Maintenance Planning and Control IENG 411

Tutorial 1

Maintenance and Productivity

Failure Metrics

Objectives

- Availability
- Reliability
- Maintainability
- Failure Metrics
  - MTBF
  - MTTF
  - MTTR
  - MDT

Availability, Reliability, Maintainability

Availability

- is a metric used to measure the percentage of time an asset can be used for production
- calculates the probability that a system isn't broken or down for preventive maintenance when it's needed for production
- allows maintenance teams to determine how much of an impact they are having on uptime and production.

Reliability

- is the probability that an asset can perform without failure for a specific period of time and under normal operating conditions
- a reliable piece of equipment performs like it's supposed to every time you use it.

Maintainability

- measures the ability to maintain or restore a piece of equipment to its functioning state
- calculates how easy it is to identify problems with a system and solve the problem
- impacts the length of downtime for an asset, it also has a direct impact on availability.

How to calculate system availability

- There are two components to the system availability formula. The first is total uptime and the second is total downtime. Uptime is any time that asset is performing at a normal output. Downtime is any time the equipment is not available for production, including planned and unplanned downtime.
- To calculate system availability for a certain period of time, divide an asset's total amount of uptime by the sum of total uptime and total downtime.

Availability = Uptime ÷ (Uptime + Downtime)

Example 1

- One of your top production assets ran for 100 hours last month. The asset broke down twice during the month, and it took one hour to repair each time. The asset was also shut down for eight hours in a month for routine inspections.
- At the end of the month, you can see that there was 100 hours of uptime on the machine and 10 total hours of downtime on the machine. Therefore, the availability calculation looks like this:
- Availability = $\frac{100}{100+10}$
  Availability =
  Availability = 0.909
  Availability = 90.9 %

Comment

If you're looking to benchmark your operation against the best in the world, top-tier organizations achieve system availability of 90% or higher.

Question

Why should availability be as high as possible?

Practical Insight

.....Availability.....

90%

Threshold	Downtime
99%	1.1 hr
99.9%	6.3 min
99.99%	37.8 sec
99.999%	3.8 sec
99.9999%	0.38 sec

Failure Metrics

Failure exists in varying degrees (e.g., partial or total failure). In the most basic terms, equipment failure simply means that a system, component, or device can no longer produce desired results.

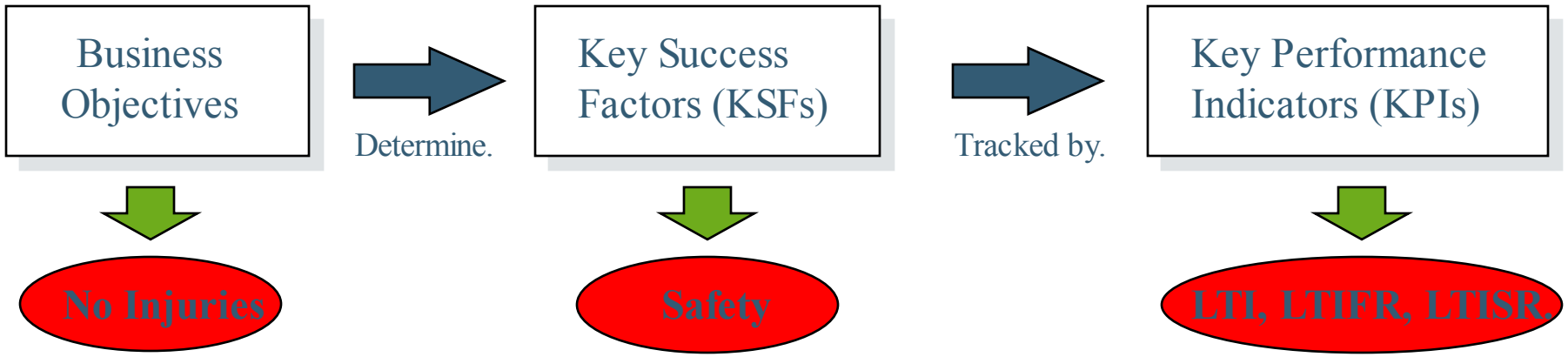
Even if a piece of manufacturing equipment is still running and producing items, it fails when it stops delivering the expected quantities or quality of products.

Maintenance metrics (like MTTR, MTBF, and MTTF) are not the same as maintenance KPIs. Maintenance metrics support the achievement of KPIs, which, in turn, support the business's overall strategy. With so many maintenance performance metrics out there, it's hard to know which one to choose.

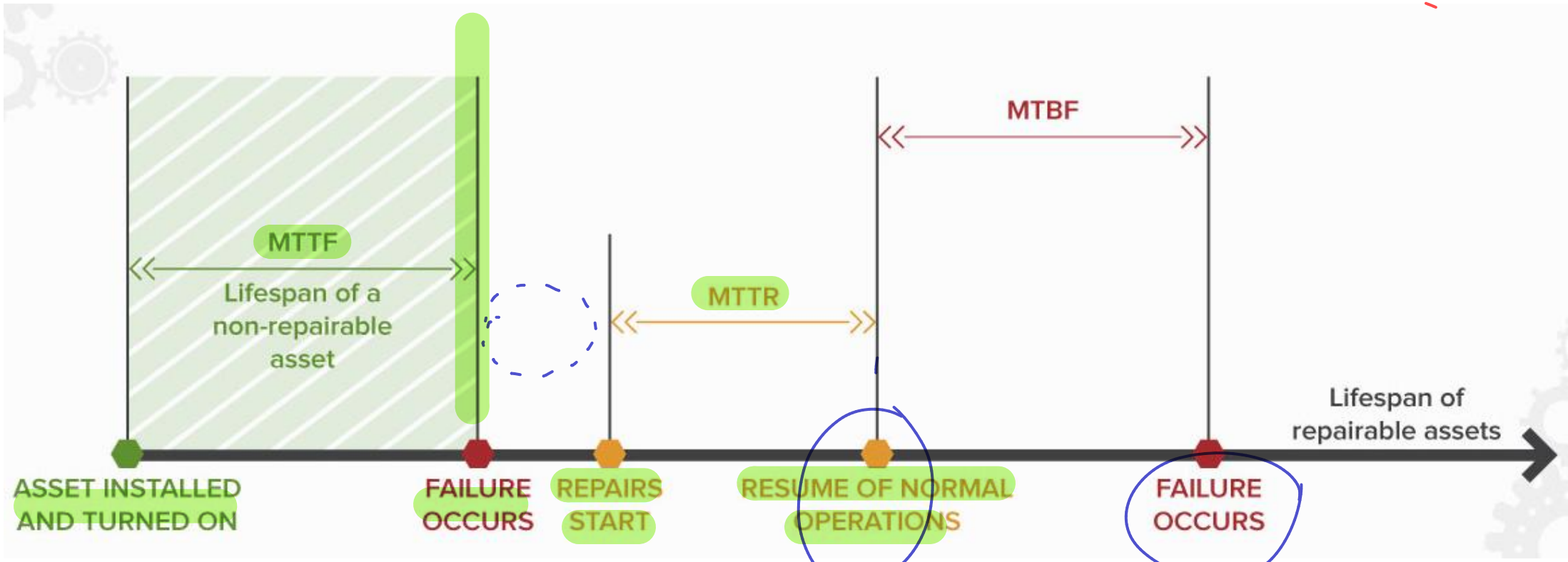
What is a KPI?

KPIs track performance against established key success factors.

- KPIs are directly linked to the overall goals of the company.
- Business Objectives are defined at corporate, regional and site level. These goals determine **critical activities (Key Success Factors) that must be done well for a particular operation to succeed**.
- KPIs are utilised to track or measure actual performance against key success factors.
  - Key Success Factors (KSFs) only change if there is a fundamental shift in business objectives.
  - Key Performance Indicators (KPIs) change as objectives are met, or management focus shifts.



Failure Metrics



What is MTTR (Mean Time To Repair)?

Mean Time To Repair (MTTR) refers to the amount of time required to repair a system and restore it to full functionality. The MTTR clock starts ticking when the repairs start, and it goes on until operations are restored.

MTTR includes:

- Time to troubleshoot and diagnose the problem
- Repair time
- Testing period
- Time to assemble and start up the asset

MTTR

MTTR is the metric you'll use to prove operational excellence. You cannot, however, expect it to solve all your problems. It needs to be coupled with other metrics to help build a strong and valuable KPI that will speak directly in the greater company strategy.

MTTR can easily be distorted by outliers. If you have a single incident with a vastly different resolution or repair than others, your data might be skewed.

For example, let's say the bulk of the water heaters in your building tend to suffer from broken thermostats. For most of them, this is relatively easy and inexpensive. But one is standing out from the rest. It's making strange noises, has mineral buildup, and needs to be drained and the unit repaired before a costly leak or explosion. It takes a lot longer to fix that thermostat. As a result, your mean time to repair a thermostat will seem unusually high.

MTTR and Maintainability

- The maintainability of an asset is commonly measured with mean time to repair (MTTR)
- A shorter MTTR means higher maintainability.
- Higher maintainability can be achieved with a variety of strategies, such as better training and knowledge transfer, maintenance checklists, improved troubleshooting, smarter inventory management, and a bigger focus on a modular design.

Why is MTTR helpful?

- Assets under repair means Downtime. Regular system failures and lengthy downtime periods have a huge effect on **productivity.** That, in turn, has an even bigger impact on **business results.** This is especially the case for processes that are particularly sensitive to failure.
- In a manufacturing environment, **long mean time to repair** leads to missed production deadlines, increased labor costs, loss of revenue, and various operational issues.
- **Understanding MTTR is an important tool for any organization because it tells you how well you are responding to issues with your assets.** Most organizations work to shorten MTTR with an in-house maintenance team supported with the necessary resources, tools, spare parts, and CMMS software.

$$\text{MTTR} = \frac{\text{total maintenance time}}{\text{total number of repairs}}$$

How to calculate MTTR?

- To calculate MTTR, you need to add all the time you've spent on the repairs and divide it by the number of repairs you performed.

Example 2

- A pump that fails three times throughout a workday. The first repair lasted for 30 minutes, while the other two repairs lasted only 15 minutes each. What is MTTR?

$$MTTR = \frac{30+15+15}{3} = \frac{60}{3} = 20$$

$$MTTR = \frac{\text{total maintenance time}}{\text{total number of repairs}}$$

Comment

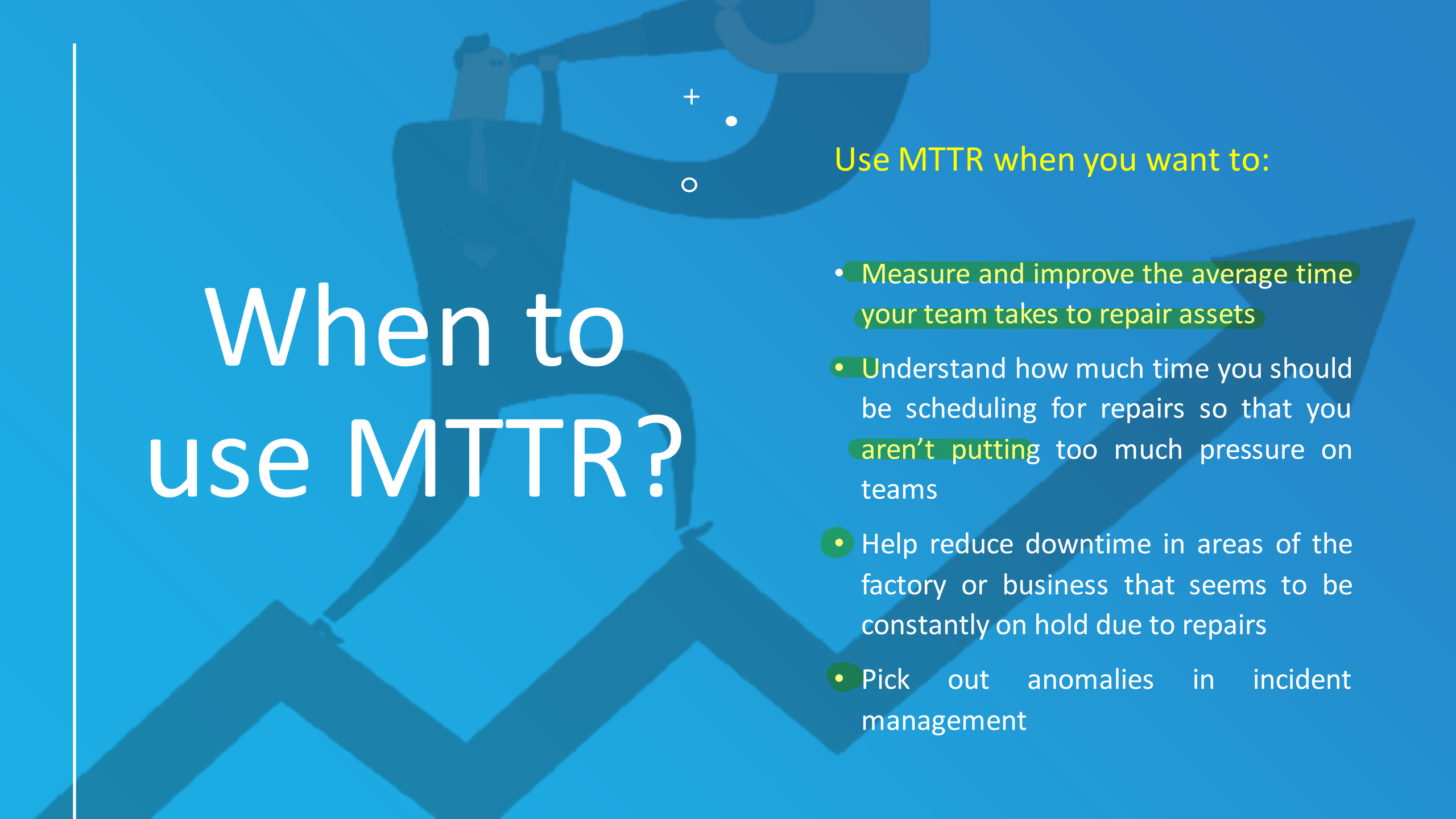
The average time for performing repairs on that pump is **20 minutes**.

- **A special note about MTTR calculation —**
- Each failure will have a different severity level, so while some will require days to diagnose and repair, others could take minutes to fix. MTTR can give you an average of what to expect.

What can MTTR tell you?

The MTTR figure itself is excellent, but a lot more data analysis is required to get to a specific action. MTTR can tell you:

- **Repair vs. replace**. MTTR is a particularly good tool to help you decide when it's time to finally stop repairing an asset and replace it. When you notice it taking more and more time to repair and the costs keep climbing, you can use MTTR as one of the reports to help you make the case for investing in new equipment.
- **More training.** Even the best-trained staff make mistakes. MTTR can highlight gaps in the training or skill of certain staff members or teams. Suppose you see an unusually high MTTR for a certain individual or group. In that case, you may want to look at their training more closely and consider a refresher.
- **Better processes**. As is with training, workflow and operating procedures can have a big impact on the MTTR. These should be evaluated regularly, regardless of performance. Using your MTTR report, you can easily spot issues with assets.



When to use MTTR?

Use MTTR when you want to:

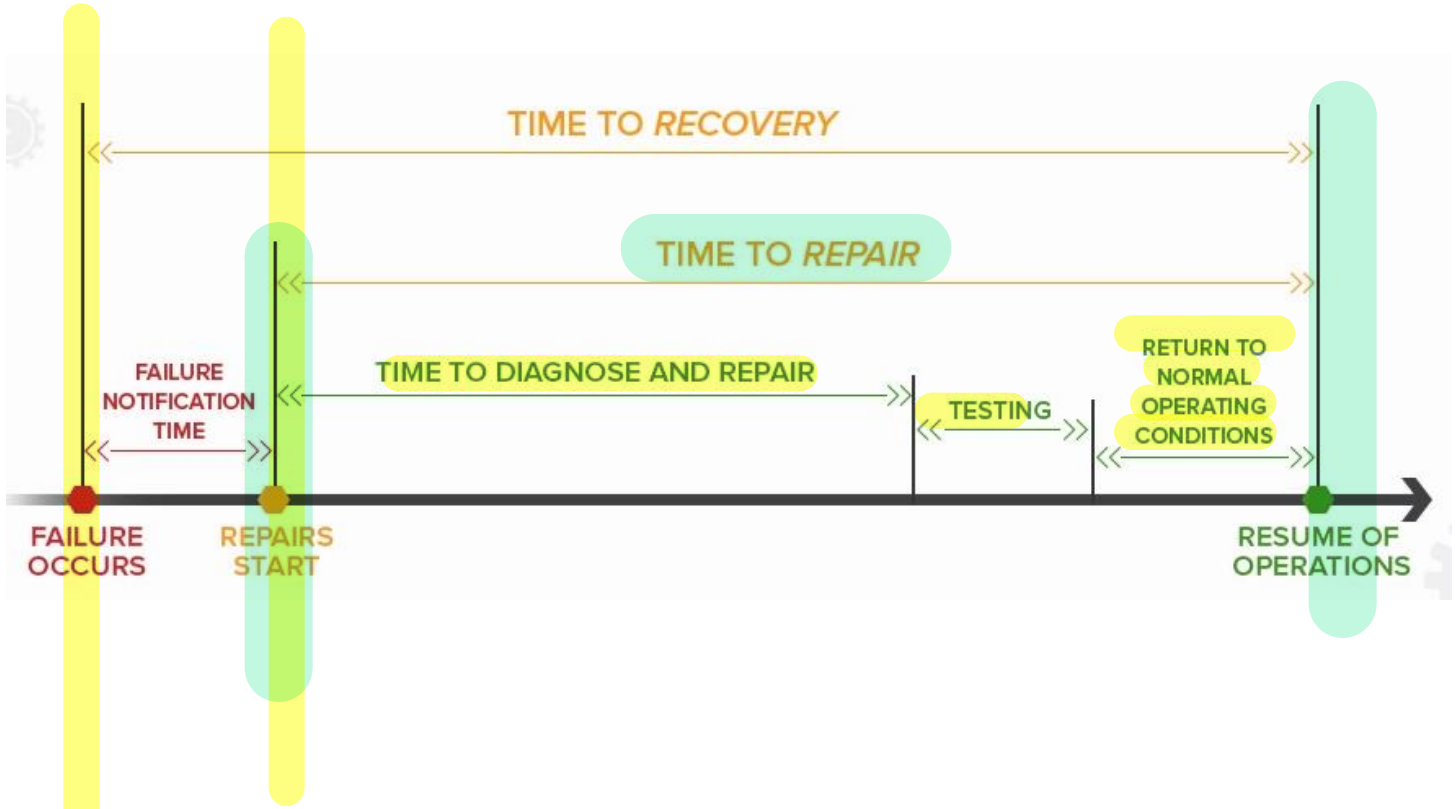
- Measure and improve the average time your team takes to repair assets
- Understand how much time you should be scheduling for repairs so that you aren't putting too much pressure on teams
- Help reduce downtime in areas of the factory or business that seems to be constantly on hold due to repairs
- Pick out anomalies in incident management

Tactics to reduce MTTR

Every efficient maintenance system needs to look at how to reduce MTTR as much as possible. That can be done in a few different ways:

- **Optimize spare parts management and asset inventory management processes**. Doing this makes sure that your technicians have quick access to tools and spare parts when they need them.
- **Use condition-monitoring sensors** to track machine health and performance. While sensors should be utilized to prevent unexpected failures, sensor data can also speed up the diagnosing and troubleshooting process. Knowing your baseline and tracking deterioration signs can give your team more time to arrange for all the resources needed to complete the repair.
- **Implement CMMS software.** Mobile CMMS solutions allow technicians quick access to maintenance history (logs, reports, notes from previous repairs…), which can speed up the repair process and shorten both planned and unplanned downtime.
- **Streamline the repair process.** Create clear standard operating procedures and maintenance checklists for repairs that are performed regularly
- **Proper training.** If you want the job done properly and in the shortest time possible, your technicians need to be qualified and know what they are doing. If you find there are deficiencies, you can swoop in and train up the team members who need it, ensuring you give the best quality service every day.

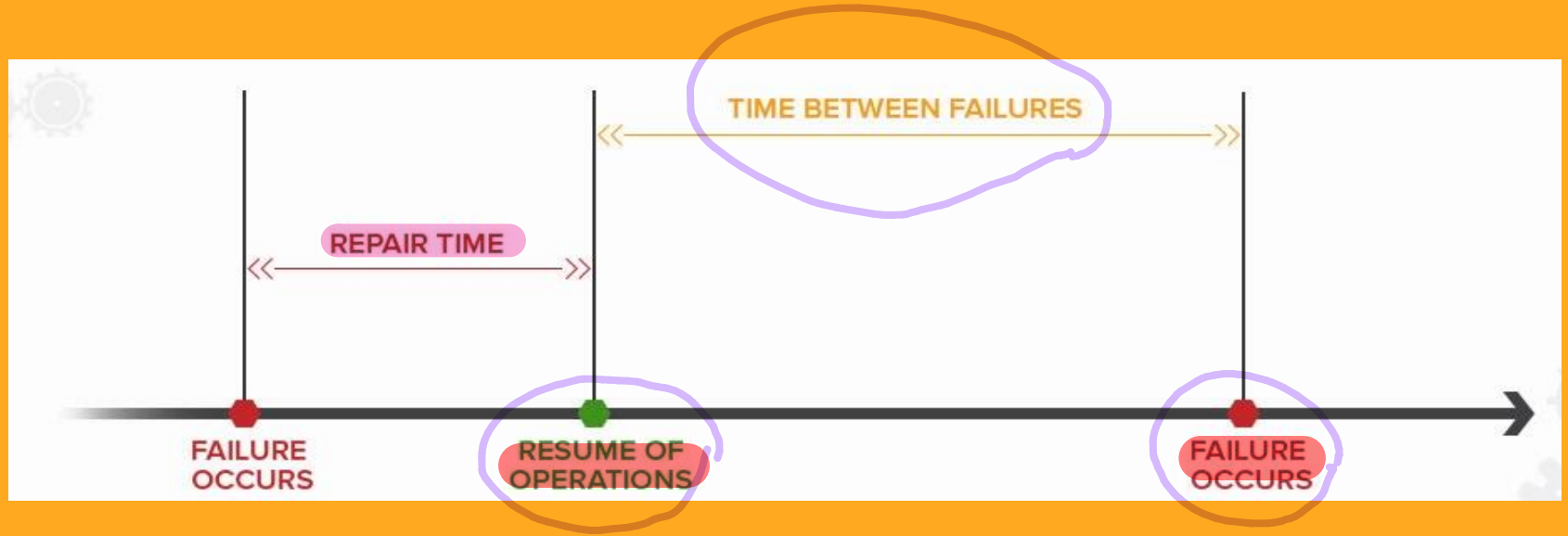
Mean Time to Repair vs. Mean Time to Recovery



MTTR has A LOT of different meanings. The two most relevant for our discussion are "mean time to repair" and "mean time to recovery."

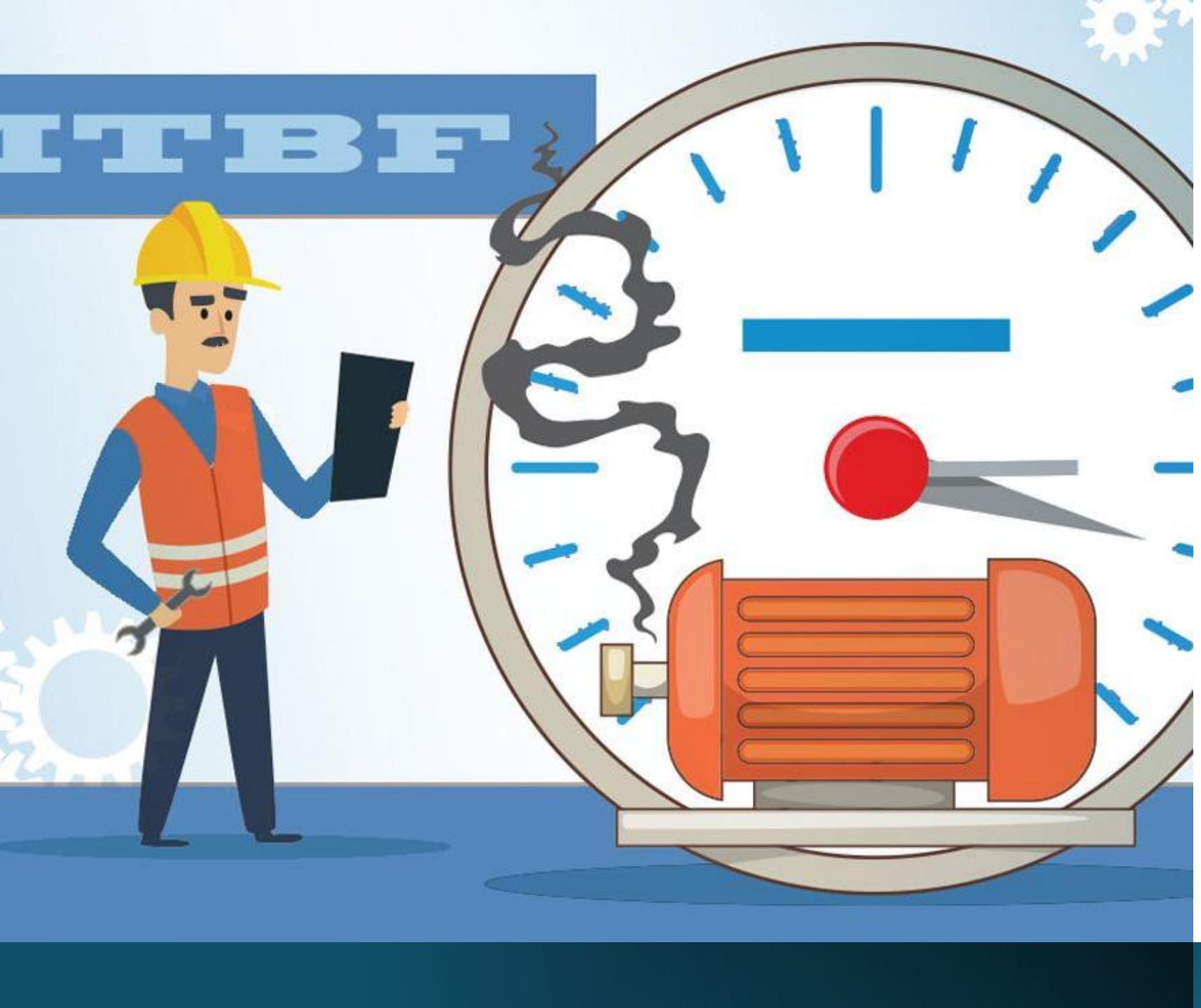
Mean Time To Recover

- **Mean Time To Recovery** measures the time between when the failure is first discovered until the equipment returns to operation. So, in addition to repair time, testing period, and return to normal operating condition, **it captures failure notification time.**
- Although these terms are often used interchangeably, they need to be more clearly defined when it comes to Service Level Agreements (SLAs) and maintenance contracts so that all parties agree on exactly what they mean and what they are measuring.



What is MTBF (Mean Time Between Failures)?

- Mean Time Between Failures **measures the time it takes from one equipment failure to the next time it fails.** This gives you a better idea of how long equipment can stay running over a given period between unplanned breakdowns. It's a way for you to plan around the unexpected.
- So, while **MTTR impacts availability, MTBF measures availability and reliability**. The higher the figure of the MTBF, the longer the system will likely run before failing.



What is MTBF?

Mean Time Between Failure (MTBF) is the amount of time between failures, where failure is defined as a departure from acceptable service for a system. This is a measure of reliability.

Why is MTBF helpful?

- Because equipment failure can be expensive and damaging to the organization, you need to be on top of unexpected breakdowns as much as possible. MTBF is an important indicator of expected performance. **If the MTBF value is low, it means you are experiencing a significant number of breakdowns**, which likely means there's a deeper issue to uncover.

- Manufacturers can use the mean time between failures as a quantifiable reliability metric during many product design and production stages. It is commonly used today in mechanical and electronic systems design, safe plant operations, product procurement, etc.

- MTBF does not consider planned maintenance, but it can still be used to calculate the frequency of inspections for preventive replacements.

- If it is known that an asset will likely run for a certain number of hours before the next failure, introducing preventive actions like lubrication or recalibration can help prevent that failure.

- Essentially, it helps save you money, reduces downtime, and makes you look good at your job (and who doesn't want that?).

How to calculate MTBF?

$$MTBF = \frac{\text{total operational time}}{\text{total number of failures}}$$

MTBF = sum of **operating time divided by the number of failures.**

For the pump example we have:

Out of the expected runtime of ten hours, it ran for nine hours. It failed for one hour spread over three occasions.

MTBF = 9 hours / 3 repairs

MTBF = 3 hours

The pump is failing **every 3 hours on average.**

Keep in mind this is a very simplified example. You will generally want a much bigger sample of information to work with to get a more accurate prediction. As you can see from the example above, we did not include the repair time in the calculation of MTBF.

Other common factors can influence the MTBF of systems in the field. A big one is the fact that we have humans doing the work. For example, low MTBF could either indicate poor handling of the asset by its operators or a poorly executed repair job in the past.

What can MTBF tell you?

- Because of where MTBF falls in the process, it is often coupled with other maintenance strategies. MTBF can help inform your decisions by telling you:
- **Cost of breakdowns.** Pairing MTBF with MTTR and failure codes can help you avoid expensive breakdowns by planning ahead based on the data at hand. This can have a big impact on the bottom line.
- **Frequency of failures**. MTBF measures how frequently you can expect a failure to happen. The higher the figure of the MTBF, the longer the system will likely run before failing.

When to use MTBF?

Use it to start **conquering downtime.** This is by far the most important application of MTBF. Using MTBF, you will also be able to predict, prevent and prevail over the bulk of your unplanned breakdowns. You'll be able to use it for:

- Inventory planning
- Planning your maintenance schedule.
- Indicator of PM performance
- The quality of the information you have in your system and how it is being used

Tactics to increase MTBF

There are small things you can do to increase the time between failures. Some of them are:

Do more proactive maintenance work. Assets that are well maintained are less likely to have critical failures. By using Limble as your CMMS, you can create monthly maintenance schedules in minutes.

Use quality replacement parts. The cheapest part is not always the best long-term. Make sure that you are using quality, proven parts in your work. It will save you a ton in the long run.

Use recommended input material. Whether it is the size of the chicken in the poultry processing system or the thickness of the foil used for product packaging, every machine is designed to work within specific parameters. Respect those parameters.

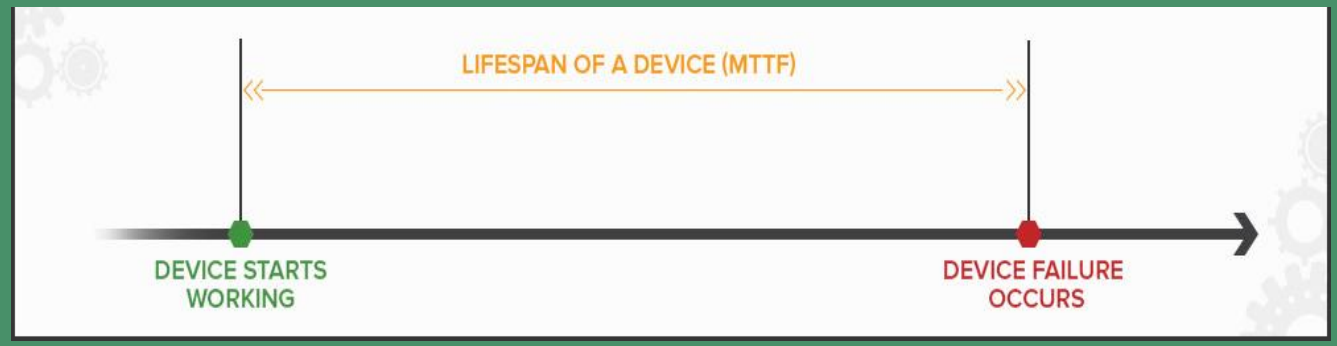
Ensure proper working conditions. Don't push machines beyond their limits to make your productivity numbers look good. Misusing machines is a sure fire way to decrease their useful life and MTBF.

Have a solid onboarding program for machine operators. Assets should be used in respect of how they are designed. Improper handling is bound to shorten MTBF.

Understand the kinks of old equipment and aging assets. Whenever possible, maintenance technicians should give machine operators tips on which actions they should avoid doing with old assets to manage avoidable recurring issues.

What is MTTF (Mean Time To Failure)?

- Mean Time To Failure is a very basic measure of reliability **used for non-repairable systems**. It represents the length of time that an item is expected to last in operation until it needs to be replaced.
- MTTF can be used to represent the lifetime of a product or device. Its value is calculated by looking at a large number of the same kind of items over an extended period and tracking how long they last.



Why is MTTF helpful?

- MTTF is important because **it helps estimate the lifespan of products that are not repairable**. Some common examples of these products range from items like fan belts in automobiles to light bulbs in our homes and offices.

- MTTF is particularly useful as a reliability metric. Engineers can use it to estimate how long a component would last as part of a larger piece of equipment. This is especially true where the entire business process is sensitive to the failure of the equipment in question. Shorter MTTF means more frequent downtime as the failing items need to be replaced

How to calculate MTTF?

- MTTF is calculated as the total time of operation, divided by the total number of units being tracked.
- Let's assume we tested 3 desktop hard drives. The first one failed after 500,000 hours, the second one failed after 600 000 hours, and the third hard drive failed after 700,000 hours in use. MTTF in this instance would be:
- MTTF = (500,000 + 600,000 + 700,000) / 3 units
- MTTF = 1,800,000 / 3
- MTTF = 600,000 hours
- We can now assume that this particular type and model of the hard drive is likely to fail after **600,000** hours of use.

What can MTTF tell you?

Mean Time to Failure can be used for:

- **Inventory lead time.** Understanding your MTTF can help you plan for replacement equipment, making sure that you are never stick waiting for new equipment to come in
- **Quality control.** MTTF that gets shorter and shorter can be an indicator of quality issues from your suppliers. Use this information to have conversations or know when to look for new suppliers.
- **Misuse of equipment**. As with quality control, a change to your MTTF could be an indication that users are not using the equipment correctly, meaning that there is a need for better training. It could also indicate an increase in general usage or an upstream problem that negatively affects this particular part. Either way, these are important pieces of information to note.

When to use MTTF?

Suppose you are looking at investing in new equipment that will replace your current equipment. It's important to know how long they are expected to last. This will be a core component when you are putting your budget together.

MTTF will inform you of a lot of the spending on both your capex and opex budgets. How often will you be replacing things, and at what costs?

You can sometimes find information about MTTF from the OEM. While we are always optimistic that they are correct, they can sometimes be misleading. Reach out to other maintenance managers to get their input if you can. Always run your own MTTF reporting to keep track of your asset lifespans.

Tactics to increase MTTF

Use the best quality items you can find — ones that are made from more durable materials and have gone through a thorough quality control process. Limble let's you keep track of your preferred parts and vendors in each asset record so you can always source the right parts and service.

Take action to improve the lifespan of the asset. Make sure that the devices are used for their intended purposes and in the conditions (humidity, heat, pressure, voltage, etc.) they are designed for. You can store the equipment operating and maintenance manual in Limble to double-check if the device was properly installed/retrofitted before it is used.

Use your time, budget, and resources wisely. Because you are not planning to fix anything, scheduling maintenance is not an option here. You can maybe wipe off the dust or run high-level diagnostics to estimate remaining useful life. Still, you are not going to perform preventative maintenance on a computer hard drive or a lightbulb. You are just going to replace them when they stop working properly.

Other noteworthy maintenance metrics related to failure

- There are at least 10 different metrics, if not more, with overlap between many of them. This article has covered the three most popular. Still, there are a few others we'd like to introduce you to so that you can make an informed decision about the metric set that's right for you:
- **MDT (Mean Down Time)** is something that the Finance will think about first. How long is something not working for? This is what they care about.
- **MTTD (Mean Time to Detect)** is helpful when monitoring how long it takes to detect and report an issue. This can be helpful when you have a situation where there are multiple assets dependent on the functionality of one another. Using tracking devices, you can get your reporting down to the shortest possible time and keep the system running smoothly.
- **MTTI (Mean Time to Identify)** is a metric that focuses on reducing the length of time it takes your team to identify the issue so they can fix it.
- **MTTA (Mean Time to Acknowledge)** is a great key performance indicator. It helps you track your team's incident response time and see how they are reacting to the workload over a period of time. If your team is overloaded, their time to acknowledge will be much slower.

Calculation of Maintenance Parameters

The mean time between failures and mean time to repair in a certain department of the factory are 400 hours and 8 hours, respectively. The department operates 25 machines during one 8-hour shift per day, five days per week, 52 weeks per year. Each time a machine breaks down, it costs the company $200 per hour (per machine) in lost revenue. A proposal has been submitted to install a preventive maintenance program in this department. In this program, preventive maintenance would be performed on the machines during the evening so that there will be no interruptions to production during the regular shift. The effect of this program is expected to be that the average MTBF will double, and half of the emergency repair time normally accomplished during the day shift will be performed during the evening shift. The cost of the maintenance crew will be $1500 per week. However, a reduction of maintenance personnel on the day shift will result in a savings during the regular shift of $700 per week.

(a) Compute the availability of machines in the department both before and after the preventive maintenance program is installed.

(b) Determine how many total hours per year the 25 machines in the department are under repair both before and after the preventive maintenance program is installed. In this part and in part (c), ignore effects of queueing of the machines that might have to wait for a maintenance crew.

(c) Will the preventive maintenance program pay for itself in terms of savings in the cost of lost revenues?

The mean time between failures and mean time to repair in a certain department of the factory are 400 hours and 8 hours, respectively. The department operates 25 machines during one 8-hour shift per day, five days per week, 52 weeks per year. Each time a machine breaks down, it costs the company $200 per hour (per machine) in lost revenue. A proposal has been submitted to install a preventive maintenance program in this department. In this program, preventive maintenance would be performed on the machines during the evening so that there will be no interruptions to production during the regular shift. The effect of this program is expected to be that the average MTBF will double, and half of the emergency repair time normally accomplished during the day shift will be performed during the evening shift. The cost of the maintenance crew will be $1500 per week. However, a reduction of maintenance personnel on the day shift will result in a savings during the regular shift of $700 per week.

(a) Compute the availability of machines in the department both before and after the preventive maintenance program is installed.

(b) Determine how many total hours per year the 25 machines in the department are under repair both before and after the preventive maintenance program is installed. In this part and in part (c), ignore effects of queueing of the machines that might have to wait for a maintenance crew.

(c) Will the preventive maintenance program pay for itself in terms of savings in the cost of lost revenues?

MTBF Before = 400 ⇒ up time
8 hrs ⇒ down time

MTBF After = 800
4 hrs

(a) availability Before = $\frac{\text{up time}}{\text{up time + down time}}$

$= \frac{400}{400+8} = 98\%$

availability After $= \frac{800}{800+4} = 99.5\%$

without PM

total operating hours = 8 * 5 * 52
= 2080 hrs

$MTBF = \frac{\text{total operating hours}}{\#\text{ OF Failure}}$

$\#\text{ OF Failure} = \frac{2080}{400}$

= 5.2 Failures/year/Machine

total Down time = 25 * 5.2 * 8 = 1040 hrs

With PM

$\#\text{ OF Failure} = \frac{2080}{800} = 2.6$ Failures/year/Machine

For 25 Machine = 2.6 * 25 = 65

total Down time = 65 * 4 = 260 hrs/year

(c)

without PM total Cost of Down = 200 * 1040
= 208000/year

With PM total Cost of Down = 200 * 260 = 52000 $/year

Additional labor Cost = (1500 - 700) * 52 = 41600 $/year

Cost saving = 208000 − (52000 + 41600)

= 114400 $