Optimising operating list scheduling in the day surgery department: can statistical modelling help?

O. Faiz[a], P. Tekkis[b], A.J. Mcguire[c], J.A. Rennie[d], P. Baskerville[d], A.J.M. Leather[d]

Abstract

Introduction: Optimal theatre usage involves maximal utilisation of scheduled theatre sessions without incurring overruns. The aim of this study was to explore the use of statistical techniques that might facilitate efficient operating list scheduling.

Methods: Historical theatre data relating to individual general surgery teams' day surgery sessions carried out over a seven year period at a London teaching hospital were acquired and subjected to linear statistical analyses.

Results: The relationship between the time spent operating on a list correlated strongly with the time taken to complete the list (r=0.617,P<001). The size of lists also correlated strongly with list duration (r=0.601,P<0.001). The strength of these relationships varied greatly for differing surgeons' sessions. A multi-level model was constructed for the prediction of list duration (the dependent variable) according to the size of operating lists (the explanatory variable) where operations and surgeons were designated first order and second order hierarchical ranks respectively. The model demonstrated large differences between the operative workloads that are appropriate for individual surgeons' 4-hour sessions. Two thirds of the model variance was attributable to the unpredictability associated with operations and one third to the surgeons.

Discussion: The correlation between list size, the time spent operating on individual surgeons' lists and list duration may have applications as robust markers of inefficient theatre time usage. Statistical modelling permits improved understanding of surgical service delivery in the ambulatory setting and could facilitate managerial decision making regarding appropriate surgeon specific list scheduling.

Keywords: workload, theatre utilization, multilevel modelling.

Authors' addresses: [a]Dept. Surgery, St. Mark's Hospital, Harrow, Middlesex HA1 3UJ, U.K. [b]Dept. Surgical Oncology and Technology, St. Mary's NHS Trust, Praed Street, London W21 NY, U.K. [c]Dept. Health and Social Care, Cowdray House, London School of Economics and Political Science, Houghton Street, WC2A 2AE, U.K. [d]Dept. Surgery, Kings College Hospital, Denmark Hill, London, SE5 9RS, U.K.

Correspondence: O. Faiz *Tel:* +44 (0) 7732 314975 *E-mail:* omarfaiz@aol.com

Introduction

Operating theatres are resourced with nursing and anaesthetic personnel only during designated scheduled sessions. Efficient theatre usage relies upon optimal utilization of scheduled theatre time. As such the avoidance of under-utilized theatre time is essential. Conversely, operating lists that over-run the scheduled finish time often incur additional hospital and patient costs due to staff overtime payments and case cancellations respectively. In consequence, lists that finish either excessively early or late are to be avoided if efficient theatre usage is prioritised.

In the NHS long waiting lists for surgery exist within most Trusts [1,2]. The current government has attempted to expand day surgery services [3] as a means of enhancing elective operative capacity within the health service. To this end emphasis has been placed upon improving theatre efficiency within theatre units [4]. Ideally, all theatre sessions would be utilized to maximal capacity without ever over-running. In reality however, the operative workload achieved on differing surgeons' sessions, as well as their tendency to 'under-run' or 'over-run' the scheduled session time, varies significantly [5]. Although the workload achieved per session does, in part, reflect the operative speed of surgical teams it is also dependent upon other session factors many of which are beyond the direct control of the surgeon. Specifically, late starting sessions, early finishes and large time gaps between patients all serve to limit optimal session output. In contrast, list over-runs tend to enhance list output albeit at the expense of incurring additional costs.

Extreme caution should be taken regarding the unquestioned desirability of 'efficient' service performance in the absence of measures of clinical outcome. Certainly, effective service providers are not necessarily associated with good clinical outcomes. As such dangers potentially exist if managerial efforts focus on accelerating clinical service provision without the measurement of adverse clinical consequences. Under these circumstances it is perhaps more appropriate that managerial efforts focus on optimisation, rather than maximization, of session performance according to the differing abilities of individual surgical teams to manage operative workload.

Study Aim

This study specifically sought to investigate potential methods that might facilitate operating list scheduling on general surgical lists at an NHS day surgery centre. The ability of surgeon specific markers such as the size of an operating list and the historical workload achieved on surgeons' day surgery sessions were evaluated as potential predictors of list duration. The potential use of multilevel statistical modelling to enable surgeon-specific tailoring of list size to suit session duration was investigated.

Methods

Data methods

The study data comprised all elective day case (DC) procedures performed at a London teaching hospital between April 1997 and April 2004. Prospectively entered theatre data were retrieved from the hospital theatre database (*Surgiserver ©McKennon systems*) and aggregated into operating lists. General surgeons that had conducted >100 database operations were entered into the database on an individual basis.

Definitions

List length was defined as the time consumed from the start of the scheduled session to the removal of the surgical drapes of the last patient on the operating list. For example, the list length of a session scheduled to start at 2PM where the last case finishes at 5:30PM, is 3 hours and thirty minutes (i.e. 210 minutes). The start of the session was defined as the scheduled start time.

The *procedure time* of an individual case was measured as the time spent carrying out the operation i.e. from the start of anaesthesia until the removal of drapes at the end of the procedure.

The *cumulative list procedure time* was defined as the sum of the 'procedure times' of the constituent list procedures i.e. the time on the operating list actually spent performing anaesthesia or operating.

A scoring system for operating list size

A scoring system – *the Operative Score of Complexity Index (OSCI)* – was developed from all database procedures to quantify the size of general surgery operating lists.

Case scores (OSCI units) were assigned to the *Office of Population, Censuses and Surveys – Classification of Surgical Operations and Procedures – 4th Revision (OPCS-4)* codes on the basis of the historical median case duration of all database procedures that had been assigned to the corresponding code. The case score represented the procedure median duration (in seconds) divided by 30. For example, the case score of a day surgery primary inguinal hernia repair was 106 OSCI units. This numerical value represented the median duration (in seconds)/30 of all historical database procedures that had been performed in the day surgery department (by all surgeons who had performed this procedure) and coded to the 'Primary Repair of Inguinal Hernia' OPCS code. Operating list size (the *list score*) corresponded to the sum of the case scores of constituent list procedures. Average historical surgeon specific operating list size was described as the mean list size (+/- standard error) in OSCI units per 4-hour day surgery session.

Statistical Analysis

Correlation statistics: Pearson correlation analyses were used to evaluate the relationship between the cumulative procedure time for all cases on an operating list and session duration, as well as operating list size (measured in OSCI units) and session duration. For all tests of significance, $P<0.05$ was considered statistically significant.

Hierarchical theatre output models: multilevel regression analysis was used to develop surgeon specific regression curves that predicted for list duration as a function of operating list volume. The model was fitted with a Maximum Likelihood (ML) method known as IGLS (iterative generalised least squares) technique. All multilevel modelling was carried out using MlwiN software. The model construction, including definition of the model levels and predictors included, is described below in detail. The relative influence of predictor categories on utilization within models was investigated by changes in the –2 Log likelihood (IGLS deviance) statistic. Criteria were set so that variables were excluded from the model if their probability of influence was low ($P>0.1$). The mean (± standard deviation) and median (Q1-3, n) were recorded for test variables where appropriate.

Model construction: the regression equation employed considered list length as the dependent (y) variable with list volume as the predictor variable (x). A second-order hierarchical model structure was used with the 2nd level pertaining to individual surgeons and the 1st level to individual operations. The model was constructed according to the following equation definition:

$$\textit{List length}_{ij} = \beta 0_{ij}\ \textit{constant} + \beta 1_{j}\ \textit{list size}_{ij}$$

Where: i=individual operations
j= individual surgeons sessions
List length = represents the time from the scheduled start of the session to the end of the last case (measured in minutes).
List-score = represents the size of the operating list (measured in OSCI units)

Results

Operating list characteristics

Throughout the study period 8,314 operations were carried out on 2,092 general surgery lists in the day surgery (DS) centre. Nearly all (99.2%) procedures were performed on sessions scheduled to last 4 hours. 14 surgeons performed more than 100 database procedures (Table 1). 61.1% (n=5,083) of all operations were performed on afternoon operating lists. The median late start for operating lists was 32 minutes (interquartile range 17-48minutes, n=2,087). The median list over-run was 50 minutes (interquartile range 24 – 84 minutes, n=627).

The relationship between cumulative list procedure time and operating session duration

When all surgeons' operating sessions were considered collectively the cumulative duration of all of the procedures on the list (i.e. cumulative procedure time) demonstrated a clear relationship with the session duration (Pearson correlation $r=0.617$, $p<0.001$). Individually, all surgeons demonstrated a significant relationship between cumulative list procedure time and list duration but the strength of this relationship varied greatly (Table 2).

The relationship between list size and operating session duration

The size of operating lists correlated significantly with the duration of the session (Pearson correlation $r=0.601$, $p<0.001$). Once again all surgeons' lists demonstrated a clear relationship between list size and duration ($p<0.001$) but differed in the magnitude of this relationship (Table 2).

Optimisation of list volume to session duration – development of a multilevel statistical approach

Figures 1 and 2 demonstrate a scatter plot with regression line of list volume against operating list duration for all consultant surgeons' day surgery operating lists (n=2,092) that took place between the study dates. As one would anticipate a clear linear relationship between list volume (i.e. list-score) and list length was observed. The regression curve (illustrated in grey in Figure 2) represents a simple linear curve (i.e. non-hierarchical) for all general surgery consultant surgeons operating in the day surgery department at the study centre.

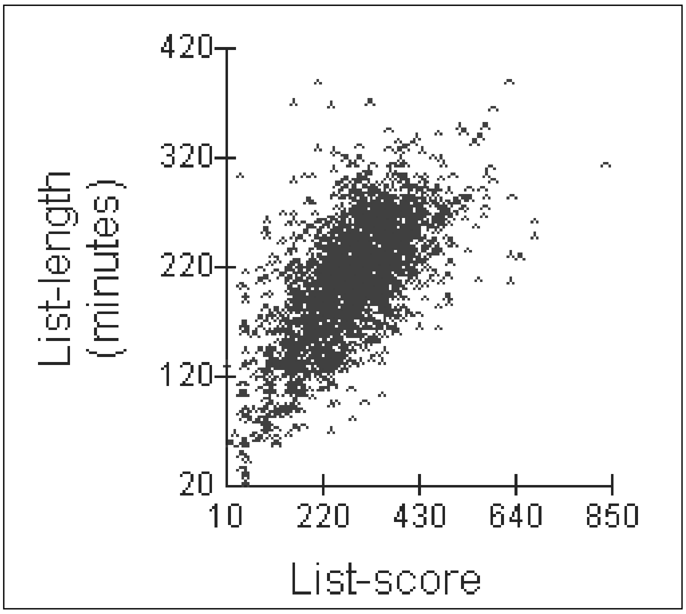
Use of the simple regression curve above permits that a crude estimate of achievable 'optimal' operating list volume can be derived when a hypothetical list length is set. For this model a target list duration of 4 hours was used. The latter session length was selected as 99.2% of all day surgery lists were of 4 hours duration. As such it represents a 4-hour session that starts on time and is performed by general surgeons at the study institution. Under these circumstances, the optimal list volume that predicts a 4 hour finish is 353 units (Figure 3). This 'volume' represents a crude estimate of the operative load that could be scheduled on a routine day surgery operating list and could be expected to finish at the end of a 4 hour operating

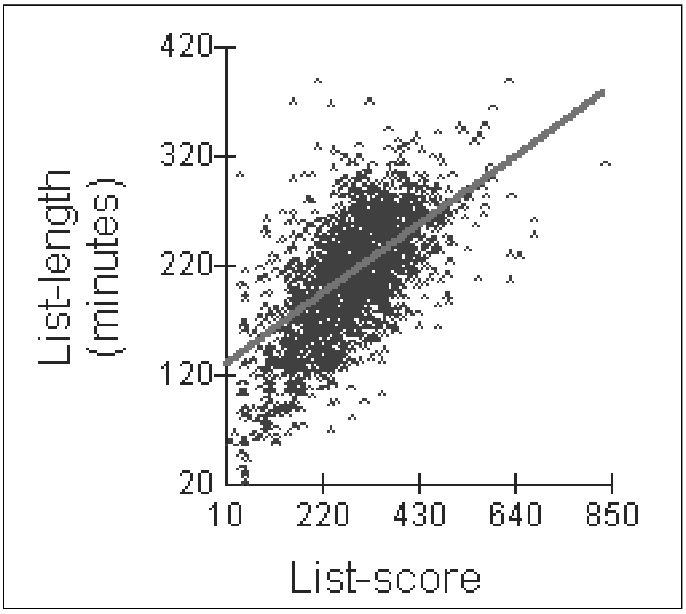
Table 1. The predicted list volume ranges for surgeons finishing their 4 hour operating lists within 20 minutes of the scheduled session finish time and their historical mean list scores per 4 hour session in the day surgery department.

Surgeon	No of cases	Predicted list-score (OSCI units) for: Surgeon No of cases		Mean list-score in OSCI units/ session (standard error)	% cases on overrunning lists
		220 mins	260 mins		
Surgeon 1	612	228	357	340.2(4.2)	59.9%(367/612)
Surgeon 2	146	285	486	343.8(7.3)	42.2%(62/146)
Surgeon 3	1269	270	418	317.1(2.6)	43.3%(551/1268)
Surgeon 4	384	362	463	325.1(5.4)	27.0%(104/384)
Surgeon 5	185	354	434	284.4(6.6)	9.1%(17/185)
Surgeon 6	249	254	334	253.3(4.5)	34.1%(85/249)
Surgeon 7	1106	365	578	379.4(3.2)	34.2%(378/1104)
Surgeon 8	158	340	445	272.5(7.7)	13.9%(22/158)
Surgeon 9	1332	309	455	321.5(2.6)	35.6%(475/1332)
Surgeon 10	679	262	370	256.4(4.2)	39.9%(271/678)
Surgeon 11	576	344	495	317(3.8)	29.0%(167/575)
Surgeon 12	118	235	336	246.6(6.4)	44.0%(52/118)
Surgeon 13	556	327	498	307.7(4.4)	31.8%(177/556)
Surgeon 14	288	281	410	274.0(4.1)	37.8%(109/288)

Table 2. The correlation between cumulative list procedure time (in minutes) and list length and list size (in OSCI units) and list length on individual surgeons' operating lists.

Session	Cumulative list procedure time and list length (r)	p-value	Operating list size and list length (r)	p-value
Surgeon 1	0.585	<0.001	0.622	<0.001
Surgeon 2	0.338	<0.001	0.377	<0.001
Surgeon 3	0.642	<0.001	0.618	<0.001
Surgeon 4	0.733	<0.001	0.737	<0.001
Surgeon 5	0.816	<0.001	0.873	<0.001
Surgeon 6	0.717	<0.001	0.673	<0.001
Surgeon 7	0.599	<0.001	0.569	<0.001
Surgeon 8	0.825	<0.001	0.799	<0.001
Surgeon 9	0.472	<0.001	0.591	<0.001
Surgeon 10	0.697	<0.001	0.715	<0.001
Surgeon 11	0.661	<0.001	0.585	<0.001
Surgeon 12	0.747	<0.001	0.692	<0.001
Surgeon 13	0.543	<0.001	0.545	<0.001
Surgeon 14	0.640	<0.001	0.554	<0.001





Figures 1(top) & 2 (bottom) Scatter-plot (Figure 1) with regression line (Figure 2) of list length against list volume in the day surgery department.

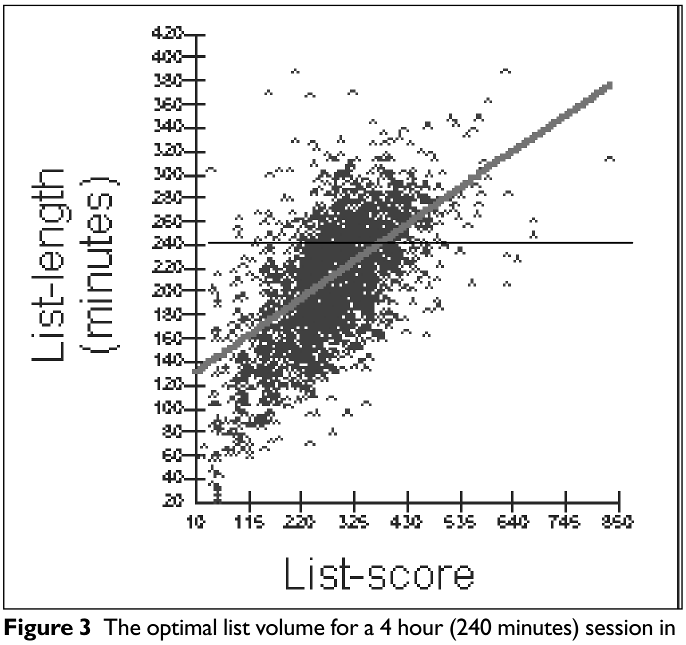


Figure 3 The optimal list volume for a 4 hour (240 minutes) session in the day surgery department.

session. Importantly, the above simple regression curve is non-specific regarding the individual surgeon's operating list. As such it represents only changes in list length (y) as a function of operative volume (x) for all general surgeons at the Trust. Adoption of the multi-level model structure below was consequently performed to incorporate the specific influence of differing surgeons' sessions in determining list duration.

Model equation*:

List $\text{length}_{ij} = \beta0_{ij}$ constant $+ \beta1_{j}$list size_{ij}

$\beta0_{ij} = 118.9(7.64)$

$\beta1_{j} = 0.335(0.025)$

Variance between surgeons of the constant $U_{0j} = 823.2(319.0)$

Variance between surgeons of the slope $U_{1j}=0.009(0.003)$

Variance between operations $e_{0j}=1412.9(21.9)$

* **Additional Notes** Figures in brackets correspond to the standard error. The regression equation permits a prediction of the list length (in minutes) through addition of the coefficient of the constant (i.e. 118.9) to the size of the operating list (i.e. the list-score in OSCI units) multiplied by the list size coefficient (i.e. 0.335).

Figure 4. illustrates the individual regression lines for all consultant surgeons operating in the day surgery department throughout the study period. From this multilevel approach it can be seen that surgeons differ in their operative output at 4 hours (i.e. 240 minutes on y-axis) as well as their abilities to handle increasing volume (i.e. the slope of their respective curves).

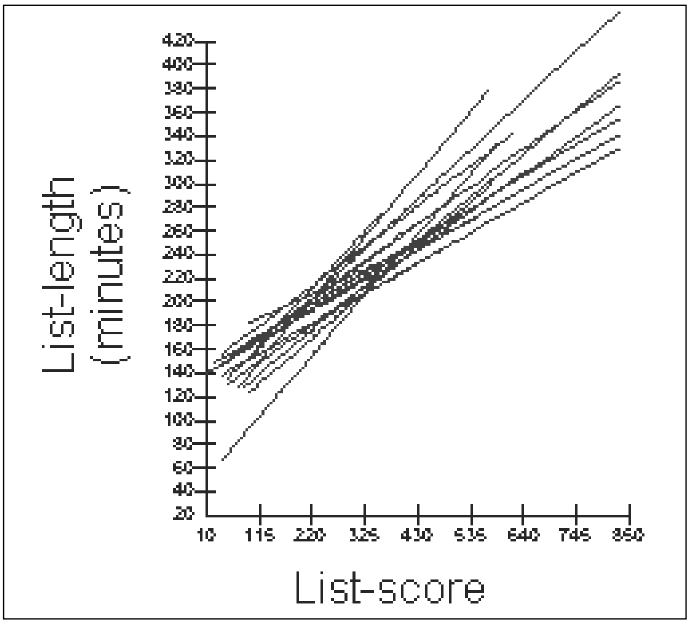


Figure 4 Individual consultant surgeons' regression curves for list duration according to list volume.

Multi-level modelling was used to theoretically investigate whether 'optimal' operating list volume could be estimated. To this end, practical parameters of the desired time zone within which to finish an operating list were chosen. In this instance 20 minutes either side of the 4-hour session duration was used as the upper and lower predictors of session volume. Figure 5 illustrates the predicted range of list score for a specific surgeon (Surgeon 5 - regression line in grey) at 220 and 260 minutes respectively. Table 1 demonstrates the predicted 'appropriate list volume' ranges for all consultant surgeons' sessions in the day surgery department – assuming that they are operating in 4 hour sessions and the session duration parameters remain at 20 minutes either side of the finish time. In addition,

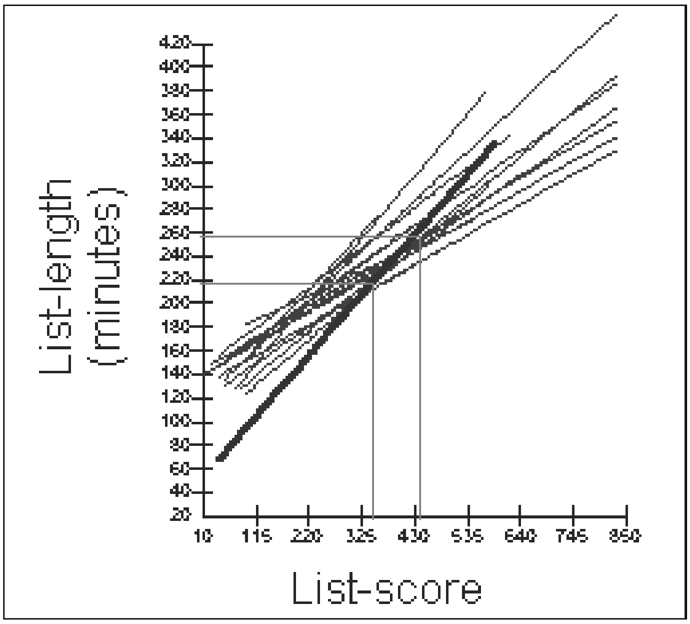


Figure 5 The predicted list volume range for Surgeon 5 (in bold) to finish a 4 hour operating list within 20 minutes of the scheduled session finish time.

the historical mean list scores for surgeons operating on 4 hour day surgery sessions is tabulated. Figure 6 represents examples of operating lists that are appropriate to the differing predicted 4 hour list capacities of surgeon 7 and surgeon 12 according to the multi-level model.

Discussion

Due to the financial costs associated with staffing a theatre complex theatre usage is expensive [6]. Attempts are consequently made to limit the time that theatres are under-utilized as this represents a missed opportunity to perform operations. In addition, significant staffing costs are associated with theatres that overrun [2]. Obviously, the prevention of overruns for the purpose of efficient theatre usage requires balancing against other managerial goals such as the need to achieve waiting list targets. The specific costs associated with chronic overruns are difficult to generalise as they differ amongst hospitals. Direct costs relate to staff overtime payments and will depend on local staff contracts. Indirect costs arise from staff absenteeism, recruitment difficulties and agency costs.

Overall, an optimal theatre list workload represents the operative volume that will fully utilize the list yet finish precisely at the end of its scheduled duration. Unfortunately, the variation associated with operative procedures renders complete accuracy of list duration impossible to predict [7]. Some investigators have found that reasonable prediction of the time taken for a specific surgeon to complete a series of operations is possible when historical data is available [8-13] although it is questionable whether this predictive ability is of sufficient strength to be of practical value [14]. In our own study a strong relationship was identified between the cumulative list procedure time and list duration. Although a clear relationship is identifiable it does not necessarily follow that this method permits a sufficiently reasonable prediction of optimal list volume for all surgical teams in order to be of managerial value. Specifically, the degree that procedure time correlated with list length varied broadly between different surgeons' lists ($r = 0.338$ for surgeon 2 versus 0.825 for surgeon 8). As such, although prediction of an optimal list schedule on the basis of historical procedure times might suffice for surgeon 8 it is too inaccurate to be of value for surgeon 2's list. Despite this apparent weakness even the identification of a poor relationship, such as the one that exists for surgeon 2, might alert operational decision makers to question why this has arisen. In consequence, remediable list events such as inconsistent late starts or erratic time gaps between patients might be identified as the basis to this poor relationship and, once highlighted, corrected. Interestingly, the strength of the relationship (i.e. the value of the coefficient) between cumulative list procedure time and list length is similar to that observed between list-score (i.e. size of the operating list) and list length even when individual surgeons' operating lists were considered. Although, on one level this might seem unsurprising as list score, like cumulative list procedure time, is a based upon historical procedure times it is essential to note that these two variables do fundamentally differ. Specifically, an OSCI score is a score assigned to a specific procedure based upon the historical time that it historically took all database surgical teams to perform that operation whereas procedure time is the amount of time to carry out an operation by a given surgical team. The fact that cumulative list procedure time and list score demonstrated such similar strength relationships with list length when individual surgeons' lists were analysed (i.e. broadly similar r values) probably denotes the uniform complexity of the operative work in the day surgery department. More precisely, the strength of their respective relationships with list length was mostly defined by the inconsistencies of the time spent 'not operating' on a list rather than inconsistencies of time spent 'operating'.

Accurate prediction of an appropriate workload to optimally consume scheduled operating time would undoubtedly facilitate planning of service delivery. In this study a technique is demonstrated that uses hierarchical statistical modelling to this end. Importantly, however, the variance in the multi-level model that arose from the operations (i.e. the level 1 variance), as opposed to the surgeons (the level 2 variance), suggests that total reliance on this method might be

Operating list 1 – suited to surgeon 12	**Operating list 2 – suited to surgeon 7**
Right Inguinal Hernia Repair (106 units)	Haemorrhoidectomy (70 units)
Left Inguinal Hernia Repair (106 units)	Right Inguinal Hernia Repair (106 units)
Haemorrhoidectomy (70 units)	Right Inguinal Hernia Repair (106 units)
	Examination Under Anaesthesia (48 units)
	Examination Under Anaesthesia (48 units)
	Examination Under Anaesthesia (48 units)
	Exc. Sebaceous cyst (42 units)
List-score = 278 units	**List-score = 468 units**

Figure 6 An example of the differing 4 hour operating list capacity for Surgeon 7 and Surgeon 12.

unrealistic for scheduling future surgeon specific list volumes. Whilst it might offer accurate prediction for certain surgeons' lists it may be too inaccurate for others. Despite this the modelling approach does give an important overview as to how individual surgeons working within a similar field deliver their ambulatory operative service (Figure 6).

In contrast to complex statistical modelling use of mean historical session productivity rates (i.e. the workload, measured in OSCI units, achieved by individual surgical teams on historical operating lists) potentially represents a far easier tool to construct. It is of less practical value than the hierarchical approach for two reasons. Firstly, mean historical session productivity rates do not give decision-makers an insight into how differing surgical teams within the same field handle increasing operative volume (i.e. the slope of the regression curve in the multi-level model). This could be important for tactical decision making such as for choosing which surgical team to incentivise with additional theatre time in order to meet operational targets. Mean historical productivity rates includes the historical tendency for surgical teams to over-run or under-run their lists. Certainly the surgical teams with the highest overrun rates demonstrated mean productivity rates (OSCI scores per session) that were higher than those that would have been expected according to the multi-level model (i.e. well above the mid-point of the 220 –260 minute range). For this reason, efficient resource usage involves optimisation of scheduling to reduce the list size for teams that tend to 'over-run' their lists and enhance the list size for teams that tend to under use the potential of their lists.

In order to answer the question posed in the title of this thesis a pragmatic approach to operating list planning is required in ambulatory centres. Certainly, direct extrapolation of the specific study findings from our institution to other NHS centres cannot be reliably made. It is possible to incorporate the study findings into a loosely applicable algorithm that might facilitate managerial decision making regarding operating list scheduling.

In the first instance attention must focus on the generation of reliable operating list volumes. This entails ensuring that patients that are listed for surgery attend for their operations and are not cancelled on the day of their expected operations. Obviously, efforts aimed at scheduling an optimal operating list volume specifically tailored to each surgical team's service performance record is futile if the desired cases fail to attend or are then cancelled. To this end the Modernisation Agency have published a toolkit that offers practical solutions to these specific problems [15]. Following this, attention should focus on poorly performing sessions. Firstly, poor operating list service performance needs to be diagnosed. In our opinion, the use of measures of historical workload or utilization of session performance should be avoided as these markers only give an idea of what has been carried out on the list and make no allowance for the differing speeds of surgical teams and whether surgical teams achieve their workload by consistently over-running the intended session duration. Furthermore, the apparent poor performers highlighted by this system could represent those surgical teams that compromise the speed of service delivery but have the best clinical outcomes and dedicate their list to the teaching of junior personnel. As such, it is our opinion that these methods should be avoided. We propose that the correlation between cumulative list procedure time and list length could represent a better marker of how well surgical teams use their theatre time. Similarly, the relationship between list workload (as measured by either the OSCI method or another equivalent case-mix adjusted measure of operative workload) and list duration could also be used. An investigation into the practical value of these qualitative markers, or 'coefficients' of list performance, and their comparison to theatre utilization, is currently underway. Once sessions where a loose relationship between time spent operating and list duration have been identified factors preventing efficient theatre time utilization can be tackled. Involvement of surgical teams themselves at this stage could facilitate this process. By improving the relationship between cumulative procedure time and list length better prediction of how list volume will translate into session length is afforded. It will enhance the predictability associated with the 'non-operative' time on the list i.e. the time intervals at the start of the list and the gaps between operations. It will not alter the unpredictability associated with operations' durations themselves. Once the former unpredictability that can be controlled has been controlled another method is required to determine how much to schedule on individual surgeons' lists. Although, in this study a complex statistical model was constructed for this purpose it is recognized by the authors that this is beyond the need or scope of what is required at a managerial level in most departments. In reality, a 'trial and error' approach to optimising volume on individual surgeons lists is likely to be equally effective once the handling of operative volume on poorly performing lists has been improved.

References

1. Department of Health. Hospital Episode Statistics. London: Department of Health, 2003. Available at: http://www.dh.gov.uk/PublicationsAndStatistics/Statistics/HospitalEpisodeStatistics/f s/en [Accessed 24th February 2006].
2. Healthcare Commission. Acute Hospital Portfolio review – Day Surgery, July 2005. Available at: http://www.healthcarecommission.org.uk/assetRoot/04/01/83/90/04018390.pdf. [Accessed 13th Decmember 2005].
3. Department of Health. Thousands of NHS patients to benefit from day surgery expansion – Hutton. London: Department of Health, 2002. Available at: http://www.dh.gov.uk/PublicationsAndStatistics/PressReleases/PressReleasesNotices/ fs/en?CONTENT_ID=4014344&chk=rR%2B7wg.[Accessed on 24th February 2006].
4. Department of Health.The NHS Plan: a plan for investment – a plan for reform. London: Department of Health, 2000.
5. Audit Commission, 2003. Operating Theatres - Review of national findings. Available from: http://www.audit-commission.gov.uk/Products/NATIONALREPORT/ 6CDDBB00-9FEF-11d7-B304-0060085F8572/TheatresAHP.pdf. [Accessed 24th February 2006].
6. NHS ESTATES, 2003. Healthcare Capital Investment. Supplement for Quarterly Briefing.Volume 1, No.1 2002/2003.
7. Lebowitz P. Why can't my procedures start on time?***AORN J***. 2003 Mar;**77(3)**:594–7.
8. Strum DP, Sampson AR, May JH, Vargas LG. Surgeon and type of anesthesia predict variability in surgical procedure times. ***Anesthesiology***. 2000 May;**92(5)**:1454–66.
9. Dexter F, Macario A, Lubarsky DA, Burns DD. Statistical method to evaluate management strategies to decrease variability in operating room utilization: application of linear statistical modelling and Monte Carlo simulation to operating room management. ***Anesthesiology*** 1999. July:**91(1)**:262–74.
10. Wright IH, Kooperberg C, Bonar BA, Bashein G. Statistical modeling to predict elective surgery time. Comparison with a computer scheduling system and surgeon-provided estimates. ***Anesthesiology***. 1996 Dec;**85(6)**:1235–45.
11. Broka SM, Jamart J, Louagie YA. Scheduling of elective surgical cases within allocated block-times: can the future be drawn from the experience of the past? ***Acta Chir Belg***. 2003 Feb;**103(1)**:90–4.
12. Dexter F, Macario A, Epstein RH, Ledolter J. Validity and usefulness of a method to monitor surgical services' average bias in scheduled case durations. ***Can J Anaesth***. 2005 Nov;**52(9)**:935–9.
13. Dexter F, Ledolter J. Bayesian prediction bounds and comparisons of operating room times even for procedures with few or no historic data. ***Anesthesiology***. 2005 Dec;**103(6)**:1259–167.
14. Zhou J, Dexter F, Macario A, Lubarsky DA..Relying solely on historical surgical times to estimate accurately future surgical times is unlikely to reduce the average length of time cases finish late. ***J Clin Anesth***. 1999 Nov;**11(7)**:601–5.
15. NHS Modernisation Agency, 2002. Step guide to improving operating theatre performance. Available from: http://www.modern.nhs.uk/theatre/6547/6706/Complete%20Step%20Guide.pdf. [Accessed on 25th February 2006].