Productivity

Introduction

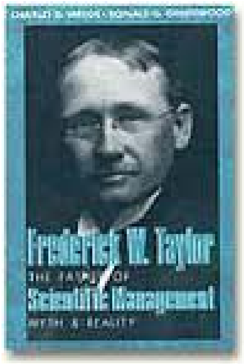
Productivity as a Major Challenge

"The conservation of our national resources is only preliminary to the larger question of national efficiency. [quote by a US president]"

Who is the president quoted here?

In this module: Subway + Airlines

Introduction to Productivity



Published in 1911

Opens with a discussion of Theodore Roosevelt’s address about improving national efficiency and making more productive use of limited resources

“We can see and feel the waste of material things. Awkward, inefficient, or ill-directed movements of men, however, leave nothing visible or tangible behind”

“Employers derive their knowledge of how much of a given class of work can be done in a day from either their own experience, which has frequently grown hazy with age, from casual and unsystematic observation of their men, or at best from records [..]”

“This work is so crude and elementary in its nature that the writer firmly believes that it would be possible to train an intelligent gorilla so as to become a more efficient pig-iron handler than any man can be”

Often, 3x productivity improvements were obtained through waste reduction, picking the right men/tool for the job, and setting the ride incentives

Formal Definitions

Basic definition of productivity
Productivity = Units Output produced / Input used

Example: Labor productivity
Labor productivity = 4 units per labor hour (looks a lot like an processing time)

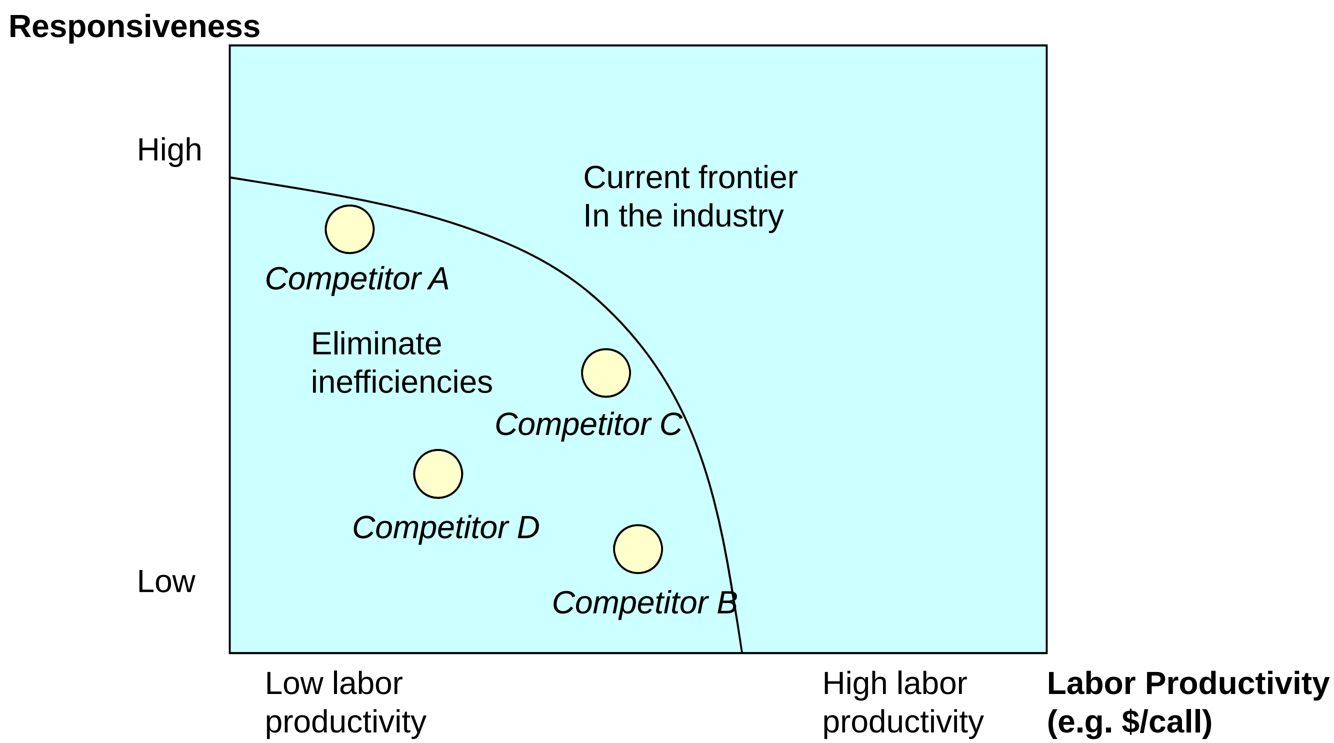
Multifactor productivity
Productivity = Output / (Capital$ + Labor$ + Materials$ + Services$ + Energy$)

Waste and Inefficiencies
Output: productive time; input: total time
Some measures of productivity have natural limits (e.g. labor time, energy)
What reduces productivity?

Productivity

Efficient Frontier

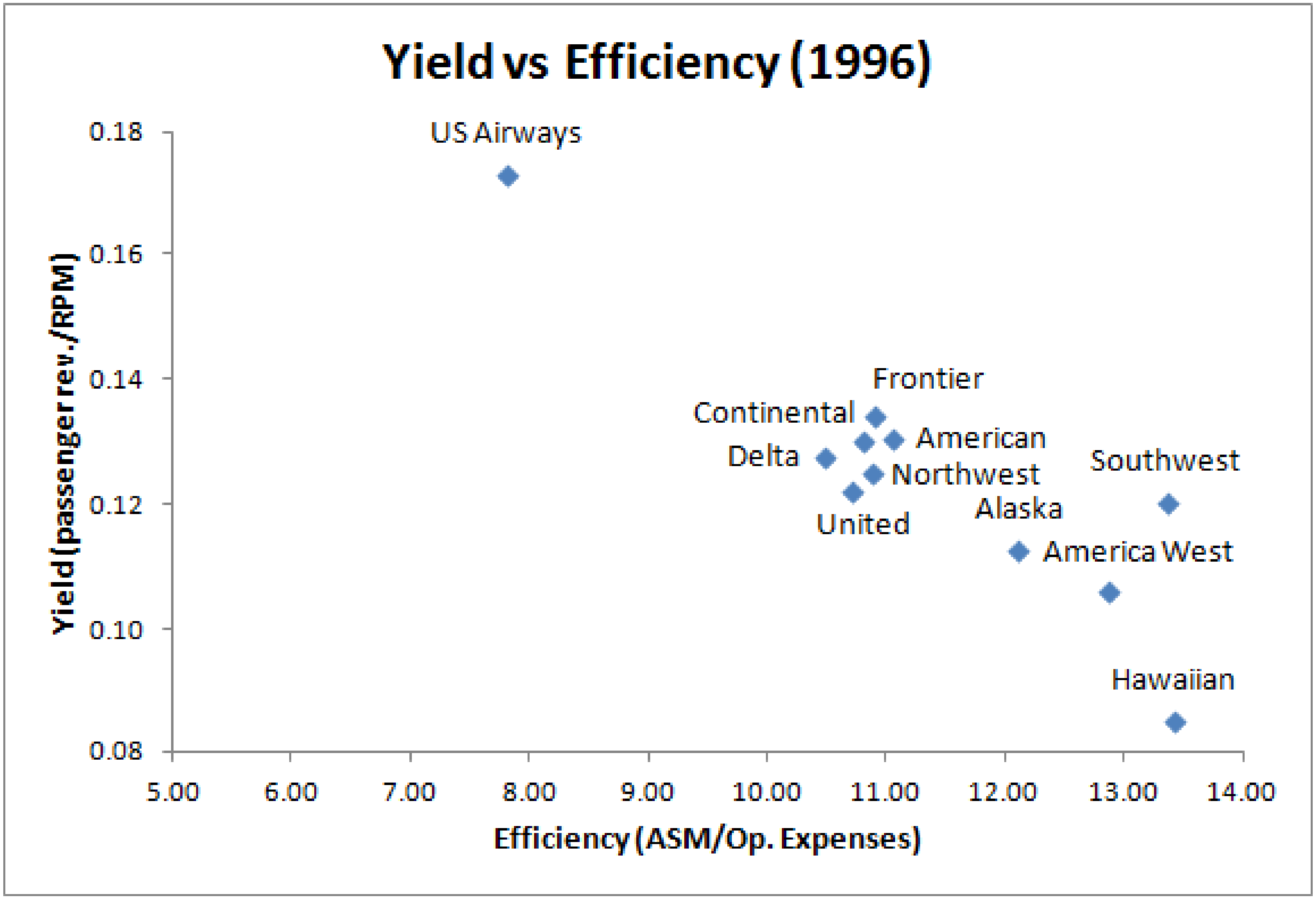
The Efficient Frontier



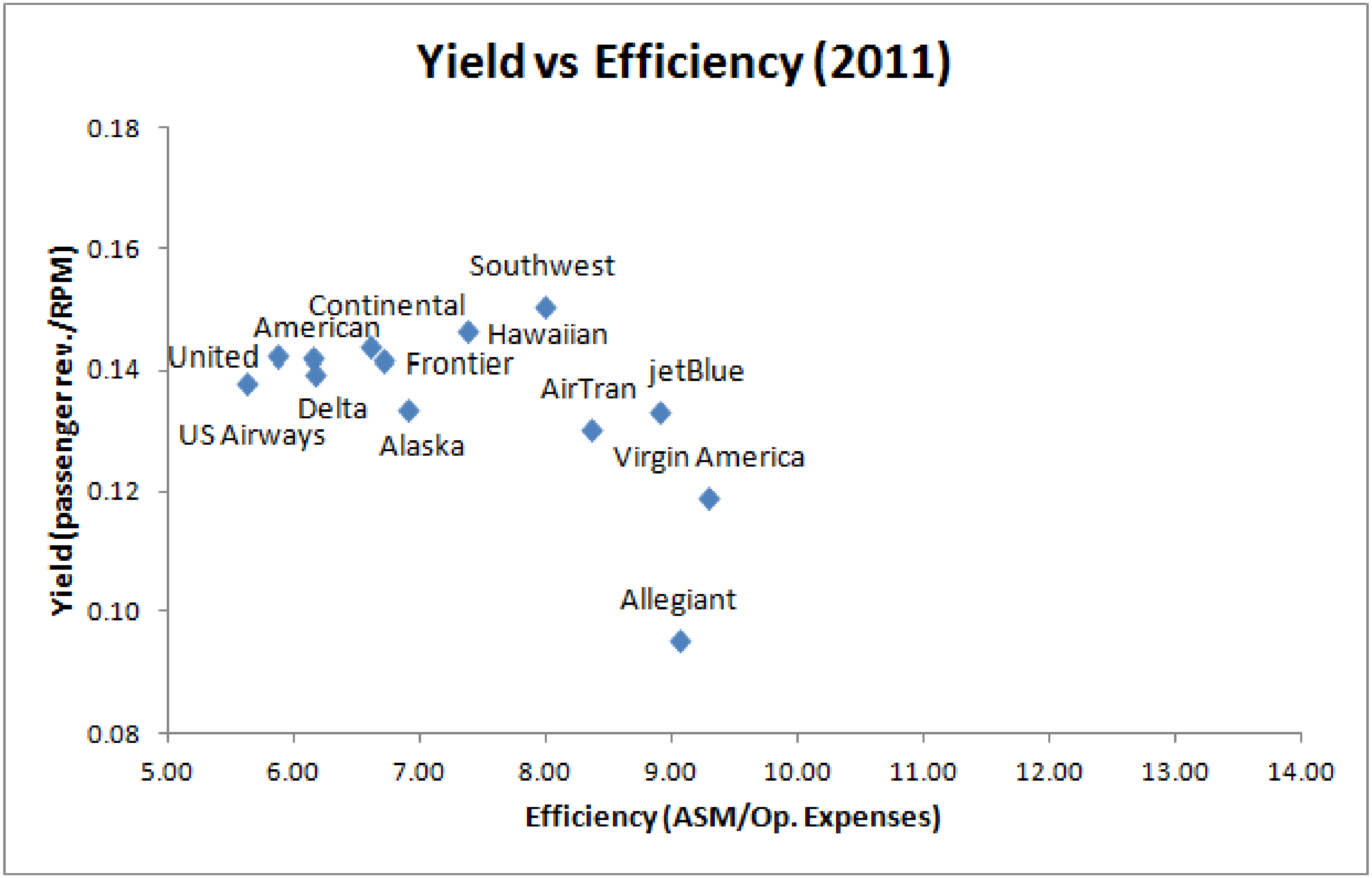
There exists a tension between productivity and responsiveness

Efficient frontier

Example: The US Airline Industry



Example: The US Airline Industry



Productivity

The Seven Sources of Waste

Overproduction

To produce sooner or in greater quantities than what customers demand

- Overproduced items need to be stored (inventory) and create further waste
- Bad for inventory turns
- Products become obsolete / get stolen / etc

Match Supply with Demand

Examples

81.6 kg of food are trashed by the average German

61% of the trashing happens by households

Large package sizes is the main reason

Transportation

Unnecessary movement of parts or people between processes
Example: Building a dining room and kitchen at opposite ends of a house, then keeping it that way

- Result of a poor system design and/or layout
- Can create handling damage and cause production delays

Relocate processes, then introduce standard sequences for transportation

Examples

Crabs fished in the North Sea

Shipped 2,500km South to Morocco

Produced in Morocco

Shipped back to Germany

Rework

Repetition or correction of a process
Example: Returning a plate to the sink after it has been poorly washed

- Rework is failure to meet the "do it right the first time" expectation
- Can be caused by methods, materials, machines, or manpower
- Requires additional resources so that normal production is not disrupted

Analyze and solve root causes of rework
=> More in quality module

Examples

Readmissions to the ICU in a hospital (also called "Bounce backs")

Readmissions to the hospital after discharge (major component of Affordable Care Act)

Over-processing

Processing beyond what the customer requires
Example: Stirring a fully mixed cup of coffee

- May result from internal standards that do not reflect true customer requirements
- May be an undesirable effect of an operator's pride in his work

Provide clear, customer-driven standards for every process

Examples

Keeping a patient in the hospital longer than what is medically required

Motion

Unnecessary movement of parts or people within a process

Example: Locating (and keeping) a refrigerator outside the kitchen

- Result of a poor work station design/layout
- Focus on ergonomics

Arrange people and parts around stations with work content that has been standardized to minimize motion

Examples

Ergonomics

Look at great athletes

Inventory

Number of flow units in the system

- "Product has to flow like water"
- For physical products, categorized in: raw material, WIP, or finished products
- Increases inventory costs (bad for inventory turns)
- Increases wait time (see above) as well as the customer flow time
- Often times, requires substantial real estate

=> the BIGGEST form of waste

Improve production control system and commit to reduce unnecessary "comfort stocks"

Examples

Loan applications at a bank

Waiting

Underutilizing people or parts while a process completes a work cycle
Example: Arriving an hour early for a meeting

Labor utilization
Idle time

Note:
- Waiting can happen at the resource (idle time)
- But also at the customer level (long flow time)

Understand the drivers of waiting; more in Responsiveness module

Examples

Often, the time in the waiting room exceeds the treatment time by more than 5x

Wasteful vs Lean
The IMVP Studies

General Motors Framingham Assembly Plant Versus Toyota Takaoka Assembly Plant, 1986

	GM Framingham	Toyota Takaoka
Gross Assembly Hours per Car	40.7	18
Assembly Defects per 100 Cars	130	45
Assembly Space per Car	8.1	4.8
Inventories of Parts (average)	2 weeks	2 hours

Gross assembly hours per car are calculated by dividing total hours of effort in the plant by the total number of cars produced
Defects per car were estimated from the JD Power Initial Quality Survey for 1987
Assembly Space per Car is square feet per vehicle per year, corrected for vehicle size
Inventories of Parts are a rough average for major parts

Source: Womack et al

Understand Sources of Wasted Capacity

Poor use of capacity – Waste of the Resource's time

Overproduction **Transportation** **Rework** **Over-processing** **Motion**

The seven sources of waste (Muda)

Potential eighth source of waste:
The waste of intellect

Not "orthogonal to each other"

Inventory **Waiting**

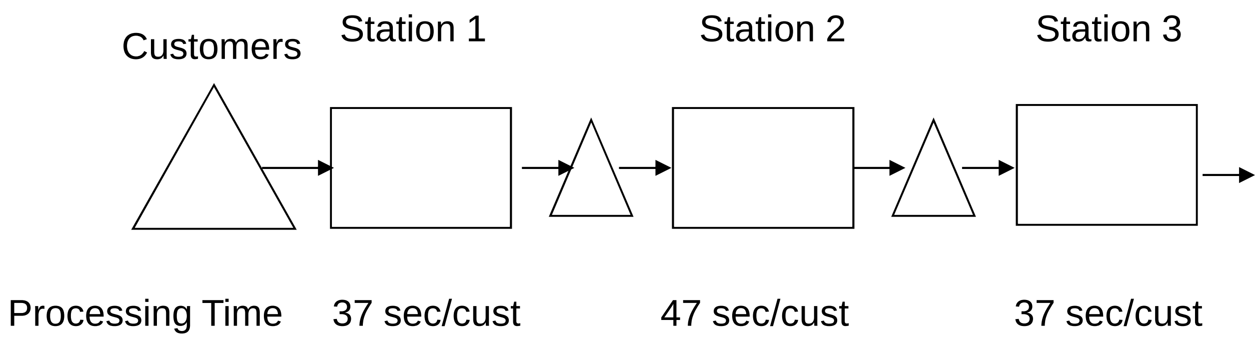
Poor flow – Waste of Customer's time

- Taichi Ohno, Chief Engineer at Toyota
- The first five sources are RESOURCE centric (and correspond to capacity):
- Ask yourself: "What did I do the last 10 minutes? How much was value-add?"
  Look around at the work-place (360 degree) – what percentage of people are working?
- The last two sources are FLOW UNIT centric (and correspond to Flow Time and Inventory)
- Ask yourself: "Did I really have to be here that long?"

Productivity

Link to Finance

Revisiting the Process Flow Diagram at Subway



Subway – Financial Importance of Operations

Activity time at Station 2	47	sec/cust		42.3			47		47
Per Hour Financial calculation	**Base Case**			**10% better productivity (and enough demand)**			**10% better productivity (and enough demand)**		**10% lower food cost**
Customers per hour (Demand)	100			100			100		100
Capacity	76.59574			85.10638298			76.59574468		76.59574
Flow Rate=Min{Demand, Capacity}	76.59574			85.10638298			76.59574468		76.59574
Average $ per customer	6			6			6		6
Revenue	459.5745			510.6382979			459.5744681		459.5745
Food cost per order	1.5			1.5			1.5		1.35
Food	114.8936			127.6595745			114.893617		103.4043
Wages	15			15			15		15
Staffing (direct and indirect)	4			4			4		4
Labor Cost	60			60			60		60
Fix cost	250			250			250		250
Profits	34.68085			72.9787234			34.68085106		46.17021
				110%			0%		33%

Productivity

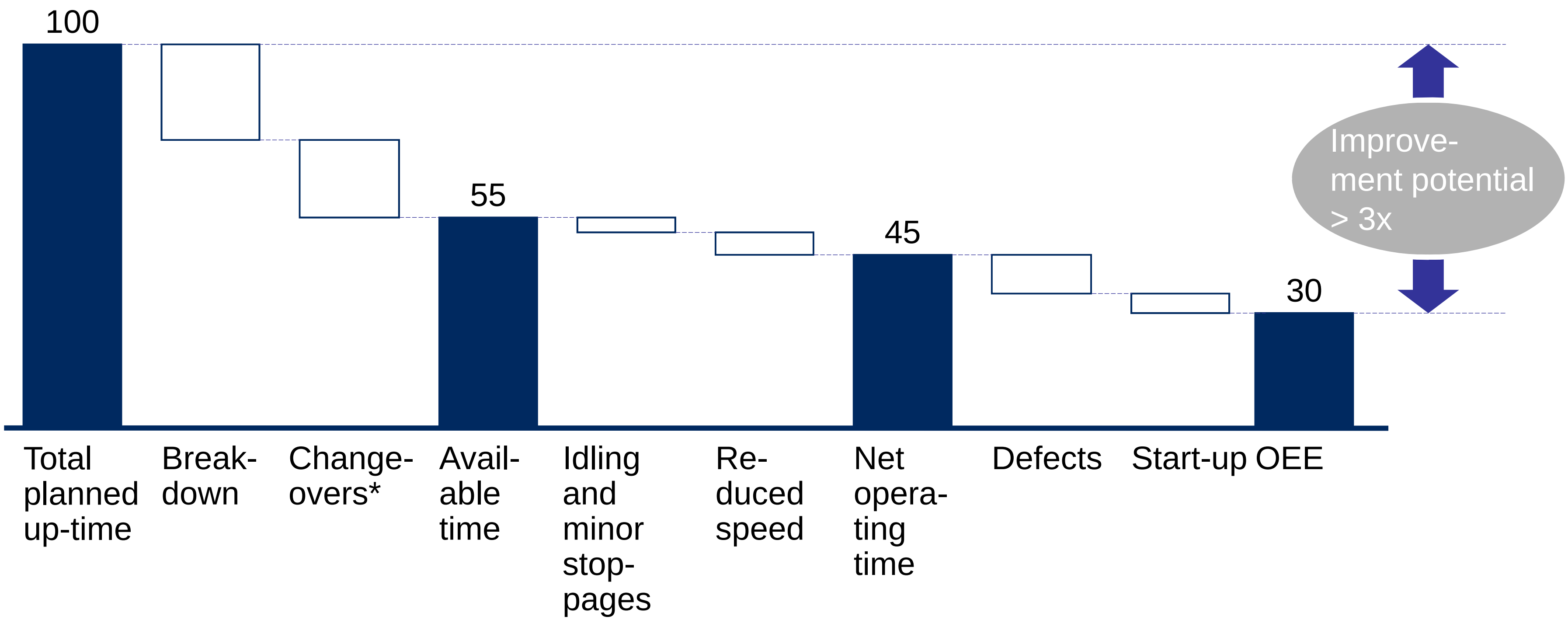
KPI trees

Subway – EBIT tree

Productivity

OEE Framework / Quartile Analysis

Overall Equipment Effectiveness



Downtime losses
Availability rate
55 %

X

Speed losses
Performance rate
82 %

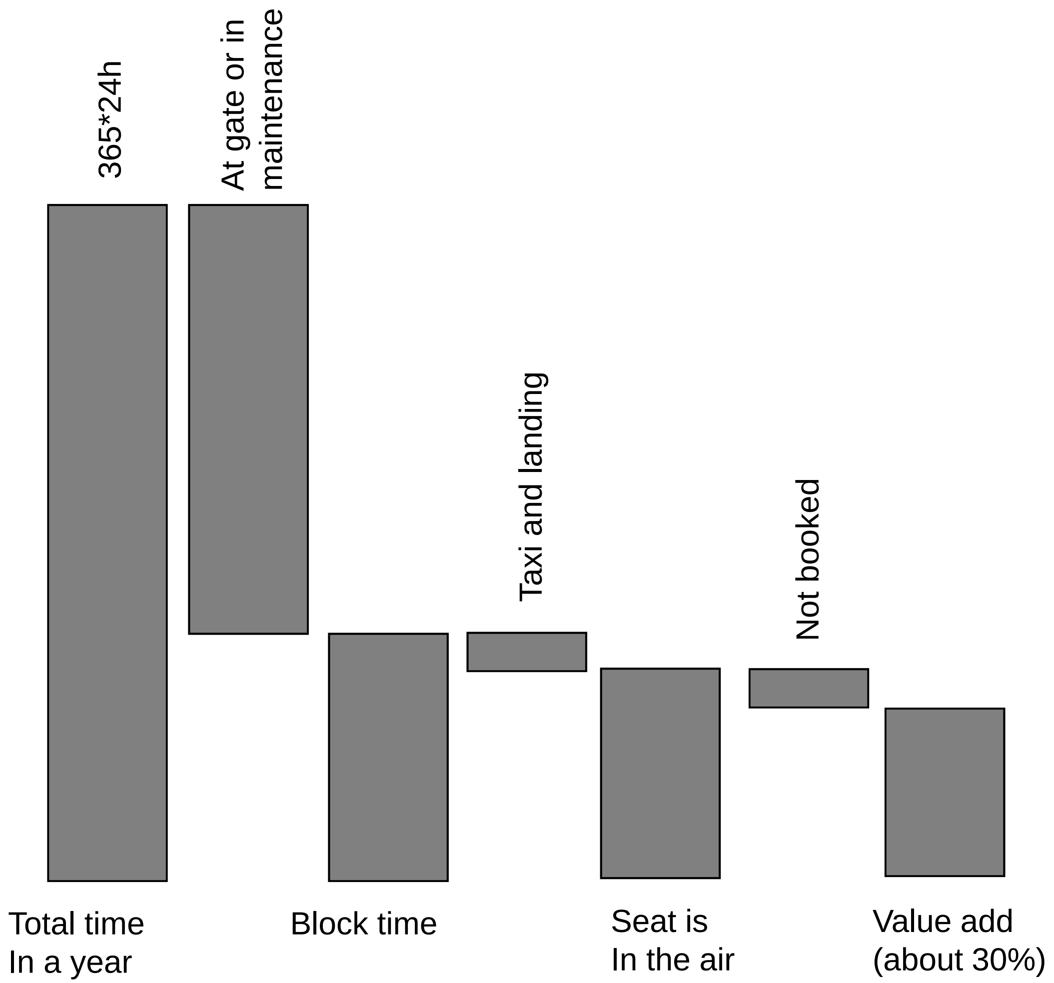
X

Quality losses
Quality rate
67 %

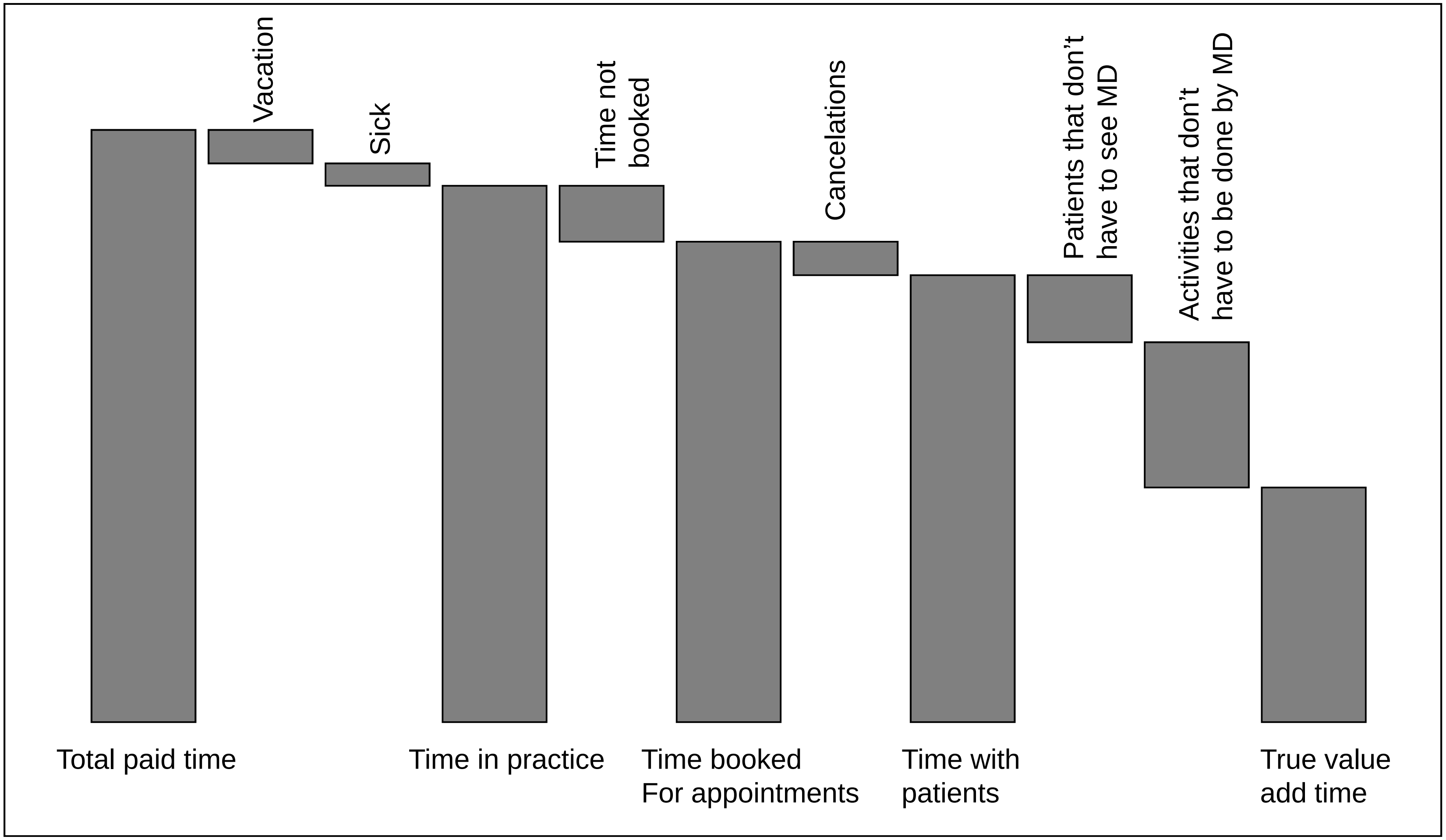
= OEE
30 %

Source: McKinsey

OEE of an Aircraft



Overall People Effectiveness



Source: Marcus, Terwiesch, Werner

Productivity

Line balancing / capacity sizing

Staffing / Capacity Sizing

So far: we started the process analysis with the process flow diagram / capacities

Often, demand can change over time

At Subway: More customers at noon than at 3pm

Typical situation in practice – Given are:

Demand (forecasts)

Activities that need to be completed

Decision situation: how to build a staffing plan?

Two strategies:

Production smoothing (pre-produce)

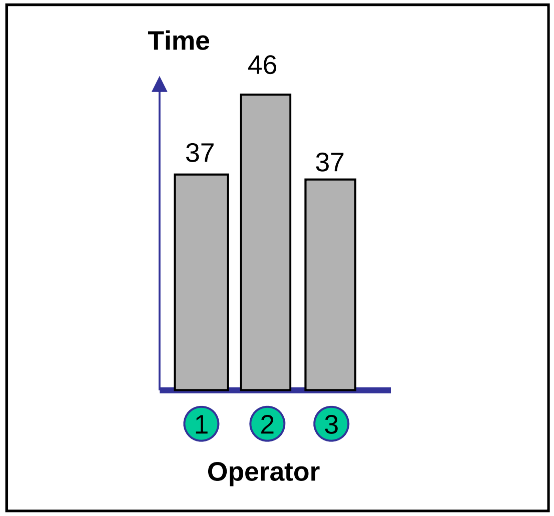
Staff to demand

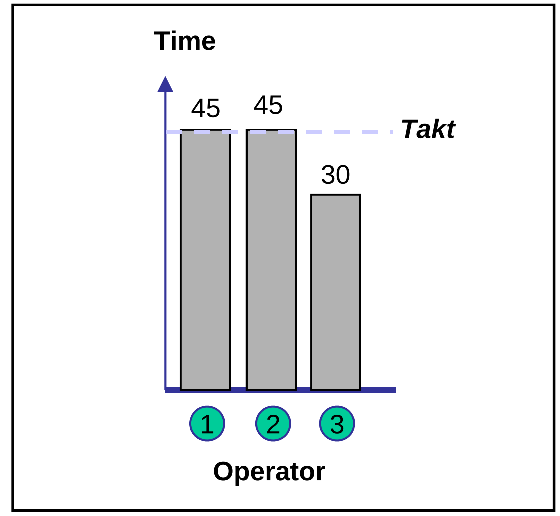
Line Balancing and Staffing to Demand

Station	Task	Seconds	3+ Support
Station 1	Greet Customer	4	1
	Take Order	5	
	Get Bread/Wrap/Salad Bowl	4	
	Cut Bread	3	
	Meat	12	
	Cheese	9	
	Toasting	30	Places Pulls
Station 2	Onions	3	2
	Lettuce	3	
	Tomatoes	4	
	Cucumbers	5	
	Pickles	4	
	Green Peppers	4	
	Black Olives	3	
	Hot Peppers	2	
	Place Condiments	5	
	Wrap/Napkins & Bag	13	
Station 3	Offer Fresh Value Meal™	3	3
	Offer Cookies	14	
	Ring on Register	20	
	Total Seconds	120 - 150	
Support Position	Phone/Fax Orders		4
	Baking Bread/Cookies		
	Filling In on Line		
	Restocking Sandwich Unit		
	Cleaning Customer Area		

Labor content: 120 seconds / unit

Demand: 80 units per hour





3,600 sec/hour

Takt: 3,600sec / 80 units=45 sec/unit

Target manpower= $\frac{\text{120 sec/unit}}{\text{45 sec/unit}}$

= 2.67 => round up

=> Staff to demand: start with the takt time and design the process from there

What Do You Do When Demand Doubles? Ideal Case Scenario

Station	Task	Seconds	3+ Support
Station 1	Greet Customer	4	1
	Take Order	5	
	Get Bread/Wrap/Salad Bowl	4	
	Cut Bread	3	
	Meat	12	
	Cheese	9	
	Toasting	30	Places / Pulls
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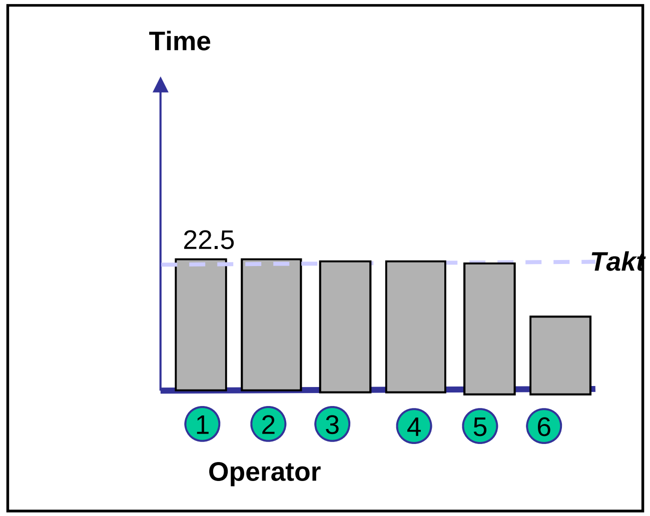
	Total Seconds	120 - 150	
Support Position	Phone/Fax Orders		4
	Baking Bread/Cookies		
	Filling In on Line		
	Restocking Sandwich Unit		
	Cleaning Customer Area		

Labor content: 120 seconds / unit

Demand: 160 units per hour



3,600 sec/hour

Takt: 3,600sec / 160 units=22.5 sec/unit

$$\text{Target manpower} = \frac{120 \text{ sec/unit}}{22.5 \text{ sec/unit}}$$

= 5.33 => round up

Balancing the Line

Determine Takt time

Assign tasks to resource so that total processing times < Takt time

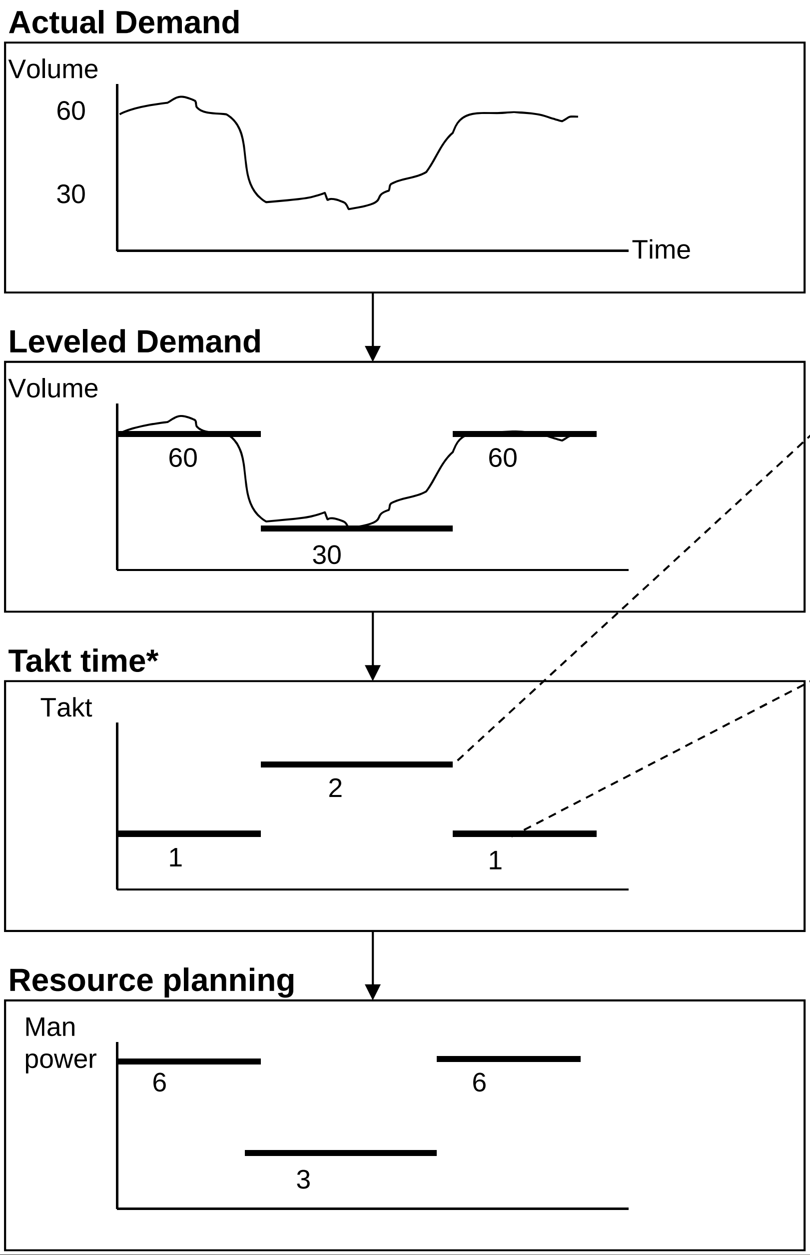
Make sure that all tasks are assigned

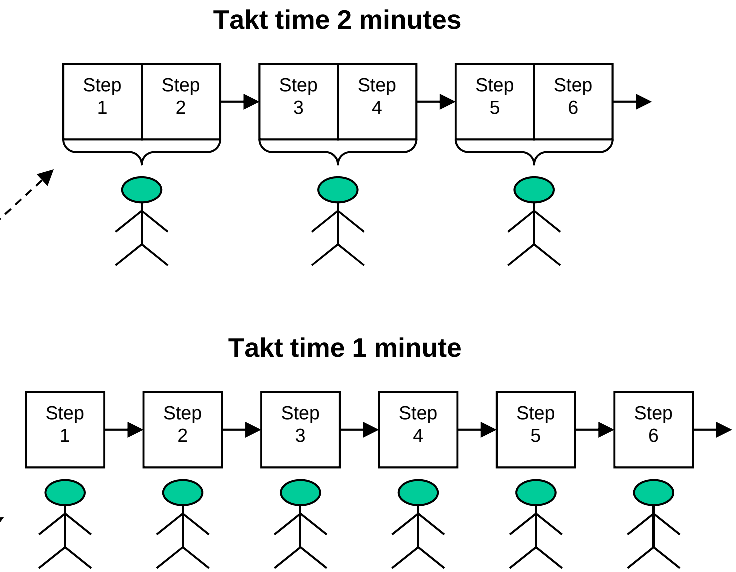
$\Rightarrow$Minimize the number of people needed (maximize labor utilization)

What happens to labor utilization as demand goes up?

Difference between static and dynamic line balancing

Line Balancing and Staffing to Demand





Volume flexibility
Ability to adjust to changing demands

Often implemented with temporary workers

Keeps average labor utilization high

Productivity

Quartile analysis / Standardization

Call Center Example

Two calls to the call center of a big retail bank

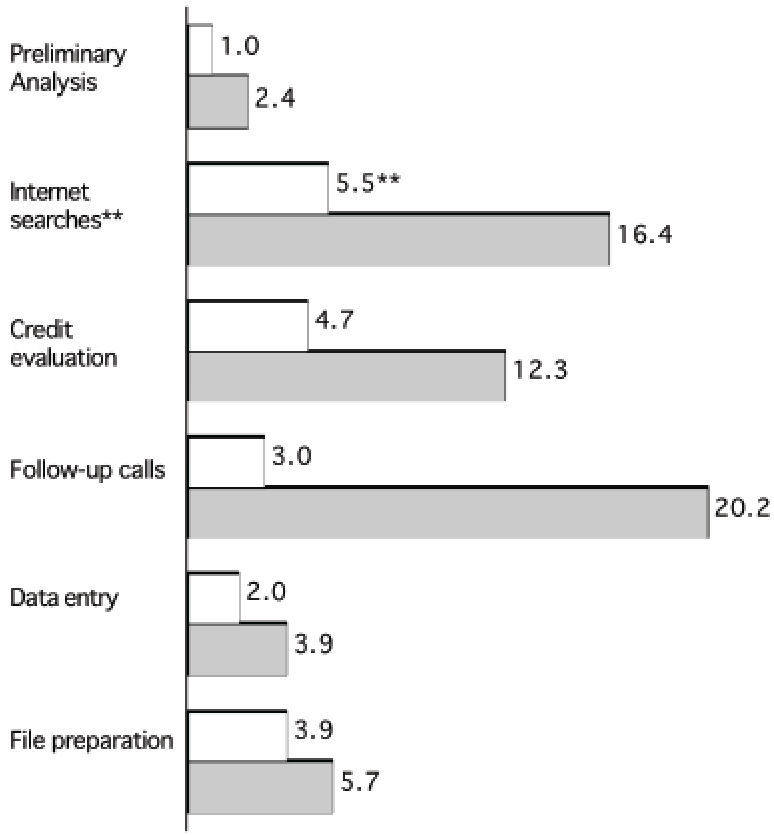
Both have the same objective (to make a deposit)

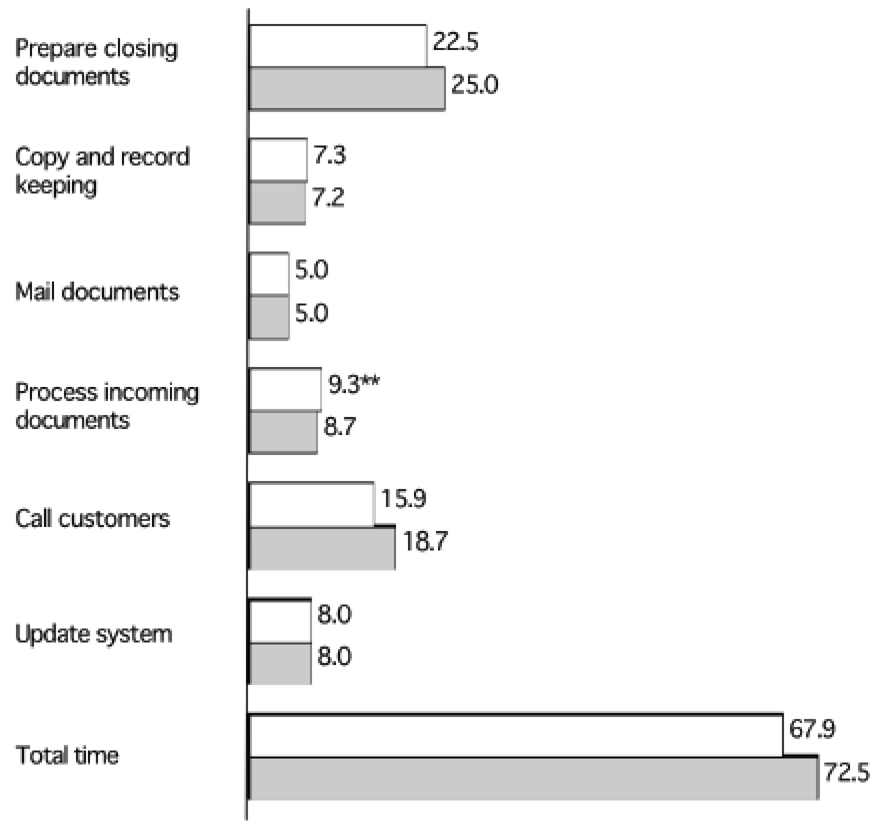
Different operators

Take out a stop watch

Time what is going on in the calls.

Beyond Labor Utilization: Quartile Analysis





Biggest productivity differences for knowledge intense tasks

Source: Immaneni and Terwiesch

Example: Emergency Department

Analyzed data for over 100k patients in three hospitals

80 doctors and 109 nurses

Up to 260% difference between the 10^{th} %-tile and the 90^{th} %-tile

=> Dramatic productivity effects

Source: McCarthy, Ding, Terwiesch, Sattarian, Hilton, Lee, Zeger

Productivity

Productivity Ratios

Basic definitions of productivity

Productivity = Output units produced / Input used

Problems:

Output is hard to measure=> often times, use revenue instead
Multiple input factors (Labor, Material, Capital) => use one cost category

Example:

Labor productivity at US Airways

1995: Revenue: $6.98B	Labor costs: $2.87B
2011: Revenue: $13.34B	Labor costs: $2.41B

Labor productivity at SouthWest

1995: Revenue: $2.87B	Labor costs: $0.93B
2011: Revenue: $13.65B	Labor costs: $4.18B

Basic definitions of productivity

But WHY is one firm more productive than the other?

The ratio alone does not tell! Use the following trick:

Airline example:
Revenue / labor costs = Revenue/RPM * RPM/ASM * ASM / Employee * Employees/Labor costs

$$\text{Revenue/Cost} = \underbrace{\text{Revenue/Output}}_{\text{Operational yield}} * \underbrace{\text{Output/Capacity}}_{\text{Transformation efficiency}} * \underbrace{\text{Capacity/Cost}}_{\text{1/unit cost of capacity}}$$

Labor Productivity Comparison between Southwest and US Airways

	Southwest		US Airways	
	1995	2011	1995	2011
Labor Expenses (B)	0.93	4.18	2.87	2.41
Total Operating Revenue (B)	2.87	13.65	6.98	13.34
RPM (M)	23,776	83,912	38,102	60,774
ASM (M)	36,841	103,891	58,679	72,598
Employee (FTE)	18,930	36,104	40,972	31,551
Fleet	251	554	379	339
Airtime (Block Hours)	852,902	2,113,654	1,342,436	1,209,431
Rev./RPM	0.12	0.16	0.18	0.22
RPM/ASM	0.65	0.81	0.65	0.84
ASM/FTE	1.95	2.88	1.43	2.30
FTE/Labor costs	20.35	8.64	14.28	13.09
Rev./Labor Costs	3.09	3.27	2.43	5.54

Do Calculations in Excel

Productivity

Review Session

Tom and Jerry

Tom and Jerry run an ice cream business out of their condo in Solana Beach, CA. They have purchased a fully automated ice cream making machine from Italy (at a $30k price tag) that they put in their basement. Tom is selling ice cream and Jerry operates the ice cream maker. Often times, however, they run out of ice cream and so Jerry suggested purchasing a second ice cream maker.

Tom, however, wants to first look at the usage of the current ice cream maker and suggests an Overall Equipment Effectiveness (OEE) analysis. Preliminary data suggests that:

- Jerry is not particularly skilled at programming the machine, which needs to be done when a new batch of ice cream gets made. Instead of spending a negligible time per set-up, he presently spends 20 minutes. A batch of ice cream takes 1h in the machine, once the machine is set-up.
- A new batch is only started if there exists sufficient time to complete the batch the same day before 7pm (including the 20 minute set-up and the 1h production)
- Since Jerry started dating a woman from the WWF, he is fascinated by energy efficiency. So he turns the machine off when he goes home at 7pm. As a result of this, the next morning, the machine has to be cooled down to its desired operating temperature, which takes from 7am to 8am.
- Jerry is also not particularly diligent at following the recipe that Tom's aunt in Italy had sent them. So roughly one quarter of the produced ice cream has to be thrown away.
- Every other Friday, Jerry prefers to go surfing rather than showing up for work. On those days, the business has to stay closed.

TJ1: How many good batches of ice cream are produced each day Jerry comes to work?
TJ2: What is the OEE of the ice cream maker? (use 12h per day as the available time)

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Penne Pesto

Penne Pesto is a small restaurant in the financial district of San Francisco. Customers order from a variety of pasta dishes. The restaurant has 50 seats and is always full during the four hours in the evening. It is not possible to make reservations at Penne; most guests show up spontaneously on their way home from work. If there is no available seat, guests simply move on to another place. On average, a guest spends 50 minutes in the restaurant, which includes 5 minutes until the guest is seated and the waiter has taken the order, an additional 10 minutes until the food is served, 30 minutes to eat, and 5 minutes to handle the check-out (including waiting for the check, paying, and leaving). It takes the restaurant another 10 minutes to clean the table and have it be ready for the next guests (of which there are always plenty). The average guest leaves $20 at Penne, including food, drink, and tip (all tips are collected by the restaurant, employees get a fixed salary).

The restaurant has 10 waiters and 10 kitchen employees, each earning $90 per evening (including any preparation, the 4 hours the restaurant is open, and clean-up). The average order costs $5.50 in materials, including $4.50 for the food and $1 for the average drink. In addition to labor costs, fixed costs for the restaurant include $500 per day of rent and $500 per day for other overhead costs.

The restaurant is open 365 days in the year and is full to the last seat even on weekends and holidays. There is about $200,000 of capital tied up in the restaurant, largely consisting of furniture, decoration, and equipment.

Define the return on invested capital as the ratio of the profits (PER YEAR) and the invested capital. You can draw an ROIC tree in the same way that we drew a KPI tree in class. Simply have the ROIC as “the root” of the tree instead of profits. Then answer the following questions.

a. How many guests will the restaurant serve in one evening?
b. What is the Return on Invested Capital (ROIC) for the owner of the restaurant?
c. Assume that you could improve the productivity of the kitchen employees and free up one person who would be helping to clean up the table. This would reduce the clean-up to 5 minutes instead of 10 minutes. What would be the new ROIC?

Assign Tasks to Workers

Consider the following six tasks that must be assigned to four workers on a conveyor-paced assembly line (i.e., a machine-paced line flow). Each worker must perform at least one task.

Time to Complete Task (seconds / unit)

Task 1	30
Task 2	25
Task 3	35
Task 4	40
Task 5	15
Task 6	30

The current conveyor-paced assembly line configuration assigns the workers in the following way:

- Worker 1: Task 1
- Worker 2: Task 2
- Worker 3: Tasks 3, 4
- Worker 4: Tasks 5, 6

a. What is the capacity of the current line?
b. Now assume that tasks are allocated to maximize capacity of the line, subject to the conditions that (1) a worker can only perform two adjacent operations and (2) all tasks need to be done in their numerical order. What is the capacity of this line now?
c. Now assume that tasks are allocated to maximize capacity of the line and that tasks can be performed in any order. What is the maximum capacity that can be achieved?
d. After focusing on capacity in questions a-c, you now want to factor in demand in questions d-e. Demand is 50 units per hour. What is the takt time?
e. What is the target manpower?
f. How many workers will you need?