5.1	-5.1	-11.3	-7.1
Hospital B													
Ablatio mamma	94	18.2	7.2	16.2	5.2	6.0	3.2	-2.0	-12.2	-10.2	-2.6	-15.6	-13.1
Appendectomy, open	73	14.2	3.8	10.5	3.2	11.2	6.1	-3.7	-3.0	0.7	-4.6	-3.8	0.9
Cholestecomy open	203	13.2	3.9	8.2	2.9	10.1	4.1	-5.0	-3.1	1.9	-6.2	-3.8	2.4
Colon resection	63	19.2	4.9	12.9	4.3	14.2	5.2	-6.3	-5.0	1.3	-4.2	-3.3	1.7
Endoscopic appendectomy	62	16.5	5.3	14.7	4.3	8.2	3.2	-1.8	-8.3	-6.5	-2.3	-10.6	-8.3
Endoscopic total prostatectomy	41	24.4	6.8	18.2	6.7	8.3	3.1	-6.2	-16.1	-9.9	-3.5	-9.2	-5.8
Laparoscopic cholestectomy	39	17.3	4.2	14.2	5.2	7.1	3.5	-3.1	-10.2	-7.1	-3.0	-9.8	-6.8
Total / Average	575	17.6	5.2	13.6	4.5	9.3	4.1	-4.0	-8.3	-4.3	-3.8	-8.0	-4.1

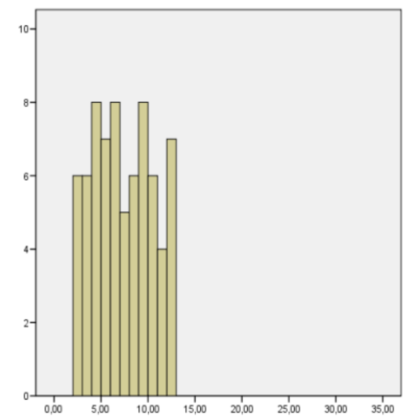
Figure 1: Histograms of absolute forecast errors (top) and differences in absolute forecast errors (bottom) for 71 procedure times of Endoscopic appendectomy



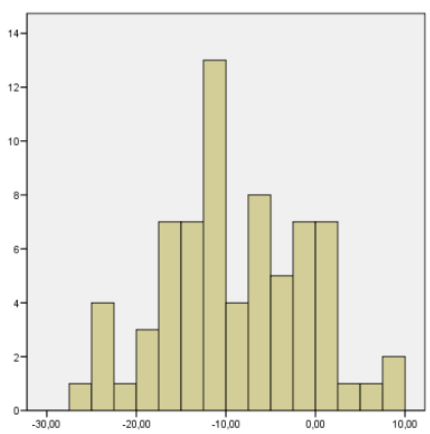
Last ten



3-logN



ANOVA



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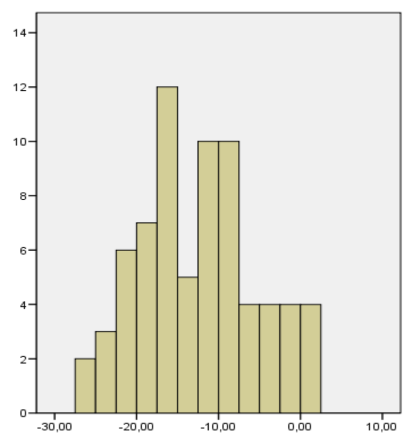

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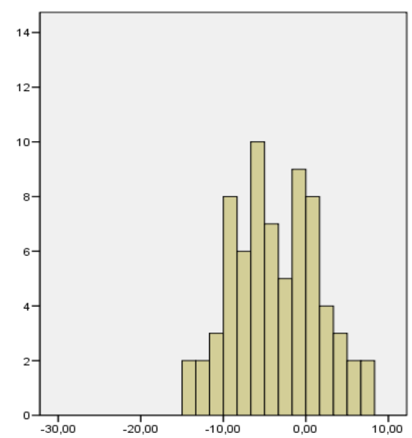

ANOVA – 3-logN