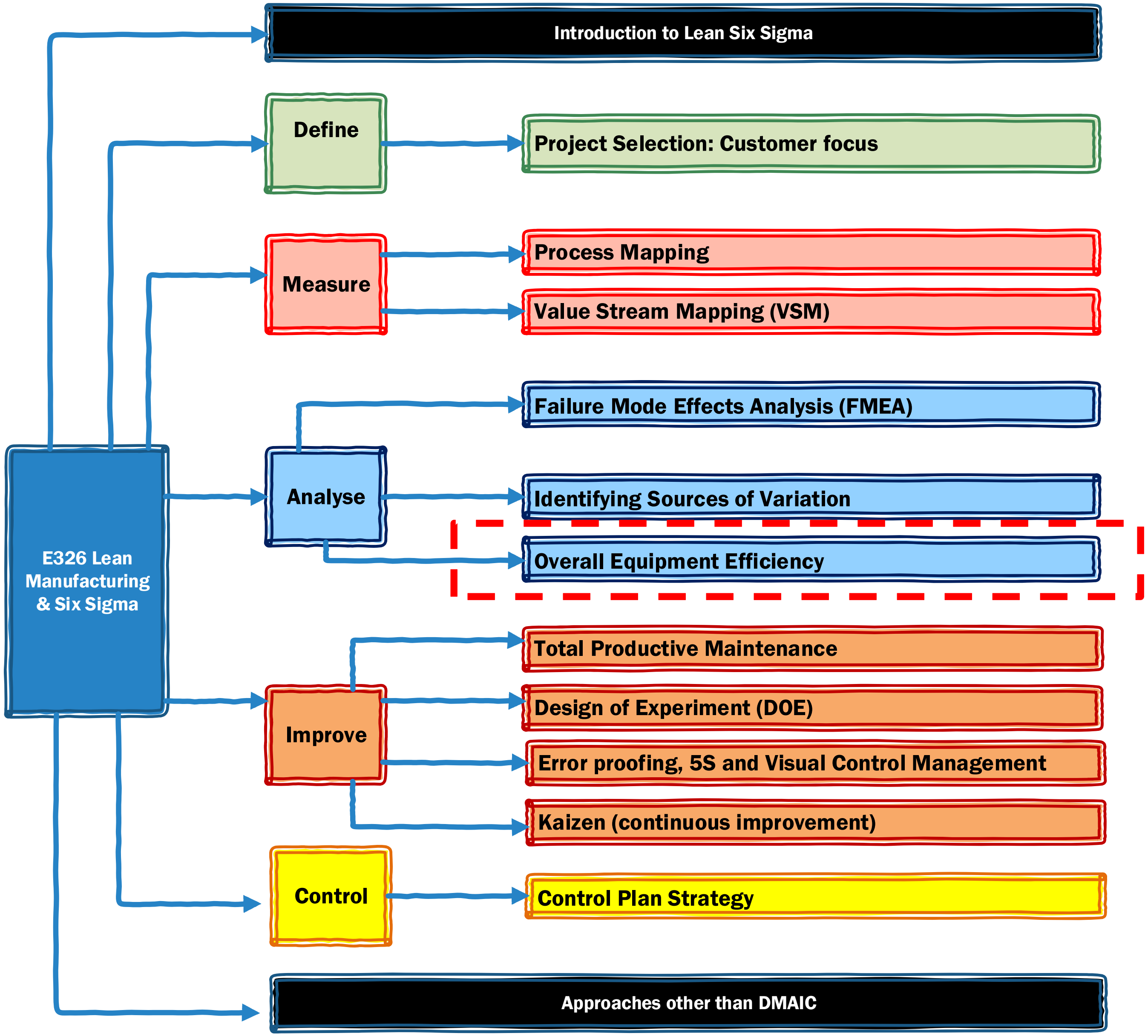
Problem 07
Equipment Performance

E326 – Lean Manufacturing & Six Sigma

REPUBLIC POLYTECHNIC

SCHOOL OF ENGINEERING

E326 Lean Manufacturing and Six Sigma Topic Tree



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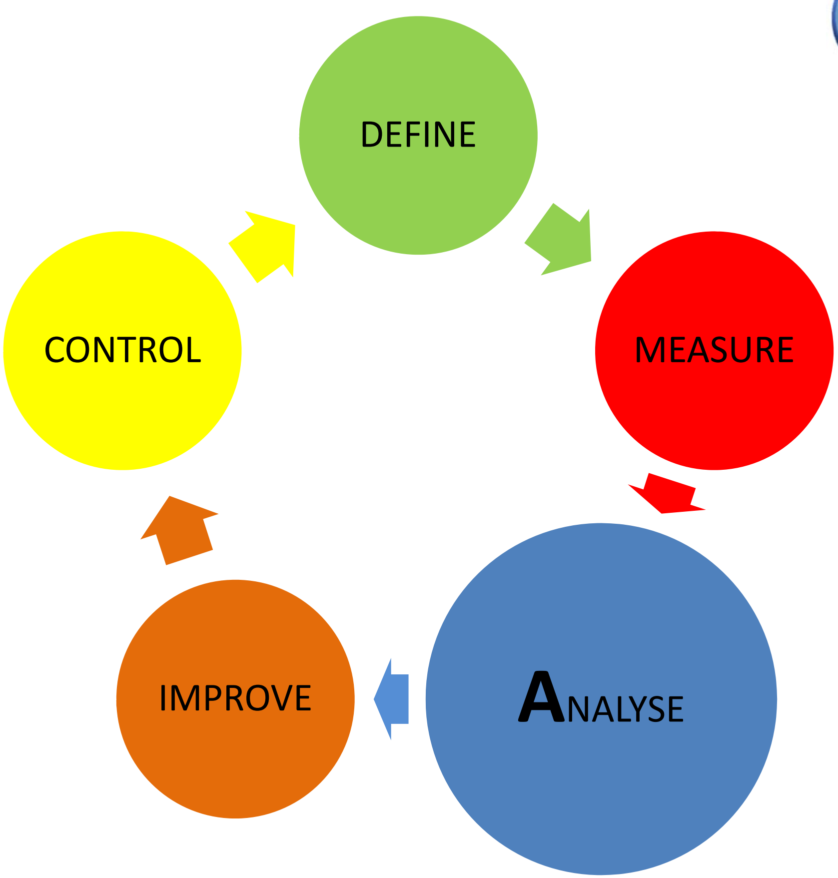


- Operation/Equipment performance analysis

Objectives of Analyse phase:

- To stratify and analyse the opportunity to identify a specific problem and define an easily understood problem statement
- To identify and validate the root causes that assure the elimination of "real" root causes and thus the problem the team is focused on
- To determine true sources of variation and potential failure modes that lead to customer dissatisfaction

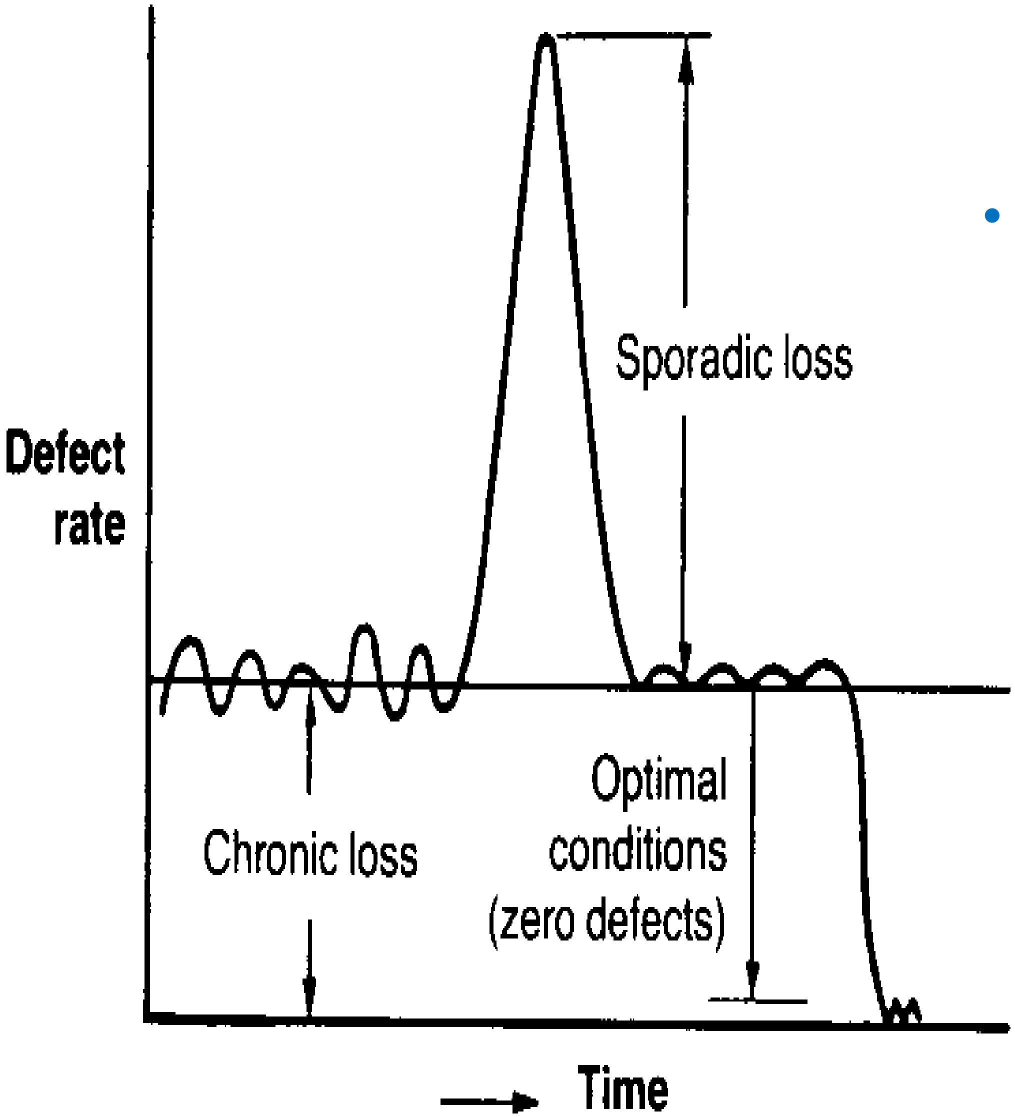
Chronic Losses and Sporadic Losses

- Equipment failures and defects appear in two ways:
  - Sporadic losses
  - Chronic losses

- **Sporadic losses** – losses which are sudden, often large deviation from the norm (as compared to existing performance and quality levels)

- **Chronic losses** – losses which appear to be smaller, but frequent deviations (sometimes gradually being accepted as normal)

Chronic Losses and Sporadic Losses



- **Chronic Losses**
  - "hidden" defects in machinery, equipment and methods
  - Difficult to "see" and "detect"
- **Sporadic Losses**
  - Sudden breakdown
  - Easily or clearly visible as considerably differ from routine operating conditions

Key is restoration

- To return to previous level

Key is innovation

- To achieve optimal conditions

Chronic losses become obvious when compared with optimal conditions

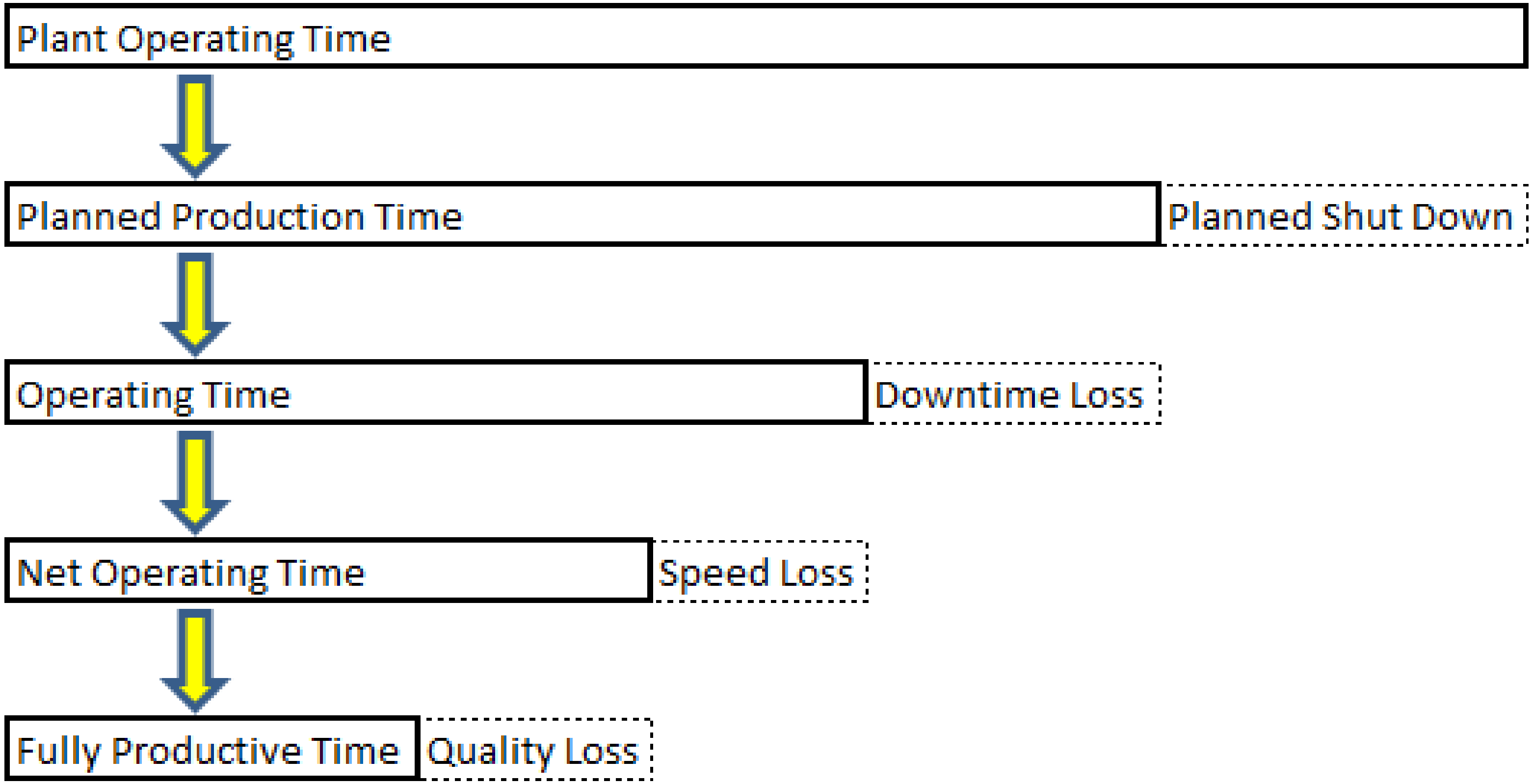
Chronic Losses vs Sporadic Losses

	Sporadic	Chronic
Characteristic	• Occur suddenly and infrequently, large deviations from the norm	• Smaller, frequent deviation, resist variety of corrective measures • Includes 1-5% of the problem
Cause	• Single cause, problem is easy to identify	• Complex, tangled cause and effect relationship, difficult both to identify causes and clarify effect
Countermeasure	• Restore to return to is previous level	• Requires innovative break through measures, that restore the mechanism or component to its original, defect-free state.
Approach	• Cause and Effect • Pareto Diagram	• P-M Analysis

Note: P-M Analysis - Physical Phenomenon and the Mechanism (and Relationship) Analysis.

Reference: http://www.rsareliability.com/chronic%20losses.pdf

Equipment Time Analysis



1. Planned shut down - no intention of running production, **e.g. tea breaks, lunch, no product request**
2. Downtime loss - any events that stop planned production for an appreciable length of time (usually several minutes - long enough to log as a trackable event), **e.g. equipment failures, material shortages, changeover time**
3. Speed loss - including factors that cause process to operate at less than max speed**, e.g. m/c wear, substandard materials, misfeeds, operator**
4. Quality loss - accounts for produced pieces that do not meet quality standards (including those require rework)

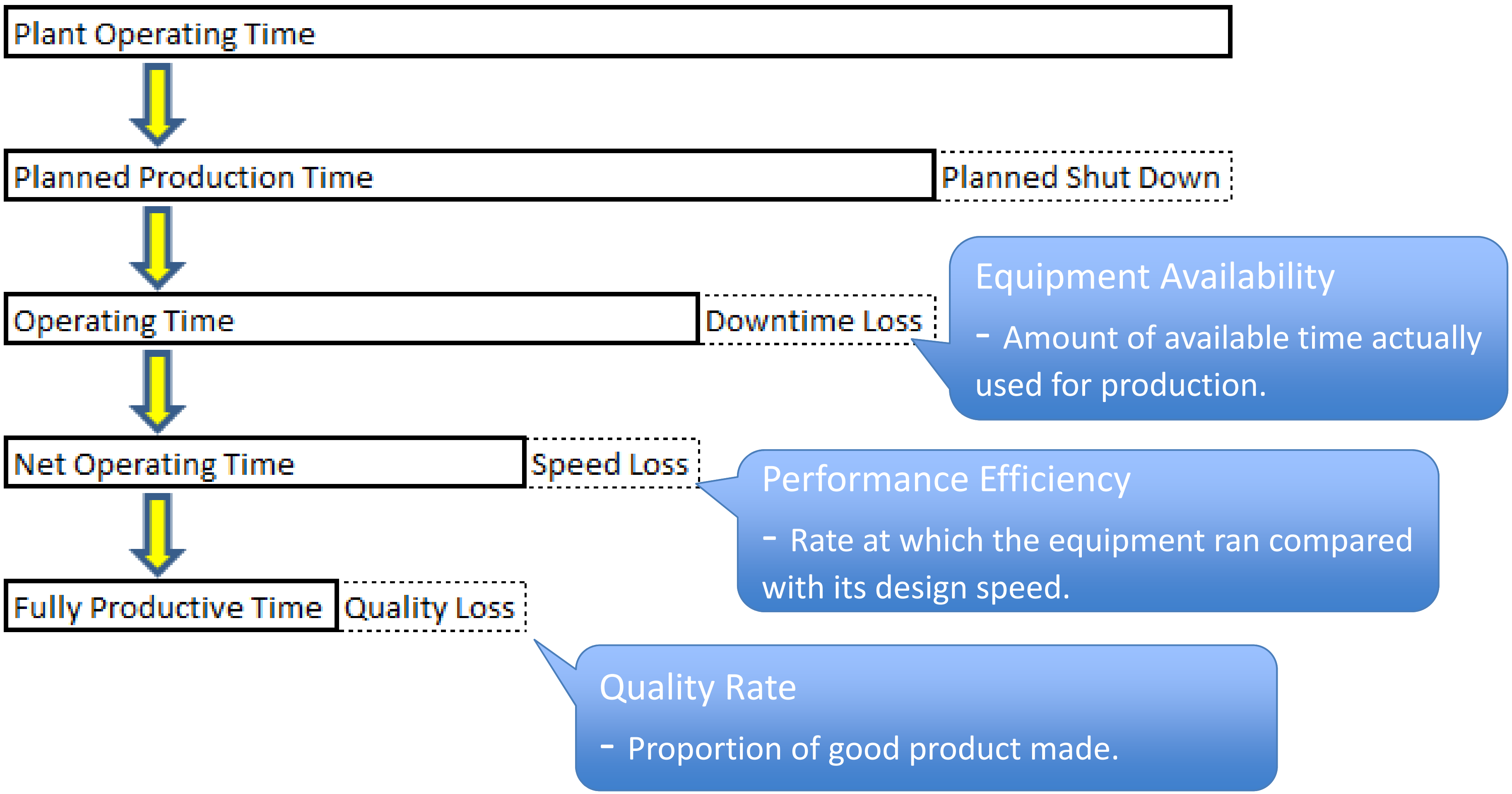
Overall Equipment Effectiveness (OEE)

- The Overall Equipment Effectiveness (OEE) is an index of measuring the delivered performance of a single piece of equipment or plant based on good output.
- This overall performance will always be governed by the cumulative impact of the three factors: **Availability**, **Performance** and **Quality**.
- OEE measures the production efficiency by taking into account major sources of manufacturing productivity losses.

- Overall Equipment Effectiveness (OEE%)

OEE% = Availability% x Performance% x Quality%

Understanding OEE Factors



Availability

$$Availability = \frac{Operating\ Time}{Planned\ Production\ Time}$$

$$= \frac{Planned\ Production\ Time - Downtime}{Planned\ Production\ Time}$$

Note:

- Planned production time <u>does not</u> include planned equipment shut down activities such as *operators' break and lunch, or periods of non-production*.
- Downtime consists of both <u>planned and unplanned/unscheduled activities</u> that are long enough to log as a trackable event, which can be from *breakdown of machine, machine setup, adjustment of machine and shortage of material*.

Performance

$$Performance = \frac{\left(\frac{Total\ Pieces}{Operating\ Time}\right)}{Ideal\ Run\ Rate}\ or\ \frac{Ideal\ Cycle\ Time}{\left(\frac{Operating\ Time}{Total\ Pieces}\right)}$$

- Ideal cycle time is the minimum cycle time that the process can be expected to achieve under optimal circumstances. Reciprocal of ideal cycle time is ideal run rate.
- Operating time is the actual time it takes to produce one unit taking into account speed loss.

Quality

$$Quality = \frac{Good\ \ Pieces}{Total\ \ Pieces}$$

$$= \frac{Total\ \ Pieces - (Startup\ \ Defects + Production\ \ Defects)}{Total\ \ Pieces}$$

- Defects consist of both production and startup defects.
  - Production defects are defined as defects occurred during the “normal” production.
  - Startup defects are defined as defects produced during the startup of a machine/ equipment.
- Defects include <u>reworks</u>, which are defects that can be salvaged. Rework falls under ‘defects’ when determining OEE.

World Class Level OEE

- The generally accepted World Class goals for each factor is shown in table below:

OEE Factor	World Class Level
Availability	**90.0%**
Performance	**95.0%**
Quality	**99.9%**
Overall OEE	**85.0%**

Reference: http://www.oee.com/world-class-oee.html

Major Losses - Availability

Six Big Loss Category	OEE Loss Category	Event Examples	Comment
Machine Breakdowns	Down Time Loss	• Tooling Failures • Unplanned Maintenance • General Breakdowns • Equipment Failure	There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss).
Setup and Adjustments Losses	Down Time Loss	• Setup/ Changeover • Material Shortages • Operator Shortages • Major Adjustments • Warm-Up Time	This loss is often addressed through setup time reduction programs.

Major Losses - Performance

Six Big Loss Category	OEE Loss Category	Event Examples	Comment
Idling and Minor Stoppage Losses	Speed Loss	• Obstructed Product Flow • Component Jams • Misfeeds • Sensor Blocked • Delivery Blocked • Cleaning/Checking	Typically only includes stops that are under five minutes and that do not require maintenance personnel.
Reduced Speed Losses	Speed Loss	• Under Nameplate Capacity • Under Design Capacity • Equipment Wear	Anything that keeps the process from running at its theoretical maximum speed (Ideal Run Rate or Nameplate Capacity).

Major Losses - Quality

Six Big Loss Category	OEE Loss Category	Event Examples	Comment
Startup Rejects	Quality Loss	• Scrap • Rework • In-Process Damage • Incorrect Assembly	Rejects during warm-up, startup or other early production. May be due to improper setup, warm-up period, etc.
Production Rejects	Quality Loss	• Scrap • Rework • In-Process Damage • Incorrect Assembly	Rejects during steady-state production.

OEE Applications to Lean Six Sigma

- The OEE can be used as a metric to measure or monitor Lean manufacturing and Six Sigma programs

- The OEE is just a number for relative comparison of equipment or plant performance. The real benefits come from using the factors of OEE, which lead to root cause analysis and eliminating the causes of poor performance to improve productivity.

Problem 07
Suggested Solution

Classroom Activity Sheet

Learning Objectives: Identify the OEE factors and the major losses contributing to each factor

Six Big Losses	Setup & Adjustment	Breakdowns	Minor Stoppages	Reduced Speed	Start up Rejects	Production Rejects
OEE Loss Category (tick / highlight correct one)	• Downtime (planned) • Downtime (unplan) • Speed Loss • Quality Loss	• Downtime (planned) • Downtime (unplan) • Speed Loss • Quality Loss	• Downtime (planned) • Downtime (unplan) • Speed Loss • Quality Loss	• Downtime (planned) • Downtime (unplan) • Speed Loss • Quality Loss	• Downtime (planned) • Downtime (unplan) • Speed Loss • Quality Loss	• Downtime (planned) • Downtime (unplan) • Speed Loss • Quality Loss
OEE Factors (tick / highlight correct one)	• Availability • Performance • Quality	• Availability • Performance • Quality	• Availability • Performance • Quality	• Availability • Performance • Quality	• Availability • Performance • Quality	• Availability • Performance • Quality
World Class Level (how many percent?)	90.00%	90.00%	95.00%	95.00%	99.90%	99.90%
Comments	Also known as 'Planned Stops'. This loss is often addressed through setup time reduction programs.	Also known as 'Unplanned Stops'. There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss).	Typically only includes stops that are under five minutes and that do not require maintenance personnel.	Anything that keeps the process from running at its theoretical maximum speed (Ideal Run Rate or Nameplate Capacity).	Also known as 'Reduced Yield'. Rejects during warm-up, start up or other early production. May be due to improper setup, warm-up period, etc.	Also known as 'Process Defects'. Rejects during steady-state production.

Classroom Activity Sheet

Learning Objectives: Identify the OEE factors and the major losses contributing to each factor

EVENT EXAMPLES (match against Six Big Losses, indicate with 'x')	**Six Big Losses**	**Setup & Adjustment**	**Breakdowns**	**Minor Stoppages**	**Reduced Speed**	**Start up Rejects**	**Production Rejects**
	Tooling Failures		x (sporadic)				
	Unplanned Maintenance		x (sporadic)				
	General Breakdowns		x (sporadic)				
	Equipment Failure		x (sporadic)				
	Setup/ Changeover	x (setup, chronic)					
	Material Shortages	x (setup, chronic)					
	Operator Shortages	x (setup, chronic)					
	Major Adjustments	x (adjust, chronic)					
	Warm-Up Time	x (setup, chronic)					
	Obstructed Product Flow			x (chronic)			
	Component Jams			x (chronic)			
	Misfeeds			x (chronic)			
	Sensor Blocked			x (chronic)			
	Delivery Blocked			x (chronic)			
	Cleaning/Checking			x (chronic)			
	Under Nameplate Capacity				x (chronic)		
	Under Design Capacity				x (chronic)		
	Equipment Wear				x (chronic)		
	Scrap					x	x
	Rework					x	x
	In-Process Damage					x	x
	Incorrect Assembly					x	x

Lab Activity Sheet

Learning Objectives: Demonstrate the ability to calculate OEE

Operating Timing: 8.00am-6.00pm
Lunch Time: 12.00pm-1.00pm
Break Time: 2x 15min tea breaks

Six Big Losses	Setup & Adjustment	Breakdowns	Minor Stoppages	Reduced Speed	Start up Rejects	Production Rejects
OEE Loss Category	Downtime (planned)		Speed Loss		Quality Loss	
OEE Factors	Availability		Performance		Quality	
Consumer 3D Printer (availability: 92.55%)		90min / wk	Throughput: 10pcs/day Ideal Cycle Time: 2500s/pc		0	2pcs/day
Industrial 3D Printer (performance : 95.44%)		15min / wk	Throughput: 40pcs/day Ideal Cycle Time: 660s/pc		0	1pc/day

Lab Activity Sheet

Learning Objectives: Demonstrate the ability to calculate OEE

Operating Timing: 8.00am-6.00pm
Lunch Time: 12.00pm-1.00pm
Break Time: 2x 15min tea breaks

Six Big Losses	Setup & Adjustment	Breakdowns	Minor Stoppages	Reduced Speed	Start up Rejects	Production Rejects
Coordinate Measuring Machine (CMM) (performance : 96.36%)	1. Conduct a homing operation (5min - setup) 2. Replace and secure workpiece with quick-release fixture (5min - setup) 3. Develop and plan measuring points on the CMM software (1hr 40min per mth - setup) 4. Change of stylus for different measuring points during job (5min - adjust) 5. Set to slower speed for higher accuracy during job (5min - adjust)	1. Stylus hitting the workpiece; shutdown/restart procedure (10min / wk) 2. Stylus is out of measuring limits due to poor fixtures position. Fixtures and workpiece need repositioning. (30min / wk) 3. Low air supply, need fixing (50min / wk)	Throughput: 100pcs/day Ideal Cycle Time: ?		1pc/day	0
Computer Numerical Control (CNC) Machine (performance : 91.12%)	1. Conduct a homing operation (5min - setup) 2. Level and secure workpiece on the clamp (30min - setup) 3. Change of drill bits for different cutting operations (10min - adjust) 4. Clear the chips from workpiece from time to time to ensure accurate operations (5min - adjust)	1. Clogged chip tray (30min / wk) 2. Machine auto stop if low on lubricating oil. Needs topping up (15min / wk) 3. Poor cutting process due to low coolant PH level. Adjust or change coolant (60min / wk)	Throughput: ? Ideal Cycle Time: 800s/pc		2pcs/day	2pcs/day
Bench Lathe (OEE: 85.38%)	1. Secure workpiece by tightening the three-jaw chuck (5 mins - setup) 2. Calculate and set to the recommended cutting speed (5 mins - setup) 3. Change of cutter for different lathe operations within same job (5 mins - adjust)	1. Poor carriage movement due to stuck chips and lack of lubricants (20 mins / mth) 2. Unreliable cutting speed due to gear misalignment (60 mins / mth)	Throughput: 219pcs/day Ideal Cycle Time: 125s/pc			

Collected Data

	Consumer 3D Printer	Industrial 3D Printer	CMM	CNC	Turning Mill
Plant Operating Timings	8.00am-6.00pm	8.00am-6.00pm	8.00am-6.00pm	8.00am-6.00pm	8.00am-6.00pm
Machine Set-up (mins)			15	35	10
Machine Adjustments (mins)			10	15	5
Breakdown Time (mins per week)	90	15	90	105	20
Throughput per day (Total number produced)	10	40	100		219
Defect Rate (Total number rejected)	2	1	1	4	
Ideal Cycle Time (Sec)	2500	660		800	125
Lunchtime (mins)	60	60	60	60	60
Breaktime (mins)	30	30	30	30	30

Assumptions:
1 hr lunchbreak, 2x 15 mins teabreaks, 5 day work week, 20 days work month and balanced line

	Consumer 3D Printer	Industrial 3D Printer	CMM	CNC	Turning Mill
Total Plant Operating Hours					
Downtime (mins per day)					
Planned Production Time (mins per day)					
Operating Time (mins per day)					
Availability	**92.55%**				
Operating Time (seconds per day)					
Performance		**95.44%**	**96.36%**	**89.89%**	
Good Pieces					
Quality					
OEE =					**85.38%**

Evaluation of the Collected Data

	Consumer 3D Printer	Industrial 3D Printer	CMM	CNC	Turning Mill
Plant Operating Timings	8.00am-6.00pm	8.00am-6.00pm	8.00am-6.00pm	8.00am-6.00pm	8.00am-6.00pm
Machine Set-up (mins)	10	26	15	35	10
Machine Adjustments (mins)	10	20	10	15	5
Breakdown Time (mins per week)	90	15	90	105	20
Throughput per day (Total number produced)	10	40	100	30	219
Defect Rate (Total number rejected)	2	1	1	4	10
Ideal Cycle Time (Sec)	2500	660	270	800	125
Lunchtime (mins)	60	60	60	60	60
Breaktime (mins)	30	30	30	30	30

Assumptions:
1 hr lunchbreak, 2x 15 mins teabreaks, 5 day work week, 20 days work month and balanced line

	Consumer 3D Printer	Industrial 3D Printer	CMM	CNC	Turning Mill
Total Plant Operating Hours	10	10	10	10	10
Downtime (mins per day)	38	49	43	71	19
Planned Production Time (mins per day)	510	510	510	510	510
Operating Time (mins per day)	472	461	467	439	491
Availability	**92.55%**	**90.39%**	**91.57%**	**86.08%**	**96.27%**
Operating Time (seconds per day)	28320	27660	28020	26340	29460
Performance	**88.28%**	**95.44%**	**96.36%**	**89.89%**	**92.92%**
Good Pieces	8	39	99	26	209
Quality	**80.00%**	**97.50%**	**99.00%**	**86.67%**	**95.43%**
OEE =	**65.36%**	**84.12%**	**87.35%**	**67.97%**	**85.38%**

Evaluation of the Collected Data

Those highlighted in green indicate above world-class level OEE – Good.

Those highlighted in pink indicate below world-class level OEE – can improve further.

- For Consumer 3D Printer, output loss is due to poor machine Performance and poor product Quality.
- For Industrial 3D Printer, output loss is due to poor product Quality.
- For CMM, output is able to meet World Class level OEE.
- For CNC Machine, output loss is due to poor machine Availability, poor machine Performance and poor product Quality.
- For Turning Mill Machine, output is able to meet world-class level OEE.

Possible Contributors

- Poor machine Availability because of too much downtime could be due to:
  - ✓ Improper or poor maintenance of the machine

- Poor machine Performance could be due to:
  - ✓ Inefficient design of operational procedure or process flow problem resulting in idling and minor stoppages (e.g. redundant operating steps, product delivery is blocked)
  - ✓ Hidden failures or normal wear in packing machine that causes a reduction in operating rate
  - ✓ Poorly trained operator: insufficient professional training

- Poor product Quality could be due to:
  - ✓ Improperly calibrated tools that cause some misalignments
  - ✓ Eventual wear and tear of the tools

Sample OEE Calculations (Based on Consumer 3D Printer)

- Planned Production Time = Plant Operating Time – Planned Shut Down
  = (10 hours x 60 mins) – 60 mins – 2*15 mins
  = 510 mins

- **Availability** = Operating Time / Planned Production Time
  92.55% = Operating Time / 510 mins
  ⇒ Operating Time = 510 x 92.55%
  = <u>472min</u>

- Operating Time = Planned Production Time – Downtime
  = Planned Production Time – (planned or unplanned) downtime
  = Planned Production Time – (set-up + adjust + breakdown)
  472min = 510 min – (set-up + adjust + (90/5)) min
  ⇒ set-up + adjust time = 510 – 472 – 90/5
  = <u>20min</u>

- **Performance** = Ideal Cycle Time / (Operating Time / Total Pieces)
  = 2500 secs / (472 mins x 60 secs / 10 pcs) = <u>88.28%</u>

- **Quality** = Good Pieces / Total Pieces = (10-2) / 10
  = <u>80.00%</u>

- **Overall Equipment Effectiveness = 92.55% x 88.28% x 80.00% = 65.36%**

Sample OEE Calculations (Based on Consumer 3D Printer)

- The OEE of 65.36% falls short of the world class benchmark.
- Low OEE is mainly due to poor Performance Factor of 88.28% and poor Quality Factor of 80.00%.
- Poor Performance Factor could be due to:
  - ➢ 3D printing speed not optimize, print speed need to be set higher.
  - ➢ Update printers with latest software that creates more efficient machine G-codes.
- Poor Quality Factor could be due to:
  - ➢ Rejects during startup and warming up.
  - ➢ Improper setup or steady state rejects.
- To improve the OEE, address root causes of the poor machine Availability and poor Quality Factor. Moreover, further improvement on Performance Factor will further improve the expected throughput per day.
- Improvement of OEE will help to improve throughput (hence increasing productivity).

Learning Objectives

- Identify the OEE factors and the major losses contributing to each factor
- Demonstrate the ability to calculate OEE
- Compare the individual and overall OEE factors with reference to World Class OEE Level
- Apply Overall Equipment Effectiveness (OEE) in measuring equipment performance

Overview of E326 Lean Manufacturing and Six Sigma