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# Data Driven Approach to Enhancing Efficiency and Value in Healthcare

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# Part V

# Performance metric

# Chapter 7

# A new healthcare system performance metric


Measurement is a key component of quality improvement in healthcare, it provides context for what healthcare systems actually do and helps to identify planning deviations [199]. The Overall Equipment Effectiveness (OEE) is a metric developed in the manufacture industry to minimise hidden productivity losses, through the evaluation of three components: availability, performance, and quality [147]. This chapter presents a framework for the implementation of the OEE as an effective performance measure in a healthcare service. An evaluation of an endoscopy service using OEE is presented as a case of study.

This chapter is structured as follows: Section 7.1 introduces the problem and research aims; Section 7.2 presents the research methods and design. The study case is presented in Section 7.3; Section 7.4 focuses upon conclusions and study limitations; and Section 7.5 summarises the chapter.

## 7.1 Introduction

Around the world, healthcare systems are under constant pressure to improve performance, quality and efficiency. These pressures are caused by an ageing population, lifestyle factors, changes in public expectations, increasing number of people visiting Accident & Emergency (A&E) departments and minor injury units, advances in medicine and technology, rising costs and resources constraints, among others. Examples of the strain that NHS organisations are in can be seen in areas such A&E, General Practitioners (GP) services, and diagnostic services.

To be able to maintain and develop their ability to respond to the different stakeholders, healthcare organisations need to be successful in designing robust and flexible process, providing the best preconditions for operational excellence.

The concept of lean healthcare has been implemented world-wide to cope with many of the challenges involved in managing a complex healthcare organisation. A well-know and widespread concept of improving production performance in the industrial sector is the *Total Productive Maintenance (TPM)* [147]. Overall Equipment Effectiveness (OEE) is a metric developed in the manufacture industry to minimise hidden productivity losses, through the evaluation of three components: availability, performance, and quality [147]. OEE is an important measure within the concept of TPM [147]; the OEE measure is traditionally used by practitioners as an operational measure to monitor production performance and as an indicator for process improvement activities in industrial and service sector [173].

Using OEE for performance measurement purpose is common in machines and manufacturing process globally. Despite some examples, the use of OEE in the healthcare sector is still limited. De Mast et al. [47] developed a conceptual framework for healthcare process improvement, and proposed the Overall Resource Efficiency (ORE) metric, based on OEE concepts, as a tool to reduce wasting capacity in non-bottleneck resources within a healthcare system. Smith and colleagues [174] used a modified formulation of the OEE as a key performance indicator as part of a sensitive analysis of unit capacity and patient flow for a hospital-wide system dynamic model.

In this chapter we elaborate on the challenges to implement OEE as a driver for improvement at the process level within hospitals, and how to overcome them. A case is presented, using an Endoscopy Department as example. These findings will be useful to practitioners aiming to improve performance in their hospitals by suggesting measures and implementation issues.

The objective of presenting how a new healthcare system efficiency metric could be used for performance improvement purposes and what issues are involved with this approach is reflected in the following research questions:

- RQ1: How can the OEE measure be utilised by practitioners for efficient management and improvement of healthcare services performance?

- RQ2: How could OEE be defined and used as driver for improvement, and what are the criteria for successful implementation on a healthcare setting?

## 7.2 Method

The research methodology used in this chapter is a combination of literature review and case study. A theoretical review of current OEE definition, assessment and framework was performed in combination with a case study at an Endoscopy service within a UK based hospital. The data collected was based on multiple sources in evidence such a flow process observations, studies of documentation, meetings with clinicians and service managers, and retrospective data extracted from the hospital electronic patient records system. The case study is part of a transformational project managed by the NHS Wessex Clinical Network and was performed as a project within a NHS hospital. The aim of the case study was to develop a framework for increased efficiency in a particular cancer diagnostic service, with the potential for reuse to improve all the diagnostic services across the region, and to facilitate benchmarking between services across the region.

### 7.2.1 Performance measures

Healthcare systems are complex entities with many different stakeholders, including patients, clinicians, healthcare providers, purchasing organisations, regulators, the government and the broader public. Different stakeholders in healthcare systems have different performance metrics needs, both in term of the nature of the information, its details and time-lines, and the level of aggregation required. Performance metrics seeks to monitor, evaluate and communicate the extent to which various aspects of the healthcare system meet their key objectives [199].

The ultimate goal of healthcare is better health, however, there are man intermediate measures of both process and outcomes. Performance is a key component of quality improvement in healthcare, it provides a context about what healthcare systems actually do and it helps to identify deviations with plans in order to identify opportunities for improvement [199].

A report published by the World Health Organisation (WHO) regional office for European Health Evidence Network (HEN), mentioned that the performance measures in hospitals are mostly based on descriptive studies or expert reports. Regulatory inspections was identified as the principal method used for measuring hospital

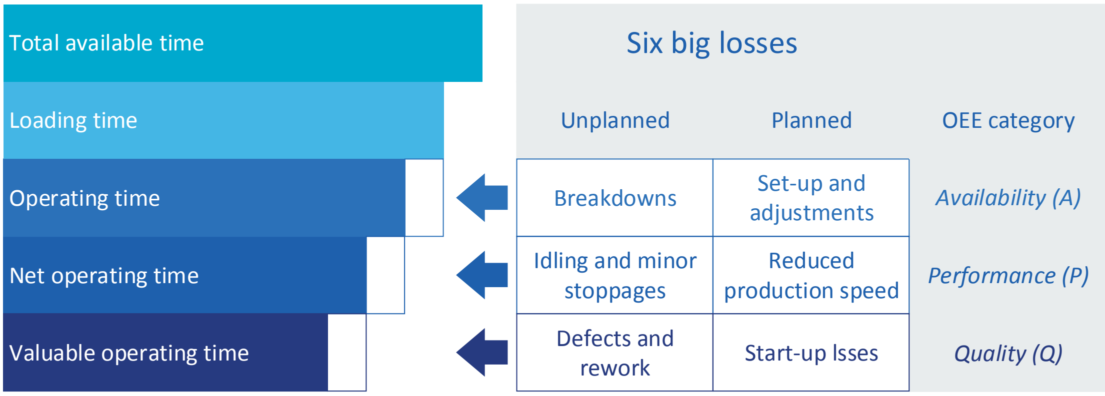


Figure 7.1: The classic Six big losses monitored by the Overall Equipment Effectiveness (OEE) measure. These losses are categorised by asset Availability, Performance and Quality issues; each of these being sub-divided under Planned and Unplanned loss headings.

performance, followed by public satisfaction surveys, third-party assessment, and statistical indicators; it is argued, that the most of them have never been tested rigorously [196].

One purpose of applying performance measures is to set targets for improvement activities in alignment with organisation strategic goals and objectives. In [206], effective performance monitoring was identified as one of the main factors associated with high performance hospitals. Those monitoring includes accurate measurement and goal setting, sophisticated data systems, using data for continuous feedback and improvement, and accountability.

### 7.2.2 OEE definition

In this section, definition and implementation aspects of OEE are presented.

The original definition of OEE was developed by Nakajima [147], and compromises the six big losses - presented in Figure 7.1 - divided into three categories such *Availability efficiency*, *Performance efficiency*, and *Quality efficiency*.

The definition of OEE proposed by Nakajima excludes planned downtime such as scheduled maintenance time and non-scheduled time such as off-shift and holiday from the theoretical calendar time, while a revised definition proposed by Jeong and Phillips [102] includes these as equipment losses that are especially important in capital intense industry. They even extend the list of losses to include R&D and engineering usage time, increasing the total available time in the OEE calculation and thereby reducing the risk of overestimating OEE.

OEE is a metric that identifies the percentage of planned production time that is truly productive. The OEE definition assigns a value between 0% and 100%, with an OEE score of 100% representing perfect production (equipment or system operating close to its maximum efficiency), i.e., producing only good products, as fast as possible, with no down time. As discussed in the following sections, in order to apply OEE to the healthcare organisations, some changes are requested as unlike manufacturing, where a production process could be stopped until next day/shift, in the healthcare sector there is uncertainty when seeing a patient and the service cannot be interrupted until the procedure is finished - meaning that overtime could occur, and therefore a OEE value over 100% is accepted.

OEE does not diagnose a specific reason why a system is not running as efficiency as possible, but it does give some insight into the reason.

Following Nakajima notations, OEE can be formulated as follow :

$$OEE = A_\eta \times \Phi_\eta \times \Sigma_\eta \tag{7.1}$$

$$A_\eta = \frac{T_\upsilon}{T_\tau} \tag{7.2}$$

$$\Phi_\eta = \frac{T_\pi}{T_\upsilon} \times \frac{P^\alpha_{avg}}{P^\kappa_{avg}} \tag{7.3}$$

$$\Sigma_\eta = \frac{P_\gamma}{P_\alpha} \tag{7.4}$$

Originally, OEE analysis was developed as KPI based on single equipment data. In this study, we proposed a whole system approach, based on the assumption that a machine or equipment performance depends on the system and its environment. This idea has been discussed in [158], where the author uses overall Fab effectiveness (OFE), including costs, to evaluate the performance of a whole factory.

Next section presents a case study to evaluate performance in a healthcare setting. A modified OEE will be estimated in order to adapt a metric originally designed for the evaluation of industrial equipments and processes to the healthcare environment.

Table 7.1: OEE factors.

| Factor | Description |
|---|---|
| $A_\eta$ | Availability efficiency. It considers failure, breakdowns, set-up, adjustments and other indirect production time. |
| $\Phi_\eta$ | Performance efficiency. It considers idling and minor stoppages and time losses because reduced production speed. |
| $\Sigma_\eta$ | Quality efficiency. It considers loss of production caused by defects and rework. |
| $T_\upsilon$ | Equipment uptime during the $T_\tau$. Difference between it and $T_\tau$ is due to failure, maintenance and set up. |
| $T_\tau$ | Total time of observation. |
| $T_\pi$ | Equipment production time. Difference between it and $T_\tau$ is due to minor stoppages, resets, adjustments, and others. |
| $P^\alpha_{avg}$ | Average equipment processing time for actual product output. Gap between $P^\kappa_{avg}$ and it is due to speed or production rate slowdowns. |
| $P^\kappa_{avg}$ | Average theoretical processing rate for actual product output. |
| $P_\gamma$ | Good product output from equipment during $T_\tau$ |
| $P_\alpha$ | Actual product units processed by equipment during $T_\tau$. |

## 7.3 Case study

This study was conducted at the Royal Bournemouth Hospital endoscopy unit, part of The Royal Bournemouth and Christchurch Hospitals NHS Foundation Trust. The hospital provides health care service to the residents of Bournemouth, Christchurch, East Dorset and part of the New Forest, with a total population of 550,000, which rises during the summer months. The Royal Bournemouth Hospital has about 600 inpatient beds and 123 day case beds. Services at the hospital include urgent and emergency care, medical care, surgery, critical care, end of life care, outpatient and diagnostic services. The overall rate after an inspection of the Care Quality Commission in 2016 indicated that the hospital requires improvements [31].

Endoscopy manager led the retrospective data collection. We leaded staff interviews within the endoscopy unit, process mapping and time motion study, and data analysis.

### 7.3.1 Endoscopy unit setup

The endoscopy unit is part of the Gastroenterology Department, dedicated to the care of patients with gastrointestinal disorders both on an outpatient basis (e.g. in clinic and the endoscopy unit) and inpatients. The Royal Bournemouth Hospital is the upper gastrointestinal cancer centre for the east Dorset area serving Bournemouth, Poole, Dorchester and Salisbury as well as offering a joint colorectal cancer centre with Poole Hospital, and a bowel cancer screening centre.

The unit consists of: 5 endoscopy procedure rooms; 1 x-ray suite; 3 patient general waiting area; 3 pre-procedure admission rooms (where patients are prepared for their procedure, i.e. placement of intravenous catheter (IV), pre-procedure paperwork completed and informed consent); 1 additional waiting area for inpatients; 2 recovery rooms (gender specific areas); 1 discharge room; and 1 seated recovery area. The endoscopy unit provides gastrointestinal and liver services, and sees patients routinely Monday to Friday and as for ad hoc on weekends.

List are arranged into 2 sessions per day with additional daily lunchtime list for inpatients. Inpatients are scoped at the weekend as directed by the n-call consultant, and on-call nurses can be brought in to support this.

### 7.3.2 Data collection

Hospital heath records were extracted and pseudonimised by the hospital information department. The available dataset includes information from 48,366 endoscopy and bronchoscopy procedures from January 2013 to end of July 2016.

Figure 7.2 shows the original dataset and final dataset included in the analysis. As mentioned above, 5 endoscopy procedure rooms are available within the endoscopy department, and 1 room in radiology is used at 3 sessions per week as well as for ad hoc ERPC procedures. Because our objective is to evaluate the performance of the endoscopy unit, 2,237 records were excluded from the analysis as the procedure were performed at the Intensive Therapy Unit (ITU), operating theatres, or in a radiology room (x-ray). 5,174 procedures performed at the weekend were also excluded from the analysis as the endoscopy room availability is unknown. The final dataset includes 40,955 procedures.

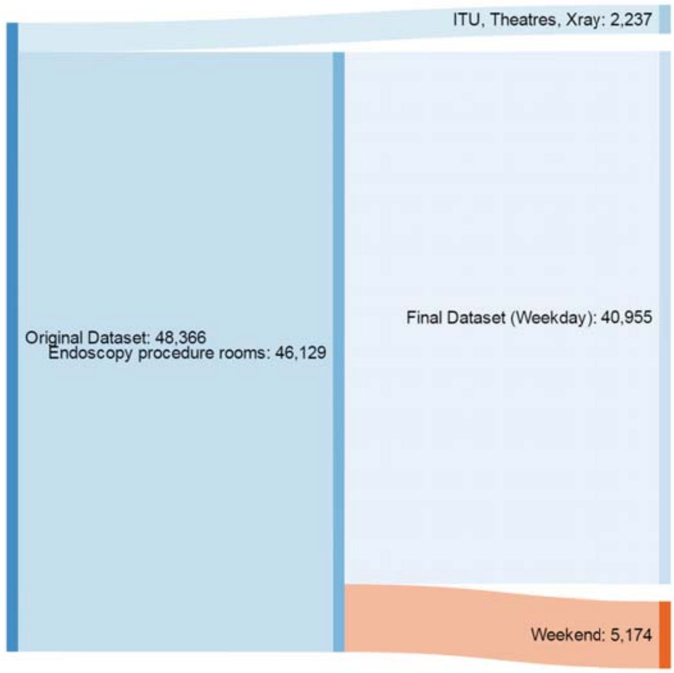


Figure 7.2: Endoscopy and bronchoscopy records extracted from the Hospital Health Record System. Data from January 2013 to end of July 2016. Figure shows database original, and procedures excluded from the analysis because performed outside the endoscopy unit or on weekend.

### 7.3.3 Endoscopy unit OEE

OEE was calculated for a system composed by by the five endoscopy rooms within the endoscopy unit. Processes undertaken outside the endoscopy rooms were excluded (e.g., reception, admission, recovery and discharge). Figure 7.3 shows a generic process map of the endoscopy unit.

### 7.3.4 OEE Availability

OEE availability was estimated using the total working hours per day for the endoscopy unit.

The dataset includes information for the procedure date, and time for procedure start and end. Using this information the total time dedicated to perform endoscopy procedures was daily estimated for each room, starting time for the first patient and finishing time for the last patient was also estimated. Lunch time, turnover times and cleaning activities were not taken into account in the analysis. Figure 7.4 shows the time for procedure start and end at the endoscopy rooms. *End time* represents

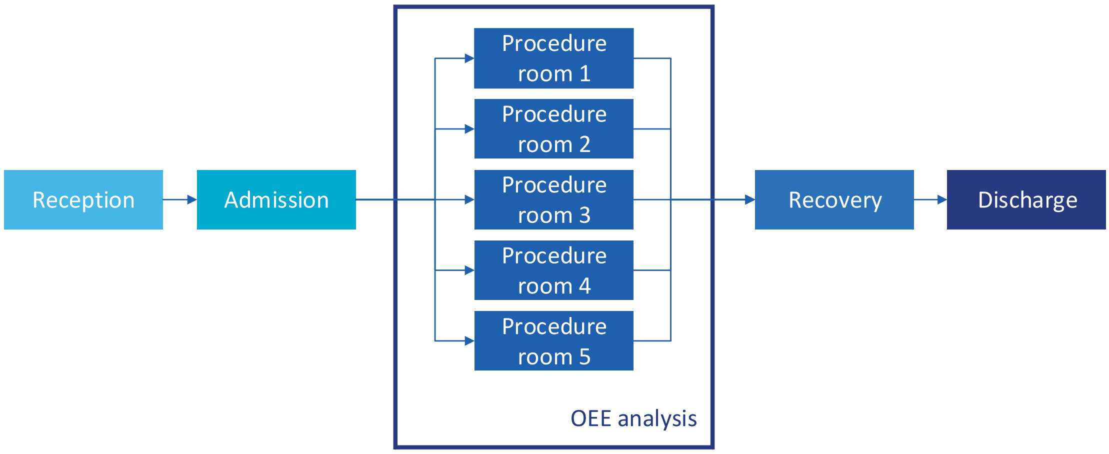


Figure 7.3: Top level process at the endoscopy unit. OEE was calculated for the five endoscopy rooms, activities performed outside this rooms were excluded.

the time when the last procedure of the day finished. Total working hours per day was calculated as the difference between start and end time (in hours).

In order to estimate the daily availability score, the *working hours* were compared with a theoretical planned run time of 10 hours. As noted, the original OEE definition assigns a maximum score of 100% at each of the components. An availability score of 100% means the process is always running during planned production time. This definition has been adapted at the healthcare reality, where sometimes overtimes are necessaries in order to finalise a clinical procedure with a patient. Figure 7.5 shows the variability in the endoscopy room availability score between January 2013 and July 2016, including variability per day, month, year and weekday.

### 7.3.5 OEE Performance

OEE performance was estimated as the rate between activity and capacity, using an endoscopy point system. As noted, endoscopy services in the UK uses a point system as a guide to convert the workload into a unit of time. In previous chapters, variation in activity between services as been identified as one of the key challenges that endoscopy services are encountering, with a large variation across hospitals and sessional activity between of the same unit. Another factor is the session length, e.g. some units work with two 4-hours sessions (morning and evening), while others assign 4 hours for morning and 3.5 hours for evening sessions.

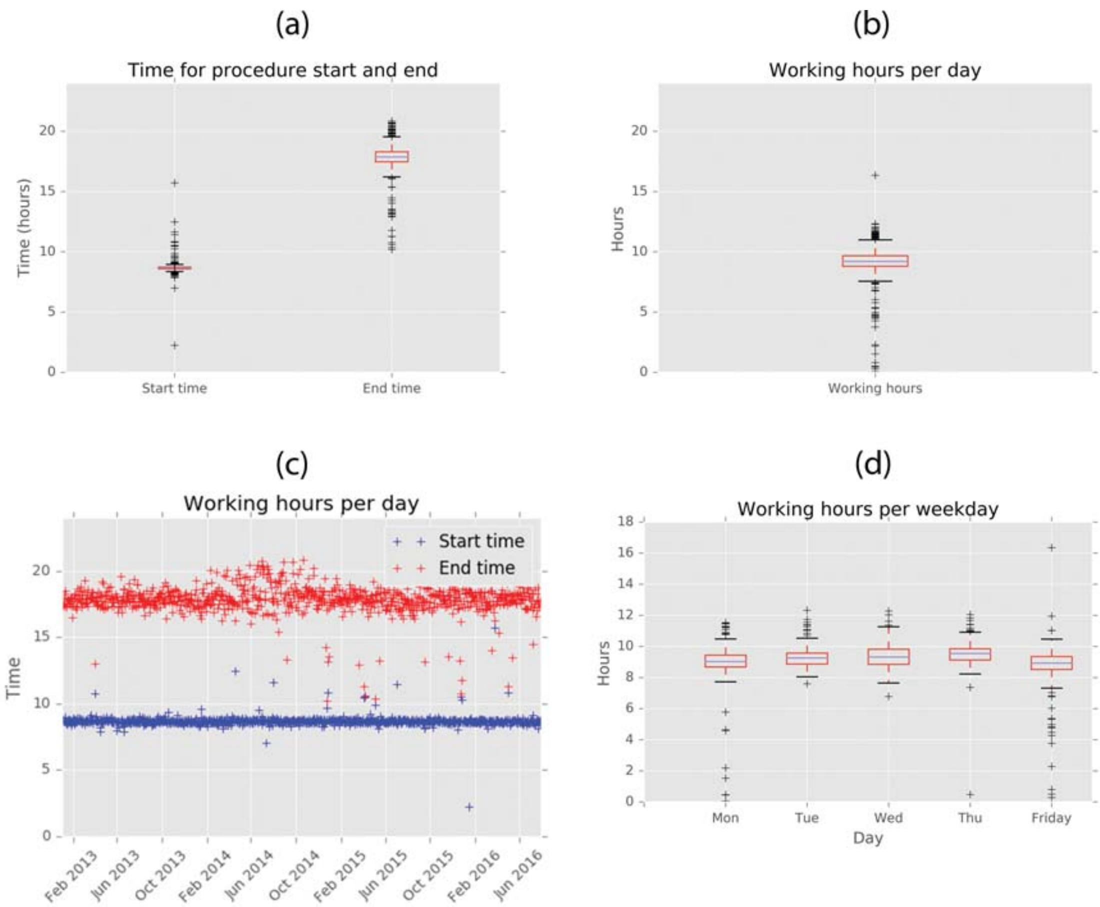


Figure 7.4: Working hours and time for procedure start and end. (a) Box plots reflect variability of the time of procedure start and end at the endoscopy rooms (N=916 days). (b) Box plot reflect variability of the total number of hours per day with one or more patients attended in one or more endoscopy procedure rooms. (c) Graph shows time for procedure start and end per day between 02/01/2013 and 29/07/2016. (d) Box plots reflect variability of the working hours between days of the week.

There is also an important variation in the maximum number of points allocated to each list, with an nationally accepted maximum of 12 points per list. Some units assign 12 points to morning sessions, and 10 to evening sessions, and with a planned activity that varies on a diary base. Points assigned for training lists also varies, typically between 7 and 8. Different number of points are also allocated to procedures, e.g., 1 point for OGD, 2 for colonoscopy, and different ways to adjust for case mix, training lists and emergency patients. Scheduled start and finish time are also different between endoscopy services across the country.

Figure 7.6 shows the activity in the endoscopy unit, including number of patients

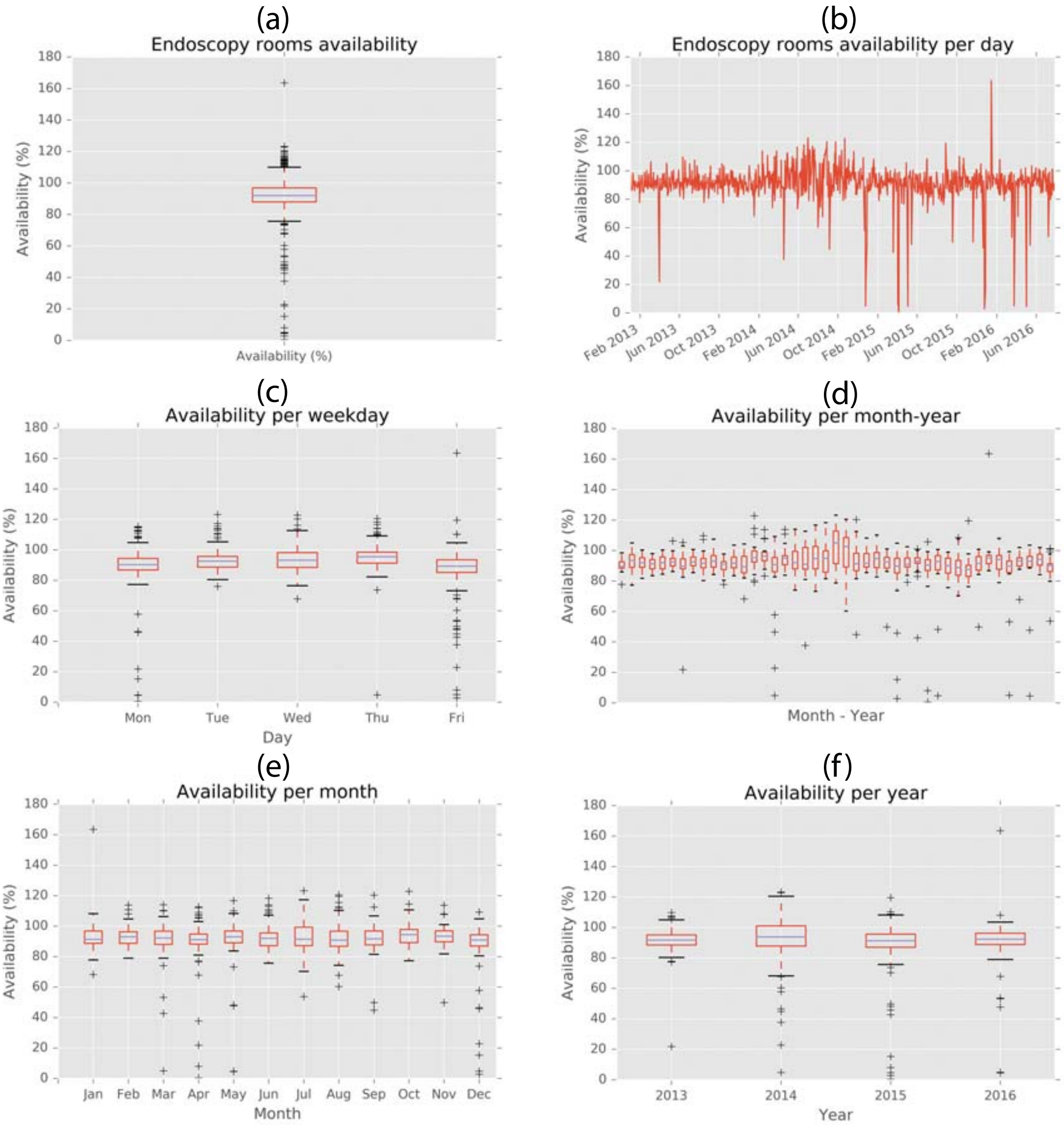


Figure 7.5: Endoscopy room availability. (a) Box plot reflect variability of the endoscopy rooms availability (N=916 days). (b) Line shows endoscopy rooms availability per day between 02/01/2013 and 29/07/2016. (c) Box plots shows variability of the availability per weekday. (d) Box plots reflect variability of the availability score per month. (e) Box plots reflect variability per month in the availability score. (f) Box plots show availability score per year.

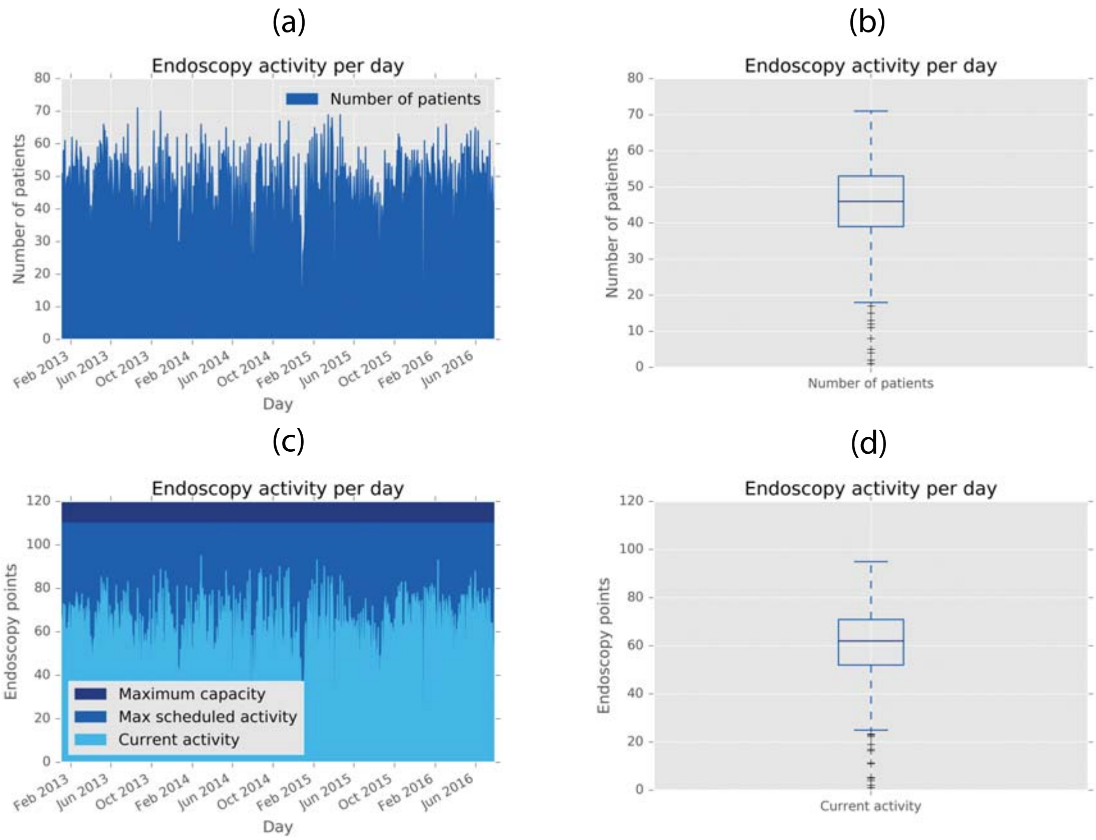


Figure 7.6: Endoscopy activity and capacity. (a) Line shows variability of the number of patients attended in the endoscopy unit per day (N=916 days). (b) Box plot shows variability in the number of patients per day between 02/01/2013 and 29/07/2016. (c) Line shows endoscopy activity per day, maximum capacity represents the maximum number of points that the unit could allocate in a day (12 points per session, 2 sessions per day); Max scheduled activity is the maximum number of points that the unit could allocate based on the current scheduling system (2 sessions per day, 12 points and 10 points); Current activity is the activity (in points) extracted from the Hospital health records. (d) Box plot shows variability of the activity performed at the endoscopy unit.

seen per day, and the equivalent activity in points per day. Maximum capacity was estimated using the national standard of 12 points per session and 2 sessions per day. Maximum scheduled activity was calculated using the standard in this unit (2 sessions per day, 12 points and 10 points, morning and evening sessions). Figure 7.7 shows the OEE performance per day, computed using the ratio current activity/maximum scheduled activity. Figure 7.8 shows variability of the endoscopy OEE performance per weekday, month, and year.

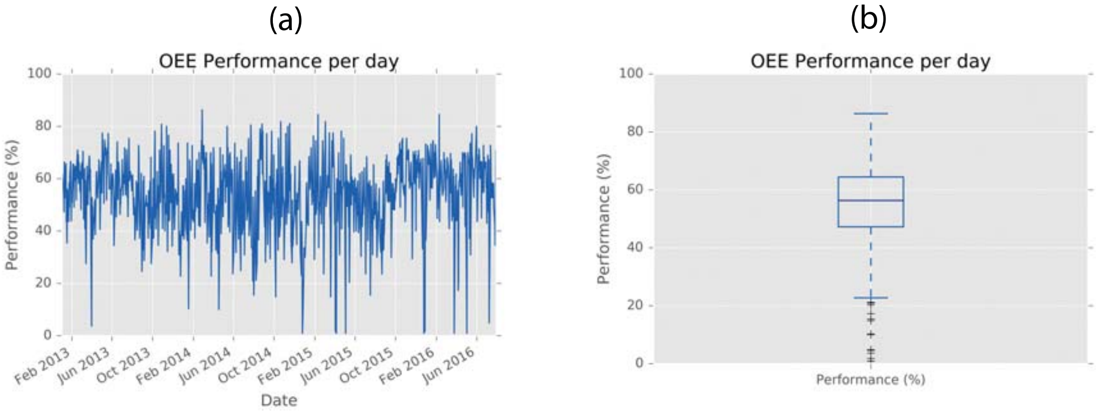


Figure 7.7: Endoscopy OEE performance. (a) Line shows OEE performance per day (N=916 days) computed using the ratio Current activity / Max scheduled activity. (b) Box plot shows variability in the OEE performance per day between 02/01/2013 and 29/07/2016.

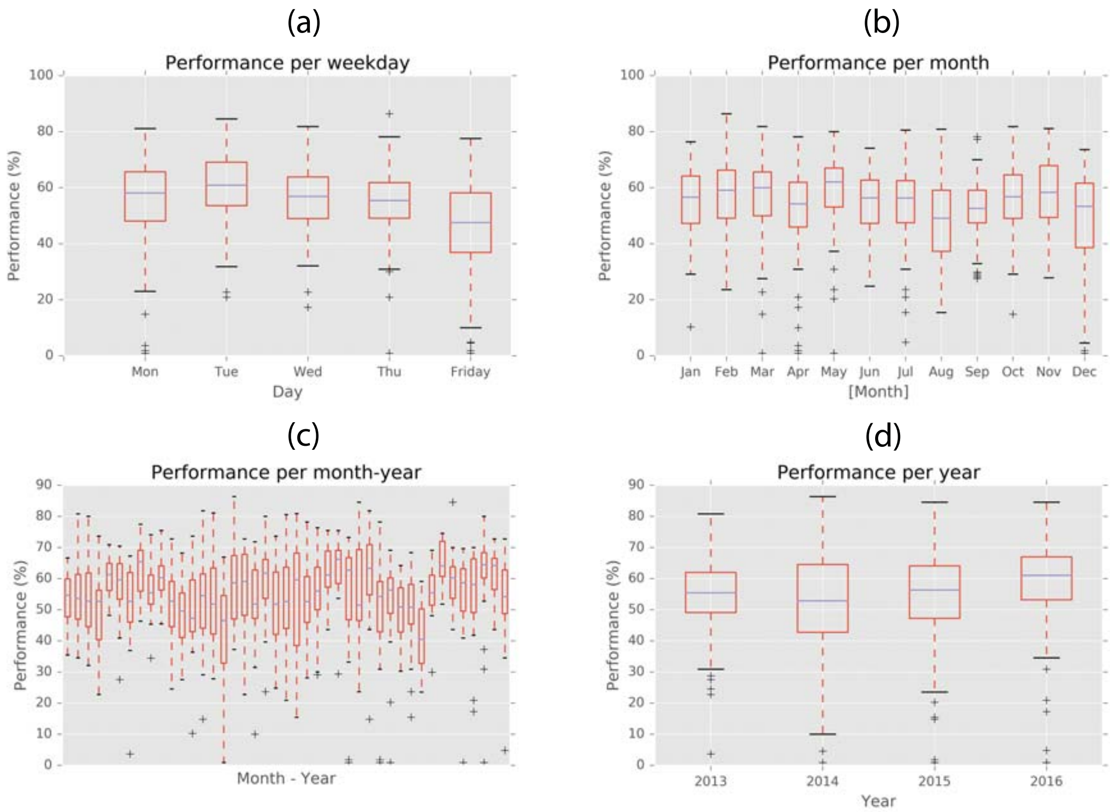


Figure 7.8: Variability in OEE performance. (a) Box plots reflect variability of the endoscopy unit OEE performance per weekday (N=916 days). (b) Box plots shows OEE performance per month. (c) Box plots shows variability of the OEE performance per month-year. (d) Box plots reflect OEE performance variability per year.

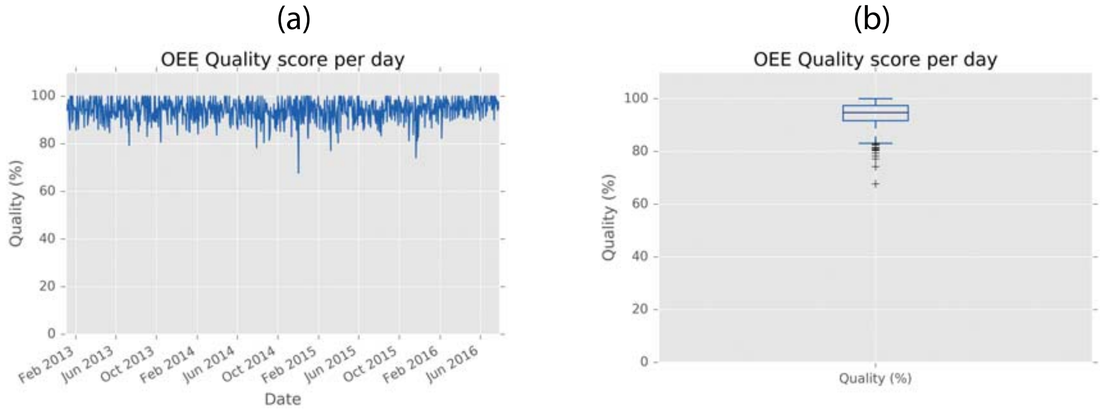


Figure 7.9: Endoscopy OEE quality. (a) Line shows endoscopy unit OEE quality score per day (N=916 days). (b) Box plots shows variability in the OEE quality score per day

### 7.3.6 OEE Quality

OEE Quality was estimated using the completion rate of endoscopy procedures (procedures completes/total procedures). This rate is one of the internationally accepted quality indicators in endoscopy services [37] [101].

Figure 7.9 shows OEE quality score per day and its variability, and Figure 7.10 reflects OEE quality score variability per weekday, month, and year.

### 7.3.7 OEE performance metric

Using the *Availability efficiency, Performance efficiency, and Quality efficiency* estimated above, a global OEE score was estimated for the endoscopy unit.

Figure 7.11 summarises OEE distribution by category, and also variability of the overall OEE score. Figure 7.12 shows variability of the endoscopy unit overall score per weekday, month and year.

### 7.3.8 Main capacity losses at the endoscopy unit

An additional dataset including patient appointment scheduling between 31/05/2016 and 30/06/2016 was analysed. This information was combined with the analysis described above in order to estimate main losses at the endoscopy unit, including the five endoscopy rooms. Figure 7.13 shows a summary of the analysis.

*Schedule loss* was estimated as the difference between the number of points nationally accepted as a maximum to lists (i.e. 12 points per session) and the accepted

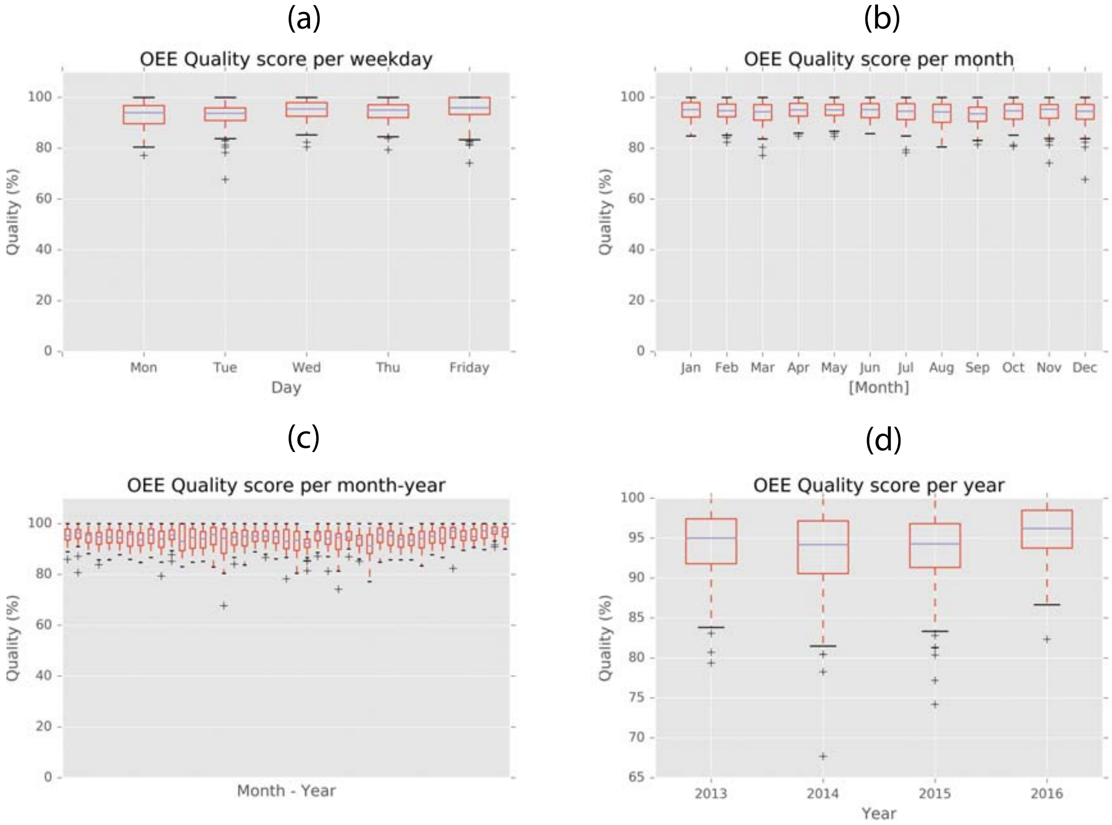


Figure 7.10: Variability in OEE quality. (a) Box plots reflects variability of the endoscopy unit OEE quality score per weekday (N=916 days). (b) Box plots shows OEE quality per month. (c) Box plots shows variability of the OEE quality score per month-year. (d) Box plots reflects OEE quality variability per year

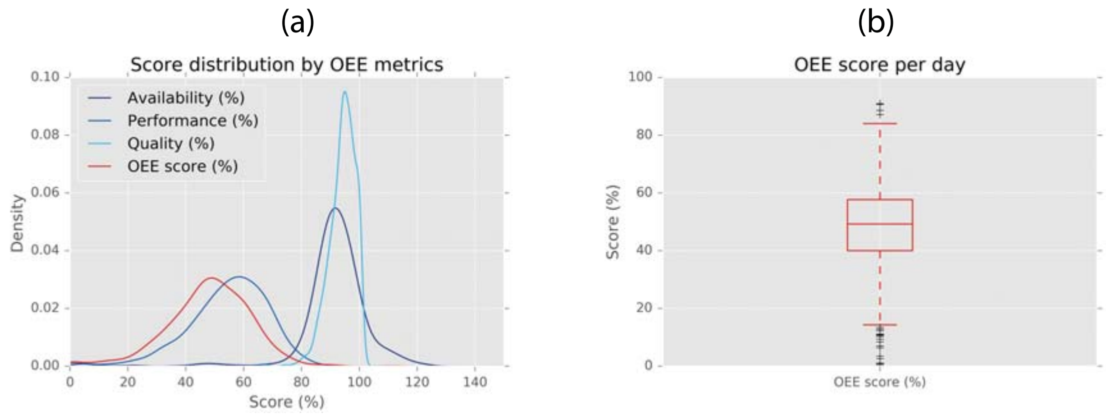


Figure 7.11: Endoscopy OEE scores. (a) Score distribution by OEE metrics, including Availability, Performance, Quality and overall OEE score. (b) Box plots shows variability of the overall OEE score.

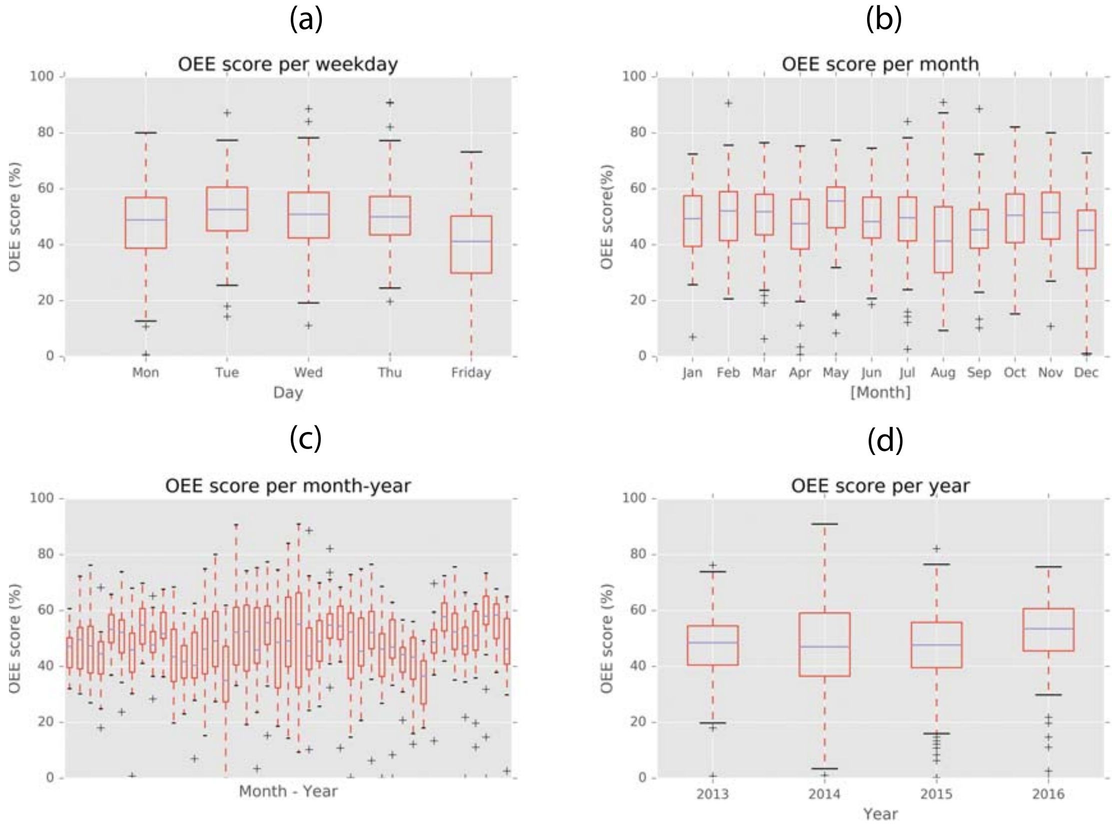


Figure 7.12: Variability in endoscopy OEE scores. (a) Box plots reflects variability of the endoscopy unit overall OEE score per weekday (N=916 days). (b) Box plots shows OEE score per month. (c) Box plots shows variability of the OEE score per month-year. (d) Box plots reflects OEE score variability per year.

standard capacity at the endoscopy unit (i.e. 12 points for morning sessions and 1 points for evening sessions).

*Availability loss* was estimated as the difference between the accepted standard capacity at the endoscopy unit and the allocated capacity per day (i.e. how many points were actually booked for endoscopy procedures).

*Performance loss* was estimated as the difference between allocated capacity and endoscopy activity (i.e. number of patients seen at the endoscopy unit).

*Quality loss* is the difference between the endoscopy activity and the completed endoscopy procedures (e.g., a proportion of procedures are not completed). Completion rate is one of the main auditable quality and safety indicators at endoscopy units.

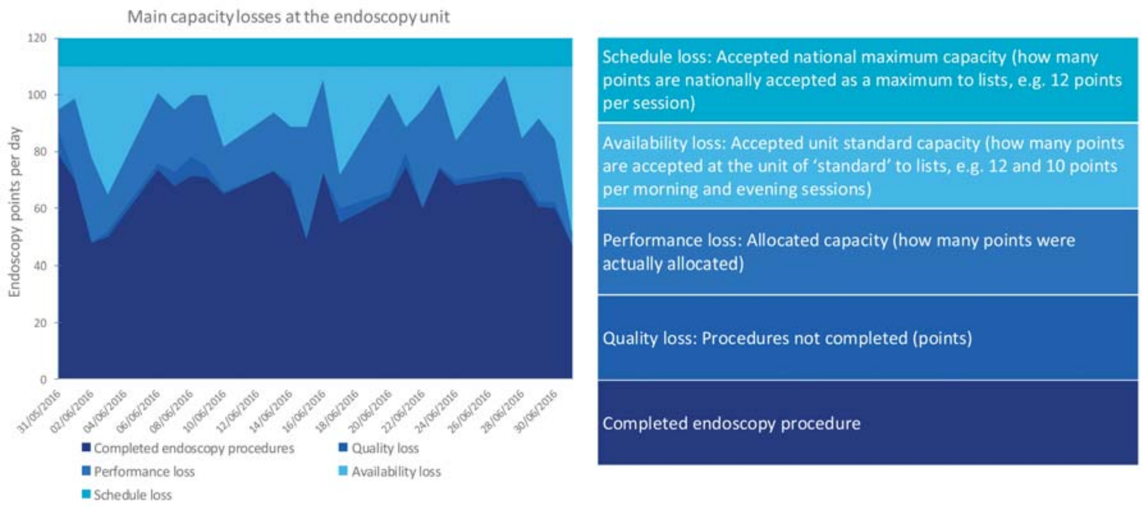


Figure 7.13: Main capacity losses at the endoscopy unit.

## 7.4 Conclusions

In this chapter we introduced a new healthcare system performance metric based on the Overall Equipment Effectiveness (OEE) metric, a KPI developed and widely used in manufacture industry. Real information from a endoscopy service within a UK based hospital was used to develop a study case and to evaluate the impact of this metric in the evaluation of a healthcare services.

Theoretical description of OEE and the six big losses was presented in this chapter, as well as a process to implement it in a healthcare setting. Extending the use of OEE as a driver for improvements in healthcare could increase performance if implemented in a structured and correct way. However, there are many challenges associated with the implementation of OEE for monitoring and managing healthcare services and processes, for example: how it is defined, interpreted and compared; how the OEE data is collected and analysed; how it is aligns with the overall organisation strategy for improvement; how it could be utilised for clinical outcomes improvement purposes.

The evaluation of OEE can be critical for the correct estimation of workstation number to attend the expected increase in the demand for healthcare services, to develop a system redesign, as also for the analysis and the continuous improvement of the system performance. The application of this new indicator can be used by practitioners for healthcare service performance evaluation and improvement, through the identification of key areas were to focusses on.

It is apparent that the successful calculation of OEE depends on the ability to collect data. If the data collected are unreliable, the OEE value may not reflect real equipment or system utilisation. Additional sources of capacity losses could be included in a future analysis if detailed data is collected and available at endoscopy units, example of these are: number of patients that did not attend an scheduled appointment; last-minute cancellations (patients & clinical staff); reduction in capacity because training sessions; capacity loss as a result of rescheduled patients; Endoscopy room turnover time (i.e., time between patient exit and entry of subsequent patient into endoscopy treatment room); equipment failures; and delayed arrival of patients and clinical staff.

A key concept in this approach is the division of performance in three categories: availability efficiency; performance efficiency; quality efficiency, highlighting that a low performance can be result of a low availability instead of a poor performance.

We described an empirical work designed to test and evaluate the relevant importance and applicability of each of the components of this performance indicator in different healthcare services. This can serve as a practical tool for planning or evaluating improvement initiatives.

## 7.5 Chapter Summary

Section 7.1 introduced the problem, research questions and the origin of Overall Equipment Effectiveness (OEE). Section 7.2 described the methodology applied in this chapter, discussed current healthcare performance measure, and presented the concepts of OEE. Section 7.3 described the case of study and the process for the implementation of the OEE in a real-world setting. Finally, Section 7.4 presented conclusions and future research.