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ABSTRACT The discussion of performance measurement is often on a conceptual, not operational, level; advice on the operational and practical matters of obtaining data for process flow improvement is scarce.

We define a measurement plan and study four measurement study designs and corresponding methods and techniques, illustrating these with practical applications and solutions. The measurement plan is presented as a tool to organize the measurement systems for process flow improvement in services and health care.

Our study contributes terminology to the methodological development of improvement initiatives, and we present a tool for practitioners to organize the measurements in process flow improvement projects.

KEYWORDS capacity management, Lean Six Sigma, performance metrics, resource utilization, theory of constraints, throughput time

INTRODUCTION

In operations management, the subject of capacity management has been researched extensively, also in relation to health care and services; see, for example, Sasser (1976), Smith-Daniels et al. (1988), Van Looy et al. (1998), and Olhager et al. (2001). Capacity management aims to make and keep the operation as efficient as possible so that it matches demand and supply. The goal is to minimize customer waiting time and avoid resource idle time (Adenso-Díaz et al. 2002). Note that in a more comprehensive view, capacity management relates to the well-known basic operations performance objectives: quality, speed, dependability, flexibility, and cost (Slack et al. 2010).

Capacity is the maximum level of value-added activity over a period of time that the process can achieve under normal operating conditions (Slack et al. 2010). For planning and control as well as improvement of the organization's operational performance, an important question is: What is the current operational performance compared to the organization's capacity? To answer this question we could quantify the operational performance.

In this article we discuss how to measure the current performance in terms of operational performance metrics. In particular, we focus on how to measure the performance metrics *throughput time* and *resource utilization* in service and health care. In the context of process flow, these metrics relate to the above-mentioned losses of waiting time and idle time.

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In literature (see, e.g., Melnyk et al. 2004), operational performance metrics fulfill the need to provide, among others, the following functions:

- Planning and control: to enable organizations to control performance of the resource and to plan adjustments in the near future.
- Improvement: to enable organizations to diagnose performance of the resource in order to identify opportunities for process improvement.

Usually one does not distinguish between these two functions of performance metrics. However, practical requirements for measuring current performance in both functions are quite different. In planning and control one monitors the process to facilitate day-to-day decision making. These measurements should be of low effort and signal whether a process is in a state of control. In improvement initiatives such as Lean, Six Sigma, and the theory of constraints, one typically measures and analyzes the process to diagnose the current performance. These measurements should provide detailed insight into the process and facilitate improvement techniques for idea generation, such as value stream mapping, exploratory data analysis, and bottleneck analysis.

The literature mentions several difficulties in performance measurement in services and health care operations: low availability of valid measurements compared to manufacturing (cf. McLaughin and Coffey 1990; Snee and Hoerl 2003) and the complexity and intangibility of processes (Bamford and Chatziaslan 2009; Elmaghraby 1991). Further, the discussion of performance measurement is often on a conceptual, not operational, level (Neely et al. 2005). Despite these complications, the literature provides many case studies of successful improvement initiatives in service and health care driven by performance measurement; for example, Motwani et al. (1996), Breyfogle (1999, examples 43.6–43.8), Mabin and Balderstone (2003), Moss (2007), Elkhuizen (2007), Bisgaard (2009), Furterer (2009), and Erdmann et al. (2010).

This article discusses measurement plans for process flow improvement in services and health care. We offer a set of clear definitions for a measurement plan and its elements. We consider typical process metrics, such as the processing time, rework rate, and workload, all of which are related to the themes of resource utilization and throughput time. The first measures wasted production capacity (the provider's loss), and the latter conciders time lost by the client due to waiting (the client's loss).

For the above-mentioned process flow metrics, we elaborate useful measurement study designs and corresponding methods and techniques, illustrating these with practical applications and solutions. Finally, the measurement plan is presented as a tool to organize the measurement systems for process flow improvement in service and health care. Through these results, we translate the conceptual framework into a practical guide for project leaders.

The article is organized as follows. The following section defines a measurement plan. Then we present a selection of metrics that relate to resource utilization and throughput time and their link to organizational performance indicators. Next we elaborate four measurement study designs; for each we mention suitable measurement methods and techniques. The following section presents a measurement plan and discusses additional elements through a real-life example and the final section provides our conclusions.

MEASUREMENT PLANS

A measurement plan facilitates the measurements of performance that could identify opportunities for improvement. It specifies the why, what, how, and who of measurements (Briand et al. 1996). It specifies operational definitions, data collection techniques, roles and responsibilities, and when the data are collected. A measurement plan consists of three elements:

- Metric: the conceptually defined characteristic to be measured.
- Measurement study design: the definition of the study that measures the metric, including the type of measurement study, such as time-and-motion study, work-sampling study, or input–output study, and the measurement method(s) used in the study to record data, such as shadowing employees, self-registration, Enterprise Resource Planning (ERP) system, or Lotus Notes Activity Logging.
- Measurement system: the operational definitions of measurements, including the measurement techniques and tools, measurement procedure,

sample size, possible training, and planning and organization (Breyfogle 1999).

In the next section we discuss a set of metrics that relate to resource utilization and throughput time.

METRICS FOR ASSESSING RESOURCE UTILIZATION AND THROUGHPUT TIME

Metrics for process flow improvement often follow directly from performance measurement models; see Neely et al. (2005). These models, such as the balanced scorecard (Kaplan and Norton 1992), the theory of constraints (Lockamy and Spencer 1998), the CTQ flowdown (De Koning and De Mast 2007), or overall equipment effectiveness (Johnsson and Lesshammer 1999), relate a metric—for example, processing time—to organizational performance indicators, in this case operational costs.

Figure 1 presents a selection of process flow metrics and their relations with performance indicators (based on the model proposed in De Mast et al. 2011). In the downward direction, the model relates organizational performance indicators to process flow metrics. The relations help to translate organizational goals into measurable process flow metrics. In the upward direction, the relations indicate the relevance of the process flow metrics. We discuss the metrics in Figure 1 and relate them to the performance metrics resource utilization and throughput time.

Total Resource Time

The total resource time, given by the total time per resource and the number of resources, is the sum of scheduled or deployed times of a resource devoting its capacity to a particular activity. In services and health care operations, total resource time is usually a major constituent of operational cost.

Processing Time

The processing time of an individual task or process step is the time that a resource needs to process a single job. In the literature, processing time is also called *activity time* or *operator/machine cycle time*.

The sum of the processing times of successive process steps gives the total processing time invested in the job. Note that this total processing time is typically just a minor part of the job's throughput time in the process, because a major part is typically waiting time. The activities' processing times, however, determine the capacity of resources at the process steps.

Rework

Rework considers additional processing time for jobs after the first attempt went wrong or appeared to be insufficient.

First Time Right

The first time right is the ratio of the jobs that were processed correctly in one round to the total number of jobs. It differs from rework in the sense that it

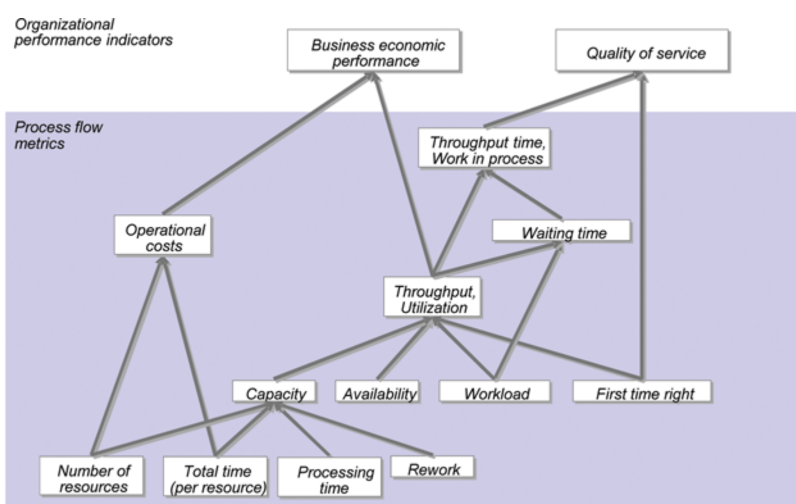


FIGURE 1 Model for process flow metrics based on De Mast et al. (2011). (Color figure available online.)

should be reprocessed (and thus it represents jobs that will pass all the process steps another time).

Capacity

Capacity (also potential capacity or design capacity) is the maximum level of value-added activity over a period of time that the process can achieve under normal operating conditions; that is, capacity is the maximum throughput. Capacity is determined by total resource time, the processing time per job, and rework.

Availability

The availability is one of the elements of resource utilization. It captures the losses in resource time due to breakdowns, setups, distractions (of staff), adjustments, preventive maintenance, or improper breaks. It is often stated as a fraction of total resource time.

Workload

Workload is the demand or work volume that is to be processed. Workload can be defined as the (actual or scheduled) number of jobs per time unit. Note that the workload relates to throughput (see below) when it is smaller than the capacity (taking into account availability and first time right), and it relates to waiting time (see below) when it equals or is larger than the capacity.

Throughput, Utilization

Throughput is the actual amount of work that flows through the process. It is typically stated as a number of jobs processed per time unit. Throughput is bounded by the process's capacity and the workload and further depends on availability and first time right ratio. The ratio of throughput to capacity gives an overall measure for resource utilization.

Waiting Time

The waiting time refers to the time spent by a job in the process while no activity is performed on it. In health care, one distinguishes between waiting time before entering the process (admission time) and waiting time in the process. In this article we will focus on the waiting time in the process.

Throughput Time, Work in Process

The throughput time is the total time a job spends in the process; it is also called the *process cycle time*. It includes the processing times of individual process steps, waiting times, and rework. In service and health care processes, waiting time is usually by far the largest constituent of the throughput time.

The work in process (WIP) is the number of jobs in the process, either undergoing an activity or waiting in between process steps. The WIP and throughput time are related through Little's law as

$$\text{Throughput time} = \text{WIP}/\text{throughput}.$$

The organization's *quality of service* refers to issues that may be an annoyance to clients. There are numerous factors affecting quality of service, such as cleanliness of the facilities and courtesy of staff. However, in the context of process flow improvement, quality of service relates to the throughput time and first time right ratio. Figure 1 also shows how the above-mentioned process flow metrics affect the organization's *business economic performance* through operational cost and the throughput (assuming that an organization receives revenues proportional to the throughput).

Table 1 presents a complete overview of these metrics (column 1) together with a brief description (column 2). In columns 3 and 4 we indicate whether the metric is related to resource utilization (RU) or throughput time (TT). In the following section, we discuss measurement study designs to measure these process flow metrics.

Note that the scope of the measurements that we aim to describe is limited to what Slack et al. (2010, p. 500) called "the operation's domain," and it concerns measurement of objective properties of the delivered service. A completely different measurement ambition is "the customer's domain" (Slack et al. 2010, p. 500), which concerns the measurement of subjective properties such as the customer's perception of the quality or value of the service, his or her expectations about the service, customer satisfaction (which could be defined as the gap between the perceived and expected quality), and customer loyalty. Such measurements of, essentially, emotional, behavioral, and affective characteristics are based on entirely different conceptual models, involving insights and techniques from marketing and psychology rather

TABLE 1 **Overview of Common Metrics, their Definitions, and Whether they Relate to Resource Utilization or Throughput Time**

Metric	Description	Resource utilization (RU)	Throughput time (TT)
Capacity (Cap)	Maximum throughput	X	
Throughput (TP)	Actual amount processed	X	X
Workload (WL)	Demand that is to be processed	X	
Work in process (WIP)	Total job volume in the process		X
Total resource time (TRT)	Number of resources (N) and planned production time (TotT)	X	X
Availability (Av)	Usage of total resource time	X	X
Processing time (PT)	Time to execute an activity	X	X
Rework (RW)	Extra processing time per activity	X	X
First time right (FTR)	Defect-free production when delivered	X	X
Waiting time (WT)	Nonprocessing time spent in the process		X
Throughput time (TT)	Total time spent in the process		X

than operations management; see, for example, Parasuraman et al. (1985), Peterson and Wilson (1992), Danaher and Haddrell (1996), and Hayes (2008).

MEASUREMENT STUDY DESIGN

In this section we describe four measurement study designs suitable for process flow improvement in service and health care (cf. McLaughin and Coffey 1990). These designs group various methods that measure process flow metrics.

Output–Input Design

In an output–input design, one measures input or output metrics of a process on a high level (treating the process as a black box). These metrics are then used to calculate aggregate metrics such as unit costs, which is the ratio of the total (operational) cost to the throughput.

For example, at a postal service company the unit cost is a common metric for resource utilization. As seen in Figure 2, weekly data on the sorting volumes (that is, the throughput), the total resource time (TRT), and the operational costs (booked under a specific code that represents the variable costs, use of material, and scheduled personnel) are recorded in a measurement form. From these data, one can calculate the average weekly unit costs (for each week divide the operational costs by the sorting volume).

Project: [title]		Date: Q1-Q2/2009		
Week number	*Sorting volume*	*TRT (hrs.)*	*Operational costs (Euros)*	*Unit costs (Euros)*
1	1453658	468	€ 8110	€ 0,0056
2	1760892	546	€ 9462	€ 0,0054
3	1825426	546	€ 9462	€ 0,0052
4	1698456	546	€ 9462	€ 0,0056
5	2002563	609	€ 10554	€ 0,0053
6	1958325	588	€ 10190	€ 0,0052
7	1856954	546	€ 9462	€ 0,0051
8	...	...	...	...
...	...	...	...	...

FIGURE 2 **Example of a measurement form for throughput, total resource time, and total operational costs.**

Other aggregate metrics that one may use are (cf. Hatry 1980; Maskell 1991):

- Throughput–capacity ratio: the ratio of throughput to capacity over a period of time indicates what part of the resources is used to process jobs.
- Workload–throughput ratio: the ratio of the workload to the throughput per time period is an indication for the waiting time before entering a process.
- WIP–throughput ratio: the ratio of the WIP and the throughput per period of time predicts the throughput time.

Input–output designs make use of the following metrics:

- Capacity: this can be established for each process step by dividing the total resource time by the potential (or design) processing time of the activity.
- Throughput: one may obtain the throughput per time period from a production schedule (that records both scheduled and released production). Note that this concerns the actual flow of work through the process.
- WIP: from a production schedule system (often such system can make snapshots of work volume in the process), or through Little's formula ($WIP = TT * TP$).

- Workload: can be collected from a production schedule system (often such systems report the workload to be processed).

Measurement System Technique: Data Warehouse

High-level data on metrics such as throughput, operational costs, workload, or even throughput time are often available from the organization's data warehouse, possibly through a finance or control department. These data are useful in an output–input study design. For example, in a hospital, data are available on the total number of beds and the number of days each bed is operational (the capacity in days, say, per week) and the total number of days these beds are occupied (the throughput in occupied bed days). Based on these metrics, one can form a capacity–throughput ratio per week to diagnose the resource utilization with respect to hospital beds. At an Internet provider, one may construct a unit cost measure through the ratio of the total operating cost to the total number of megabytes available.

The workload or WIP metrics may not be directly available in data warehouse systems. However, one can derive the WIP through a check for which jobs the beginning of the first process step is before this moment and the end of the final process step after this moment (or are still open and thus have no final time stamp).

Resource Measurement Design

In resource measurement designs we follow a resource (an employee, a machine, or a facility) during a shift and record its occupations; cf. Baines (1995). For example, we follow a nurse during his or her shift and record the beginning and end time of each activity that he or she engages in, such as serving food to patients, making beds, or distributing medicines.

A standard method for resource measurement is a time-and-motion study or continuous-time study (cf. Milne et al. 1953; Salim and Bernold 1994). In a time-and-motion study, one typically uses time stamps to record the beginning and end of each activity during a shift; see Figure 3 for an example of a time-and-motion study in health care.

Nurse:	[name]	Date:	4/2/2010
		Start/stop shift:	9:00 / 11:00
Process step	Start	Stop	Rework (Y/N)
Dismissal letter	4/2/2010 9:19	4/2/2010 9:40	N
Medicine card	4/2/2010 10:08	4/2/2010 10:14	N
Transport	4/2/2010 10:15	4/2/2010 10:16	Y
Transport	4/2/2010 10:19	4/2/2010 10:31	N
Dismissal letter	4/2/2010 10:34	4/2/2010 10:41	N
Medicine card	4/2/2010 10:42	4/2/2010 10:47	N
Transport	4/2/2010 10:48	4/2/2010 10:57	N

FIGURE 3 **Example of a time-and-motion study in health care.**

The nurse records for each activity (column 1) the start and stop times in columns 2 and 3. In addition, the nurse indicates whether the executed process step concerns rework or not (column 4). Furthermore, the name of the nurse, the date of the shift, and the length of the shift are recorded at the top of the sheet.

From the time stamps in a time-and-motion study one can calculate the processing time of a process step by subtracting the start time from the stop time. One can calculate the availability from the ratio of the sum of processing times to the total resource time (in this case the nurse was scheduled for the dismissal process from 9:00 a.m. to 11:00 a.m.).

Below we give detailed guidance on how to determine metrics for process flow improvement from time-and-motion study measurements:

- Processing time: by subtracting start time from stop time.
- Nonavailability: the total of the times in between a task's stop time and the next task's start time, as a fraction of total resource time. Note that when there is insufficient work, time in between tasks may be idle time (time waiting for a job) instead of nonavailable time (time lost due to distractions or the resource being down).
- Rework: found from the processing times of activities labeled as rework (column 4).

Another method frequently used in resource measurement designs is a work-sampling study; see Baines (1995); in health care see Urden and Roode (1997). In work-sampling one records in a tally table, on given time intervals, the type of activity the resource is engaged in; see Figure 4. These time intervals can be chosen equidistant—for example every 5 minutes—or random, to avoid interaction between observations and work schedule (e.g., in case of consults with a fixed length of 5 minutes). Consider

Nurse:	[name]	Date:	4/2/2010
Activity	Checks	Activity time	Percentage of total
Dismissal letter	IIIIIII	35	
Medicine card	II	10	
Transport	IIIIIII	35	
Other	IIIIIIII	40	
Total	24	120	

FIGURE 4 Example of a work-sampling study in health care.

the nurse whose activities were measured in Figure 3. A work-sampling study with time intervals of 5 minutes would have yielded the measurements in Figure 4.

From the data in the column "Checks" of Figure 4 we can calculate the time spent on each activity. For example, at seven time intervals the nurse was performing the transport activity. We weight these intervals with an interval length of 5 minutes and thus measure a total of 35 minutes spent on transport. In addition, we can calculate the total time covered by the study as 24 intervals (120 minutes). The availability is the ratio of the sum of times spent on designated activities (in this case 80 minutes) to the total time; that is, about $Av = 67\%$. From the time-and-motion study we would have found an availability $Av = 61/120 = 51\%$.

Below we give detailed guidance on how to derive metrics for process flow improvement from work-sampling studies:

- Total resource time: can be derived from multiplication of the total number of checks and the length of the time interval. This can also be done per activity, which forms the start of an employee occupation study.
- Processing time: provided that the throughput of each activity is recorded, the processing time per activity follows from the total resource time divided by the throughput.
- Availability: from the ratio of total checks on designated activities to the total number of checks.

Both time-and-motion and work-sampling studies have their advantages. The time-and-motion study is accurate and offers the opportunity to observe the activities in great detail, whereas work-sampling takes less effort and the possibilities to execute more measurements at the same time; see Finkler et al. (1993) for a comparison of both methods.

Measurement System Techniques: Shadowing and Self-Registration

For both time-and-motion and work-sampling studies one can collect data through shadowing. This is a technique in which an employee follows the resource during a shift or a working day. The employee who does the shadowing may use a measurement form with a preprinted tally table with activities (in case of work sampling) or a table with an activity column and columns for start and stop times. An advantage of shadowing over self-registration (discussed next) is that the observer can combine the time measurements with other observations concerning inefficiencies and improvement opportunities in the process, thus providing input for Gemba studies and other Lean improvement activities (Mazzocato et al. 2010; Womack 2006).

Another technique often used in work sampling and time-and-motion studies is self-registration. In the case of self-registration instead of shadowing, one should aim to design the measurement so it does not influence an employee's schedule and work pace. One can think of reducing the sample frequency when using a work-sampling method or reducing the number of different activities when using time-and-motion studies.

In health care one often measures time allocation of nursing personnel with time-and-motion studies through self-registration; see, for example, Wijma et al. (2009). By keeping the number of different activities small, a nurse is able to manage the measurements. Although this small number of different activities might lead to less detailed information, one can collect measurements from more shifts or more departments. A project leader may choose to do both shadowing and self-registration, so he or she can determine whether self-registration is in line with the results from shadowing and, if so, collect large amounts of data at the same time.

Job Measurement Design

In job measurement designs one follows a job through the process to capture job-specific metrics such as processing times, waiting times, and rework; that is, typical elements of the job's throughput time. A method for job measurements is the use of a traveler sheet or traveler check sheet, which travels along with the request, transaction, or patient through the process (Breyfogle 2008). It is used to record time stamps when entering or leaving an activity. This method is a simplification of process activity mapping, often used in industrial engineering (Hines and Rich 1997).

Figure 5 shows an example of a traveler sheet, attached to a sales order in a sales department. The order came in on April 1, 2010, and contained a request to prepare and deliver the order on June 23, 2010. At each process step the start and stop times are recorded. The process steps are in the first column of the measurement form. The start and end times are recorded in columns 2 and 3, and columns 4 and 5 are used to record the start and end times of possible rework activities. For example, the process step "Take order" of the job in Figure 5 initially started at 2:19 p.m. and ended at 2:26 p.m. on Thursday, April 2, 2010. After the client received a confirmation, he or she got back to the sales department to correct some of the order details. The step "Take order" was executed a second time, starting at 10:08 a.m. and ending at 10:13 a.m. on June 3, 2010.

If (internal) transportation takes place in a process (think of a patient transported from an intensive care to a long-stay department), one may also record time stamps at the beginning and end of the transport activity. Thus, we see transportation as a process step.

Below we give detailed guidance on how to get metrics for process flow improvement from traveler sheets measurements:

- Throughput time: the difference between the arrival time (4/1/2010, 2:07 p.m. in Figure 5) from the last stopping time (6/23/2010, 12:14 p.m.).
- Processing time: for each activity or process step one can calculate the processing time by subtracting the start time from the stop time.

Client number:	[client id]	Arrival date (dd/mm/yyyy):	1/4/2010
Order number:	[order id]		

Process step	Start 1	Stop 1	Start 2	Stop 2	Comments
Arrival order		1/4/2010 14:07		3/6/2010 9:34	
Take order	1/4/2010 14:19	1/4/2010 14:26	3/6/2010 10:08	3/6/2010 10:13	
Register order	1/4/2010 14:26	1/4/2010 14:35	3/6/2010 10:13	3/6/2010 10:15	
Confirm order	1/4/2010 14:35	1/4/2010 14:36	3/6/2010 10:15	3/6/2010 10:16	
Prepare order	23/6/2010 8:03	23/6/2010 11:31			
Check order	23/6/2010 11:31	23/6/2010 11:37			
Clear order	23/6/2010 11:39	23/6/2010 11:42			
Send out order	23/6/2010 12:03	23/6/2010 12:14			

FIGURE 5 **Example of a traveler sheet in a service process.**

- Rework: possible rework time is recorded for each activity as the differences between Start 2 and Stop 2. One can sum these individual rework times to find the additional processing time due to rework or compute a rework rate for each rate from the ratio of the total number of rounds to the total number of jobs.
- Waiting time: one calculates the waiting time by deducting the stop time of a process step from the start time of the subsequent process step.

Measurement System Techniques: Track and Trace and Activity Logging

Other methods for job measurements are very similar to the use of traveler sheets but generate automated time stamps through track and trace or activity logging systems.

Techniques to track and trace products in the process, such as radio-frequency identification, are commonly used in logistics and manufacturing industries (McElroy et al. 2008). For example, in warehousing in the clothing industry, a product is registered on several locations in the process. Typically, a product is scanned when entering and leaving a storage point and when eventually entering and leaving the retailer. These data can be used to compute the throughput time of an individual product as well as cycle, storage, and transport times.

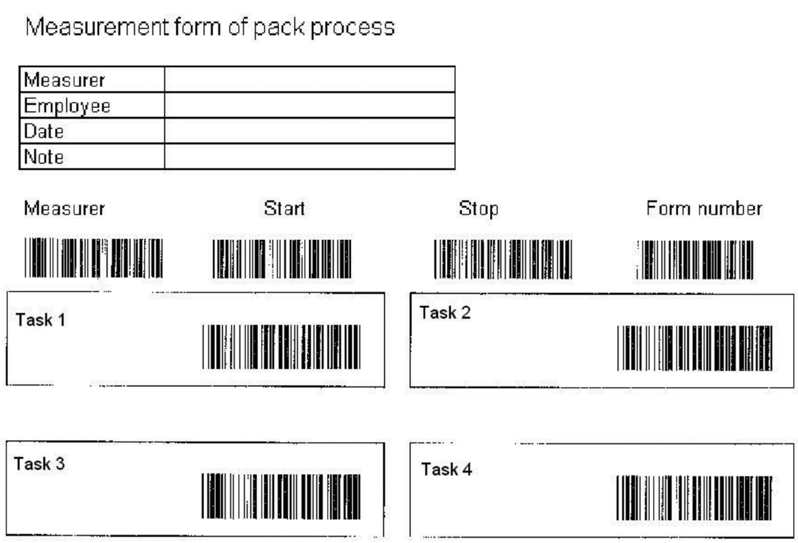
Other typical applications are found in production and assembly processes. An operator may scan the product at the start and end of an activity, thus registering the processing time. At the end of the shift, one may also analyze how much time the operator spent on the activity and how much time was spent on other activities, breaks, or nonproductive hours. These automated track and trace techniques can thus be used to combine resource and job measurement designs.

In the service industries, software such as Lotus Notes and People Soft facilitate activity logging, including start and stop times of activities. Measurement pens and barcode scanners are additional options for combined resource and job measurement designs. In case of the former, an employee registers the start of an activity with a special pen, equipped with a small camera, on a special form containing a raster code. By the scored position on the form the pen records a code linked to the activity, a code linked to the specific form, and the start time. At the end of the activity, the nurse scores the stop field on the form; the pen then records the stop time of the activity. Note that the forms are linked to individual jobs, and registrations are linked to employees. By combining information from a single form and different employees, one facilitates a job measurement design; by combining information from different forms but a single employee, one facilitates a resource measurement design.

Barcode scanners enable a similar way of working (Figure 6 shows an example). Typically, a list of activities with corresponding barcodes is used by an employee or a team member who is shadowing the resource. The list also includes a barcode that corresponds with the name of the team member who executes the measurement and barcodes that refer to the start and stop of the measurement period. In case of a resource measurement design, when a barcode is scanned, the scanner records a time stamp and a code (based on the barcode) that refers to an activity. If a job measurement design is chosen, one uses barcode forms that are unique for each job. An employee scans the barcode at the start of an activity and a stop code when finished. The scanner then records a code that corresponds with the employee (based on the scanner itself), the activity code and the product code (based on the barcode with a unique job component), a time stamp at the start, and a time stamp at the end of the activity.

Quality Inspection Design

The quality inspection design focuses on the end quality of the processed job. Such designs are particularly suited for measuring delays and defects. Focusing on delays, one records, for a number of jobs, the agreed-upon delivery time and realized delivery time. A defect is a job that a client sends back to reprocess when it does not meet the specifications. Defects are captured in methods that measure the first-time-right (FTR) ratio of the process. The FTR ratio is defined as the ratio of the throughput that meets the specifications of the client to the total throughput. Recording defects requires an inspection of the quality, either a 100% inspection on all jobs, or a sampling inspection. For example, CD-ROMs containing software products undergo an automated, 100% quality inspection before they are sent out. If the quality does not meet the specification, the CD-ROM is registered as a defect in a system's log. The defect rate over a time period is then calculated as the ratio of the number of registered defects to the total number of CD-ROMs produced and inspected. As an alternative to automated logging, check sheets can be used (Pyzdek 2001). The operator who encounters a defect places a check in the row that corresponds to the type of defect; see Figure 7. In this case, for example, the operator encounters two damaged CD-ROMs in the sample of 359 produced CD-ROMs. The measurement form also includes figures such as throughput volume, workload, date or time period, and name of inspection operator.


Measurement form of pack process

Measurer	
Employee	
Date	
Note	

Measurer Start Stop Form number

Task 1

Task 2

Task 3

Task 4

FIGURE 6 **Example of a form for barcode scanners.**

Check sheet number:	[number]	Inspection operator:	[name]
		Date:	4/8/2009
Defect	Frequency	Sample size:	359
Incomplete copy	IIII	Throughput:	359
Installation error	IIIIII	Workload:	359
Damage	II		
Other	IIIIIIIIII		
Total	22		

FIGURE 7 **Example of a defect check sheet for software updates.**

Below we give detailed guidance on how to derive metrics for process flow improvement from defect check sheet measurements:

- First time right: in case defect types are additive (a job can have at most one defect), the FTR follows from 1 minus the ratio of total number of defects to the sample size. In case defects are multiplicative (a job can have more than one defect type), the FTR per defect type follows from 1 minus the ratio of defects per type to the sample size. Under the assumption that the types of defects are independent, the overall FTR is then calculated through the multiplication of the FTRs per defect type. Note that in case of multiplicative defects, one should not add up frequencies to a total sum of defects (as done in Figure 7), because this figure has no meaning in the context of FTR on job level.
- Workload and throughput: provided that these figures are included in the measurement form.

Another method is to measure complaints (in the case of a delay) or reclaims (in the case of a defect) that the organization receives, possibly through the client contact center. Again, one could rely on log data of all incoming complaints or reclaims, or one could have employees at the client contact center record complaints or reclaims during a sampling period.

Consider, for example, an organization that offers cell phone repair services and gives a one-month guarantee on its services. To record measurements on complaints and reclaims of 2 weeks (approximately 250 repairs in the period from January 3 to January 15, 2011), employees measure all incoming complaints and reclaims for 1 month and 2 weeks (because from then on claims from the initial 2 weeks no longer fall under warranty). The measurement sheet in Figure 8 presents an example of nine

Employee number:	[employee id]	Relate to repairs in period	3-8/jan/2011 10-15/jan/2011	
Case number	Date Arrival	Date repair	Reclaim/Complaint	Comment
1	8-Jan-11	4-Jan-11	Complaint	Delivery 2 days late
2	8-Jan-11	3-Jan-11	Complaint	Delivery 1 day late
3	10-Jan-11	??	Complaint	Call for status
4	11-Jan-11	10-Jan-11	Reclaim	Display error
5	13-Jan-11	8-Jan-11	Complaint	Delivery 1 day late
6	14-Jan-11	12-Jan-11	Reclaim	OEM display
7	14-Jan-11	12-Jan-11	Reclaim	OEM display
8	14-Jan-11	7-Jan-11	Complaint	Delivery 4 days late
9	17-Jan-11	15-Jan-11	Complaint	Delivery 1 day late

FIGURE 8 **Example of a measurement sheet for reclaims and complaints in services.**

claims or reclaims recorded by an employee. For each incoming case, the employee registers the date of arrival, the date of repair, whether it is a complaint or a reclaim, and more details about the complaint or reclaim.

From the data in Figure 8 we are able to derive complaint rates or reclaim rates. Below we give detailed guidance on how to derive metrics for process flow improvement from a defect check sheet measurements:

- First time right: related to reclaim, the defect ratio of a period follows from the number of reclaims over the total throughput. This ratio excludes defects from clients who do not send in reclaims.
- Throughput time: for the subset of clients who complain about the delivery, one may obtain the throughput time of the delivery process (in this case from the comments).

Technique: Interviews for Service Quality

An alternative method is to randomly select a group of clients and interview them about the service quality regarding delays or defects. One may then use a similar sheet to record these data as for measurement done at a client contact center in Figure 8.

We end this section with Table 2, which presents an overview of the four measurement study designs as discussed above. For each design we list alternative methods and indicate metrics for which the design is a suitable study design. The table also indicates whether metrics are related to resource utilization or throughput time.

TABLE 2 Overview of Measurement Study Designs for the Process Flow Objectives Resource Utilization and Throughput Time

Measurement study design	Measurement method	Metrics	Relate to RU, TT
Output/input	Throughput capacity (or target) ratio	Cap, TP	RU
	Unit cost measure	TP	RU
	Workload throughput ratio	WL, TP	TT
	Little's law	WIP, TT, TP	TT
Resource measurement	Work sampling	TRT, PT, Av	RU
	Time-and-motion study	PT, Av, RW, TP, Cap	RU
Job measurement	Track and trace	TPT, PT, RW, WT, TP, WL, WIP	TT
	Traveler sheets	TPT, PT, RW, WT	TT
Quality inspection	Sampling inspection	FTR	RU
	Complaints/reclaims or interviews	FTR, TT	TT, RU

MEASUREMENT SYSTEMS: ADDITIONAL ELEMENTS

In addition to the designs, methods, and techniques mentioned in the previous section, a measurement plan should specify the measurement procedures, sample sizes, possible training, and planning and organization. We illustrate these elements of the measurement system in the example below.

Example 1: A Measurement Plan for a Sales Order Process

Consider an administrative department whose employees process incoming orders. The process steps on a high level are as follows:

- Take the order.
- Register the order in production planning.
- Check and finalize the order.

Currently, the department faces high operational costs. The majority of these costs are personnel costs. From an initial observational study, including brief interviews with some of the employees, it was concluded that availability of the employees could be improved by reducing time lost on disturbances, such as completing missing information, downtime of the database, and telephone calls not related to client orders.

We measure the process's current performance. The study is limited to the availability of the employees. The chosen study setup is a work-sampling design through shadowing, in which team members register the activities that an employee is engaged in at fixed time intervals. For 2 weeks the team member follows three employees and observes and records the activity of each employee every 5 minutes. Self-registration and automated recordings would have been alternative setups.

The measurement plan in Figure 9 organizes the measurements for the availability metric. First, it states the metric to be measured. Next, it states the study design. Furthermore, the measurement plan includes the following:

- Techniques: a tally table with a list of predefined activities in the process, categorized as primary task (available) and distraction (nonavailable).
- Tools: a paper form with the tally table, a pen, and a clipboard. Furthermore, one needs an interval timer that signals every 5 minutes.
- Training: Nelson et al. (2004) asserted that one should organize training and pilot measurements to fine-tune the study's setup. In addition, employees in a finance or control department may need to be informed or trained, because they are often not familiar with the metrics and definitions used in a process flow improvement project.
- Operational definition: the definition of the metric as well as on what unit basis it is measured (per shift) and the performance goal (maximize; i.e., the larger the better).
- Sample size: the planned number of observations. Here, 30 shifts on workdays that are representative for the process in terms of order types and workload.
- Planning: the actual measurements are scheduled on 10 working days in September.
- RACI: roles and responsibilities are established using the RACI (responsible, accountable, consulted, and informed party) model. Because data collection in

Metric	Measurement study design		Measurement system				
	Study	Method	Techniques	Tools	Training	Operational definition	
Availability	Work-sampling	Shadowing	Tally table registration: availabilty/ nonavailability per minute	Paper form with tally table, pen, clip-board, interval timer	2-day trial and feedback	The ratio of time spent on primary tasks to total work time	*Unit:* per shift *Goal:* maximize
...	...	...	...	...	...		...

Sample size	Planning	RACI	Deadline	Data matrix
30 shifts on work days	10 working days in September, 3 shifts per work day	*R:* assistant *A:* project leader *C:* manager *I:* manager	11/30/2010	`project_sheet.xls`
		...	...	...

FIGURE 9 **Complete measurement plan for the metric availability of employees in an administrative process, as discussed in Example 1. (Color figure available online.)**

improvement projects is often a time-consuming activity, one should consider hiring temporary staff (student workers) to assist during the data collection period.

- Deadline: the deadline for the measurement phase. Then the measurements should be processed and structured in a data matrix.
- Data matrix: raw data are processed into realizations of variables; in this case, an availability percentage per shift.

CONCLUDING REMARKS

Process flow improvement in health care is an urgent and important pursuit. In this article we present the measurement plan as a tool that guides project leaders when measuring performance metrics for process flow improvement in services and health care. In particular, we discuss the performance metrics resource utilization and throughput time, but our approach could also apply to other performance metrics. This article's contributions can be summarized as follows:

1. A well-defined measurement plan that consists of a metric, a measurement study design, and a measurement system.
2. A selection of four suitable measurement study designs for process flow improvement in service and health care:
   a. Output–input designs: these are figures obtained from high-level planning and control systems such as a resource planning and a production schedule.
   b. Resource measurement designs: refers to studies that obtain measurements by following a resource during operations.
   c. Job measurement designs: measures obtained by following a job through the process.
   d. Quality inspection designs: studies that measure the products' quality issues that relate to the throughput time and the resource utilization.
3. Detailed guidance for project leaders on which method and technique to choose, how to organize the measurement system, and how to obtain data.
4. Additional elements that should be included in a measurement plan, such as training, operational definitions, and roles and responsibilities.

These results go beyond the conceptual discussion on performance measurement in services and health care. The results have implications in several fields.

Project Management

In addition to the work of De Mast et al. (2011), this article shows *how* to measure process flow metrics. That is, the above-mentioned components offer methodological and practical guidance to a project leader responsible for the execution of measurements within the context of process improvement initiatives in services and hospital.

Standard Improvement Approaches

The presented models can be readily integrated in currently popular standard improvement approaches, such as Lean, Six Sigma, and the theory of constraints.

The presented material could form a basis for training material for any of these approaches.

Directions for Future Discussion

An important topic for further study is to share more techniques for measuring the metrics proposed in the section on metrics, so that project leaders do not need to design ad hoc measurement systems (Ljungberg 1998). In addition, the discussion is not limited by the metrics and designs discussed here. One could discuss other metrics, such as metrics that drive revenues, and more corresponding suitable designs (for any proposed metric).

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