Statistical Methods in Healthcare Management: case study of Slovenian clinic

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Abstract: Healthcare processes in hospitals may develop problems and obstacles over time, which consequently cause the processes to become ineffective and inefficient. The objective of this work was to analyze, identify, and eliminate inefficiencies in the healthcare process in order to improve it using statistical methods. A real-life healthcare process Surgery was chosen to critically evaluate factors that most affect a prolonged hospital stay. The research presents the following conclusions: (a) the Surgery process is well-organized, but nevertheless patient stay in the clinic could be shortened; however, for humane and social reasons the leadership of the clinic prefers to leave the residence time as it is; (b) concerning time-consuming activities, the leadership decided to discuss this problem with the management of the departments where the activities are executed; (c) statistical analyses yield the same result, meaning that early complications is the key factor influencing prolonged hospital stay.

Key-Words: process performance measures; healthcare process improvement; logistic regression analysis; laparoscopic surgery; risk factors.

1 Introduction

Throughout the last decade, the fields of healthcare improvement have been gaining recognition and acceptance. The reasons for such an evolution may be found in the literature, academic publications, and research studies that deal with this theme, as well as in an increasing involvement of consultancy and software development companies. Healthcare process improvement is based on the fact that a process is the key element of the analysis of the healthcare organization.

Recent literature offers various definitions of the extent of a process, process modelling, process improvement, and process management. Within this scope in mind, the process is comprehended as a transformation of inputs to outputs [1]. Furthermore, we focus on processes regardless of the organizational form of the research institutions [2,3,4] characteristics of the wider system of governance in society (see [30, 31, 32, 33, 34]).

Processes come within our scope in that they potentially add value to the organization, and as such are attracting attention, examples are given in [5,6,7,8,9,10]. Consequently, process improvement is increasing, as only a thorough comprehension of the processes within the organization can lead to effective, efficient, and value-adding systems. Business processes are the key element when integrating an enterprise [11].

The aim of this paper is to show the possibility of using statistical analysis to improve healthcare processes in hospitals. Management of healthcare is a crucial topic, gaining recognition in the last decade [12,13,14] and comprising various approaches, such as using a spreadsheet for simulation [15,16,17].

The paper is divided into four sections. In Section 2 statistical methods are discussed. Section 3 represents the results the practical implication of this work, where real data are presented and statistically described. Section 4 contains findings and conclusions. Throughout the paper, the healthcare process of carrying out surgery in the Abdominal Surgery Department of the University Clinical Center in Ljubljana, Slovenia, is illustrated.

2 Methods

Descriptive and elementary statistics were used in order to strengthen the results produced by BPM simulations. The aim of the analysis was to detect important factors attributable to a prolonged hospital stay. As already noticed, statistics are an essential aspect of biomedical informatics [18]. The purpose of the analysis was to make a comparison between two groups of patients: the ones that were hospitalized for a short period and those hospitalized for a longer period of time after abdominal surgery. Moreover, various statistical methods were applied on a sample of patients' that had undergone surgery in order to detect important factors causing a prolonged hospital stay.

Descriptive statistics accompanied with tests of proportions (Pearson chi-square) were presented in order to assess the completeness of the reported results. For numerical-valued variables the Wilcoxon rank-sum test was used, depending on the normality of data to compare the two groups [19]. When needed (hospitalization period less than 10 days/10 days or more; type of surgery laparoscopic/open) we constructed binary or dummy variables out of ratio scales when needed for computation purposes, or for clear presentation and to show the differences between variables under study. Statistical significance was interpreted as p being equal or below the threshold of 0.05 in the two-tailed option [20].

We used the Wilcoxon rank sum test to establish significant difference between two sample groups. Pearson's chi-square tests was used to compare [21] binary outcomes of the variables (early complications yes/no; reoccurrence of the illness yes/no) and two variables recoded in categories from the ratio scale.

A multivariate analysis was employed for determining the relative contribution of different factors to a single outcome – hospitalization period. Multivariate analysis allowed us to simultaneously assess the impact of multiple independent variables on a single outcome and to choose only the important predictors for the construction of the final LR model.

We use logistic regression (LG) model to predict which of two categories (hospitalization period short or long) a patient is more likely to belong to given other relevant information in the form of predictive variables. By using LR we are able to predict the binary length of the stay of the patients and whether a new patient with its own characteristics is likely to be a hospitalized for a shorter or longer period [22].

To estimate the discriminating power of the developed LR model we used receiver operating characteristic (ROC) curves, and the areas under the curves (AUC) were calculated using SPSS software. The AUC determines how well patients who stayed in the hospital more than 10 days could be distinguished from patients needed less than 10 day to recover using the model's risk prediction calculation. Value 1 of AUC represents perfect discrimination of the model, while 0.5 means no discrimination [23]. The overall discriminative ability of the final multiple logistic regression model was assessed with the c statistic (the area under the receiver operating characteristic (ROC) curve [24].

3 Results

A retrospective analysis of patients who underwent laparoscopic and open ventral surgery involvement at the university medical Centre between December 2006 and December 2009 was done. The diagnosis was established on the basis of clinical symptoms and previous laparoscopic examination. For each patient in the study we collected demographic and health data.

The purpose of this study was to establish demographic and health factors causing a prolonged hospital stay of the patient. By analysing the importance of age, early complications, type of surgery, reoccurrence of the illness we can foresee critical factors. Complications after surgery coincide with higher risk for the patient's health, jeopardizing his or her life, and result in extra costs for the hospital and society.

3.1 Sample

Treated patients were aged between 26 and 91 years. The average age was 66.9 years with standard deviation of 11.0 years. Patients were mostly men (55.0%).

The hospitalization period was extended from 1 day, till 95 days representing the longest. If we cut out the outliers, then the average hospitalization time is 10.7 days (otherwise 11 days). More than two third (67.8%) of the observed patients were hospitalized less than 10 days, while other 32.2% stayed at the clinic for a longer period. In 11.5% of the cases the illness recurred.

Most of the patients underwent an open ventral surgery (74.9%), while others underwent laparoscopic ventral surgery. After and during the surgery in the early stage, 22.6% of the patients had a complication, that turned in to long hospitalization period or re-operation in some cases (7.3%).

Ventral surgery is associated with significant complications and a recurrence rate. That is why laparoscopic ventral surgery has been shown to be safe and effective method in the field of ventral surgery [25].

The purpose of the study was to establish the important factors that are of main concern when the length of stay in the hospital in connection with the costs is in question.

3.2 Descriptive and bivariate statistics

A quarter of patients younger than 50 years were hospitalized more than 10 days, while this percent jumps to 45.5% among 80 years or older. Here we apply Pearson hi-square statistics. Results show a statistically significant association between hospitalization days and age (χ^2 = 25,547, p < .001). There is a clear division between % of patients that are recovered less than 10 days or 10 days or more. The older the patients are the more probable need more days of hospital stay. Age does not play the sole important role as a predictor affecting hospital stays, though it does play a role of a covariate with an indirect effect. Age affects the output – hospitalization days – through other important predictors (mainly incidence of early complications and open surgery).

Complications that accrued after the surgery represent an important factor in predicting hospitalization days.

In the case of early complications after a surgery the hospitalization period of the patient expands considerably, on average by 7.4 days. Patients without early complications stay in the hospital on average 9.3 days with standard deviation 4.3 days. In cases when early complications do occur, the average hospitalization rise to 16.7 days with standard deviation 11.8 days.

When checking for association between hospitalization days and patients with early complications we apply Pearson hi-square statistics. Results show statistically significant association between hospitalization days and patients with early complications (χ^2 = 135.5, p < .001). There is a clear division between % of patients that had early complications and the ones without. The percentage rises according to the number of hospitalization days. Almost 70 percent of patients with early complications stayed in the hospital 14 days or more.

The hospitalization period of patients that have undergone abdominal surgery without early complication (Mdn = 303.38) significantly differ from patients with early complications (Mdn = 515.84). Here we report Wilcoxon rank sum (Ws = 164735.00, z = −11.731, p < .001), since data are not normally distributed in both subsamples of patients. Effect size (r = −.44) below the .5 represent a moderate size effect [26]. Patients with early complication are significantly more at risk of a prolonged hospital stay.

Incidence of early complications increases with age, meaning that the patient without post-operation complications is on average 3.7 years younger than the patient where post-operation complications do occur. The average age of patient without complication is 66.0 years with standard deviation of 10.9 years, while the average age of patients with post-surgery complications is 69.7 years with standard deviation of 10.8 years.

Age of patients that have undergone abdominal surgery and without any early complications (Mdn = 334.32) significantly differ from patients with early complications (Mdn = 410.19), Ws = 181533.00, z = −4.151, p < .001, r = −.16. The effect size r, which is below the .5 threshold for a large effect, represents a minor size effect.

Patients with reoccurring gastric illness are on average 63.3 years old (a standard deviation of 10.6 years), while patients where the illness didn't reoccur are on average 3.7 years older (63.3 years with a standard deviation 12.4 years). It must be noted however, that we didn't take into account patients that died after the operation (n=22).

Patients where gastric illness reoccurred (Mdn = 293.38) significantly differ from patients where the illness did not reoccur (Mdn = 359.08). Here we report Wilcoxon rank sum (Ws = 23763.50, z = −2.744, p < .05). The effect size (r = −.10), which is below the .5 threshold for a large effect, represents a minor size effect.

Type of surgery also affects hospitalization period. Patients undergoing laparoscopic surgery need shorter hospitalization period, on average 8.9 days, while patients with open surgery need on average 11.5 days of hospitalization. Patients undergoing laparoscopic surgery need on average 2.6 days shorter hospitalization period to recover.

Between all patients that underwent laparoscopic surgery, 55.0% stayed in the hospital less than one week. Between all patients that undergone open surgery, 24.0% stayed in the hospital less than one week, 20.0% stayed in the hospital less eight days, while 28.0% of patients stayed in the hospital 14 days or more. The association test between type of surgery and hospitalization period shows statistically significant results ($\chi2 = 90.160$, $p < .001$), meaning that there is a significant difference between patients that underwent laparoscopic and open surgery.

The hospitalization period of patients that underwent laparoscopic surgery (Mdn = 229.75) significantly differ from patients that undergone open surgery (Mdn = 384.86). Here we report the Wilcoxon rank sum (Ws = 34693.00, z = −8.407, $p < .001$). The effect size (r = −.32), which is below the .5 threshold for a large effect, represents a moderate size effect. In fact, laparoscopy is an option in the case of non-complicated surgery. In general, patients undergoing laparoscopic surgery needed less time to recover.

Patients undergoing laparoscopic surgery are generally younger, on average 65.4 years with a standard deviation of 10.6 years, while patients with open surgery are on average 67.3 years with a standard deviation of 11.1 years.

The age of patients that underwent laparoscopic surgery (Mdn = 319.53) significantly differ from patients that underwent open surgery (Mdn = 360.26), also here the Wilcoxon rank sum is reported (Ws = 48249.50, z = −2.187, $p < .05$). The effect size represents a minor size effect (r = −.08).

3.3 Binary logistic regression

Patient-related demographic and surgical information were used to develop a logistic regression model. Logistic regression was employed to identify variables associated with increased hospitalization period after surgery in patients undergoing ventral surgery (open or laparoscopic). Variables used in model building are: Surgery type: open=1/laparoscopic, Early complications: yes, Age: 71 – 80 years and Hospitalization period: 10 days or more=1/ less than 10 days as the independent variable.

To permit valid statistical analyses, we used binary logistic regression to separate predictors of short from predictors of a long hospital stay. We computed binary logistic regression model parameter estimates, omnibus likelihood ratio and Nagelkerke R^2. We employed the resulting final model equations to compute predicted short and long stay occurrences, probabilities and associated sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), and overall correct prediction percentages using observed short and long stay percentages as threshold values [27].

3.4 Fit indices for LG

The value of model chi-square statistics (χ^2 =162.167) is significant at the 0.05 level, meaning that the overall model predicts whether a patients is hospitalized for a shorter or longer period significantly better than it was with only the constant included (χ^2=882.163). We use Cox & Snell R Square (C&S RS=0.206), as well as the adjusted Nagelkerke R Square (adjusting the scale of the statistic to cover the full range from 0 to 1; N RS=0.288) as effect size measures of the model [28]. From our results we can see that measures regarding goodness of fit are telling us that the model fits the data relatively well. In fact, based on selected predictive variables we can predict well our dependent variable. Another so-called goodness-of-fit test is the Hosmer and Lemeshow Test, which indicates the extent to which the model provides a better fit than a null model, with no predictors in log-linear modelling [29]. A non-significant chi-square goodness of fit (χ^2=1.616, p=0.806) indicates the model that has an adequate fit.

Table 1. Final model created using logistic regression

	β Coefficient	p Value	OR estimate	95% CI
Intercept	−2.465	<0.0001		
Laparoscopic surgery type	1.187	<0.0001	3.278	1.941 to 5.534
Early complications	2.192	<0.0001	8.949	5.926 to 13.515
Age group 71 – 80 yrs	0.541	0.007	1.718	1.163 to 2.537

Dependent variable: Hospitalization period: 10 days or more=1/ less than 10 days

The current model correctly classifies 542 patients, but misclassifies others. It correctly classifies 77.2% of cases. When only a constant was included the model correctly classified 67.8% of cases, but with the inclusion of three predictive variables this rose to 77.2%.
Beta coefficient represents the change in the logit (natural logarithm of the odds of Y occurring) of the outcome variable associated with a one-unit change in the predictor variable. The p value of Wald statistics indicates whether the b coefficient is making a significant contribution to the prediction of the outcome, while the odds ratio (OR) estimates results from a unit change in the predictor. We interpret the OR in terms of the change in odds (Y). From the Table 2 we can see that type of surgery, post operation complications, and age (71 – 80 years) are significant predictors for hospitalization period according to Wald statistics. The Exp (B) value greater than 1 indicates that as the predictor increases, the odds of the outcome also increase [28]. The odds for patients hospitalized for a longer period of time are 3.278 times higher for patients having an open abdominal surgery in comparison to laparoscopic surgery, 8.949 times higher for patients where post-operation complication occurred, and 1. The model building process of the ROC curve was iterative. The logistic regression model performed well (AUC difference: c statistic = 0.76, Hosmer–Lemeshow $\chi 2$ =1.616, HL (p)= 0.806). In patient's that underwent ventral surgery, the model-based algorithm provided better negative (476 less than 10 days of hospital stay) predictive value. The algorithm was reasonably accurate for identification of hospitalization period, with greater sensitivity and lesser specificity.

4 Conclusion

When identifying important factors affecting prolonged hospital stay we noticed that hospitalization period depends primarily on early complications, type of surgery, and age.
Patients with early complications are significantly more at risk of a prolonged hospital stay. Age affects hospital stays, both directly and indirectly. In general, it holds that the older the patient, the more days are needed for recovery. It can also be noted that patients that underwent laparoscopic surgery needed less time to recover. Laparoscopic surgery seems less risky in terms of early complications, but less effective in terms of reoccurrence of the illness.
A statistical analysis on patients' data was carried out. Pearson's chi-square test was used to analyse contingency tables, Wilcoxon rank sum test to establish difference between two sample groups and multivariate logistic regression (LG) analysis was used to predict the length of the stay of the patients based patient characteristics.
The odds for patients hospitalized for a longer period of time are substantially higher for patients' undergone open abdominal surgery, patients where post-operation complication occurred, and patients in the age group between 71– 80 years. The same predictors are for hospitalization period (short vs. long) were produced by LG. The LG model was tested for classification accuracy using ROC curve measurement.
We found the following results: (a) the Surgery process in the discussed department is efficient and well organized; (b) patient stay in the department could be shortened; and (c) the process is connected to some time-consuming activities which are performed in other departments and represent the bottleneck of the process; the key factors influencing the length of the patients' stay are patient's age, type of surgery, and occurring post-surgery complications. As the result it can be stipulated that the process efficiency is directly linked to the absence of surgery complications, as well as the demographic and health factors.

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