Time and Operations in OM

Content

1. INTRODUCTION

This chapter deals with the issue of time and operations. It discusses the so-called lead time (its origin and repercussions), the times for operating, setting up, and repairing machines and leaving them idle, and above all the times that products, machines and materials have to wait in their slow journey to the customer.

	Are transforming	Are moving	Are Waiting	Are Being transformed
Products	• Fungible and consumables • Students who collaborate	• Independently • being transported	• to be transformed • Orders	• At the right speed • When They Are Required
Clients	• Do it Yourself	• knowing where they're going • Roaming • Seeking	• To be served • In waiting rooms • Its appointment • At home	• They are patient subjects • They are active subjects • At the right speed
Static Machines	• At a speed • With a level of autonomy • With a level of quality	///////////////	• Idle • Blocked • Starved	• Under Maintenance • Preparing new production batches
Materials handling machines	//////////////////////////////////	• Products • In search of work	• In an agreed place • In an unagreed place	• In Maintenance • Battery recharging
Human resources	• Working (properly?) • At the expected pace? • Extending the task? • Sweating? • In value-added operations?	• Looking for a job/task • In search of materials • In search of tools and dies	• Work Orders • Of material to work with • Of tools to work with • Of machines available to work with • Watching how the machinery (or a colleague) works	• In Training

Table 1: how do resources spend their time, both those which transform and those which are transformed?

Lead time is often confused with operating time, and operating time with the time needed for tuning and maintenance. Due to these mix-ups and the brain's inability to keep track of time, it typically takes time to coordinate activities, which will be further explained at the end of this chapter.

The chapter begins by trying to represent time, then goes on to analyse time leaks. It defines lead time, throughput time and transport time. It then deals with operating, repair and setup times. Time estimation and the learning effect precede the most important times of all, i.e. waiting times, which are decisive for on-time delivery.

2. REPRESENTING TIME

Time is not easy to represent on a sheet of paper. By its nature, time makes phenomena dynamic, and paper is not dynamic. However, without visualising the passage of time, a common frame of reference is not possible.

When representing the passage of time, two different concepts must be distinguished: milestones, which can be associated with particular moments in time versus phases or stages, which can be associated with the time that elapses between the first and last milestones.

2.1. TIMELINES AND GANTT CHARTS

"Timelines" are the most basic way of representing the passage of time, with events represented by dots on a line and phases by thicker sections of line. Timelines are widely used to represent production schedules, and when multi-line timelines are used, each line represents one of the resources being planned.

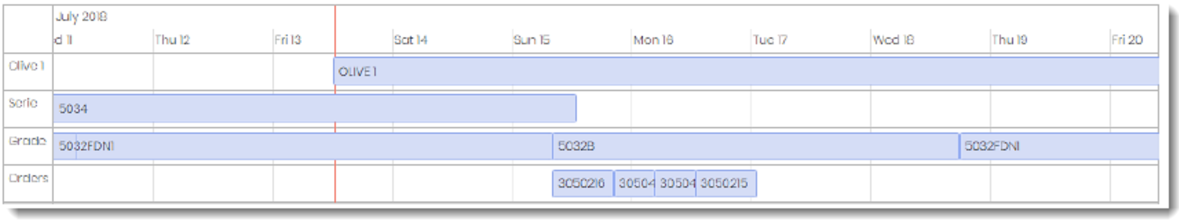


Figure 1: example of a timeline in a production schedule. Source: (Vidal-Aragon Reviriego, 2018)

A Gantt chart is a type of multi-line time diagram in which each task is represented on a different line. Gantt charts are widely used in project management, and can also be used to illustrate time in production processes.

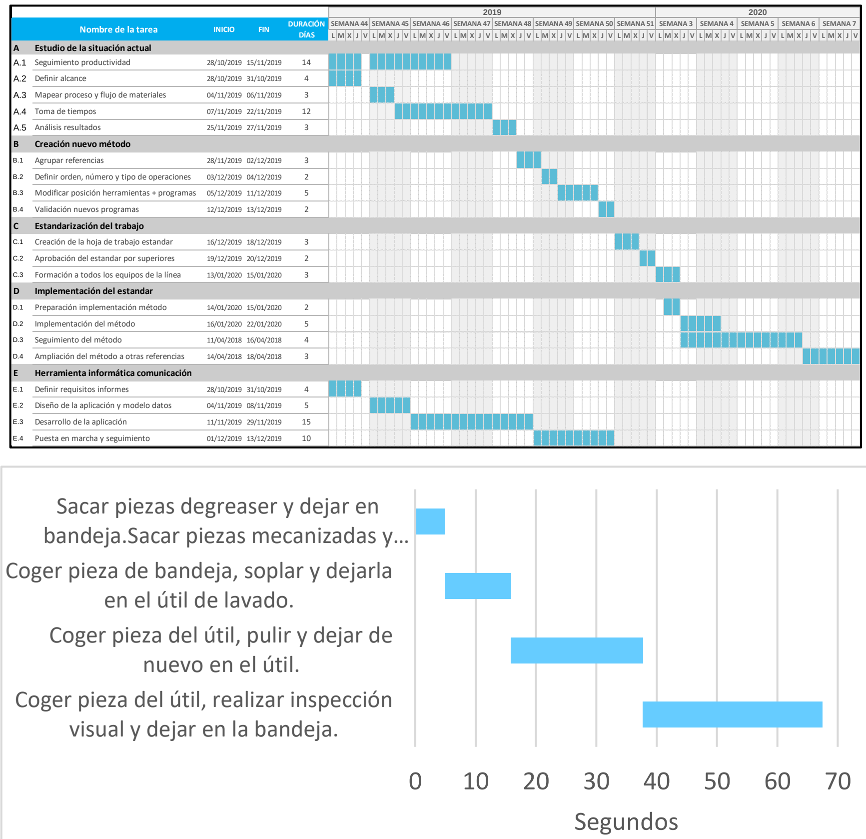


Figure 2: two ways of using Gantt charts. Source: (Sancho Chilet, 2020)

2.2. PIE CHARTS AND BAR CHARTS: YAMAZUMI

An easy way to represent what a resource spends its time on is to use a pie chart. However, stacked bar charts (*Yamazumi*, in Japanese) are also a widely used.

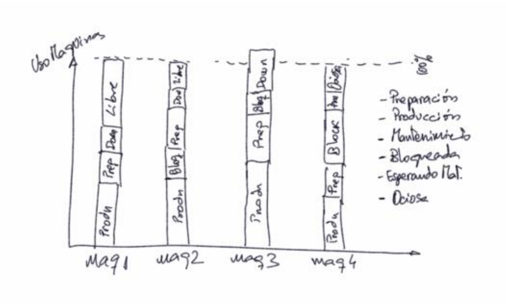


Figure 3: bar chart representing the time used by a resource

2.3. SYSTEM DYNAMICS AND DISCRETE-EVENT SIMULATION

The figure above shows what will occur over time, but not the effect of these occurrences.

System dynamics is a method of analysing and modelling the behaviour of systems over time. The approach is based on identifying feedback loops and information and material delays as well as the effects that both features combined have on the behaviour of the system. System dynamics has proven its usefulness in various environments. It is of particular interest for continuous production systems and the analysis of inventory management models.

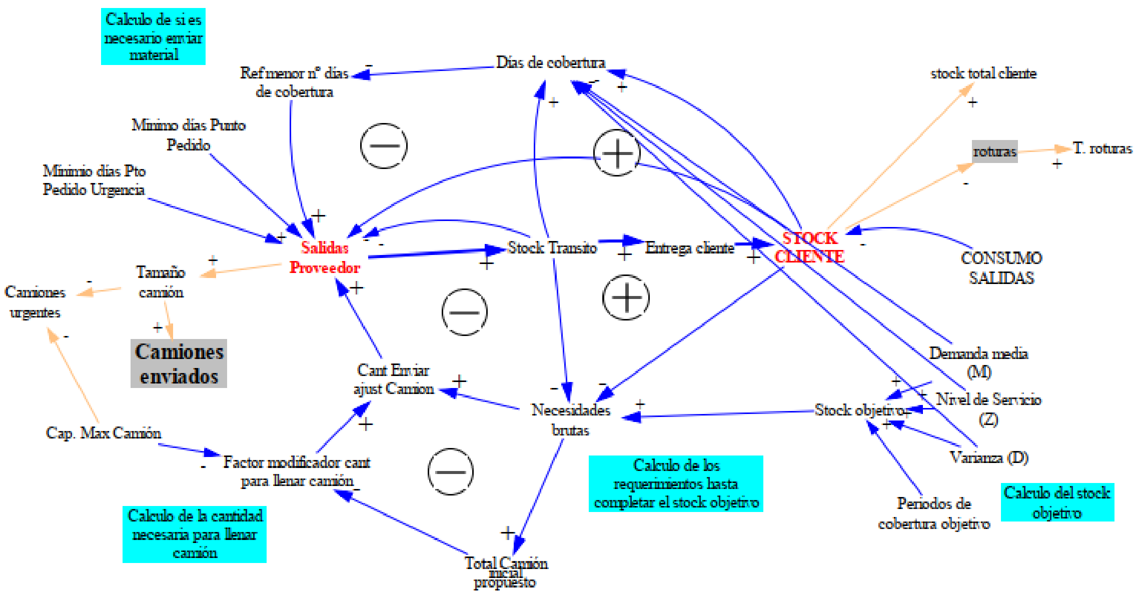


Figure 4: causal diagram. Source: (Rius-Sorolla *et al.*, 2015)

Discrete-event simulation attempts to understand the behaviour of systems through the behaviour of movements and their flow through resources. Instead of treating time as a continuum, discrete-event simulation assumes that the system behaves predictably between events, and so it limits itself to analysing exactly what happens when an event occurs. When an event occurs, it is possible to calculate what new events will occur in the future.

Originally, discrete-event simulation produced data tables for analysis. By combining it with animation technologies, discrete-event simulation can generate animations that are at times more expressive than a formal statistical analysis of the results obtained.

Despite being a fundamentally quantitative tool, since the late 1990s, discrete-event simulation has taken on a new dimension in the visual world we live in. The core of the tool is well suited to generating animations, and suitably structured it can even simulate the information systems required for the normal functioning of a factory.

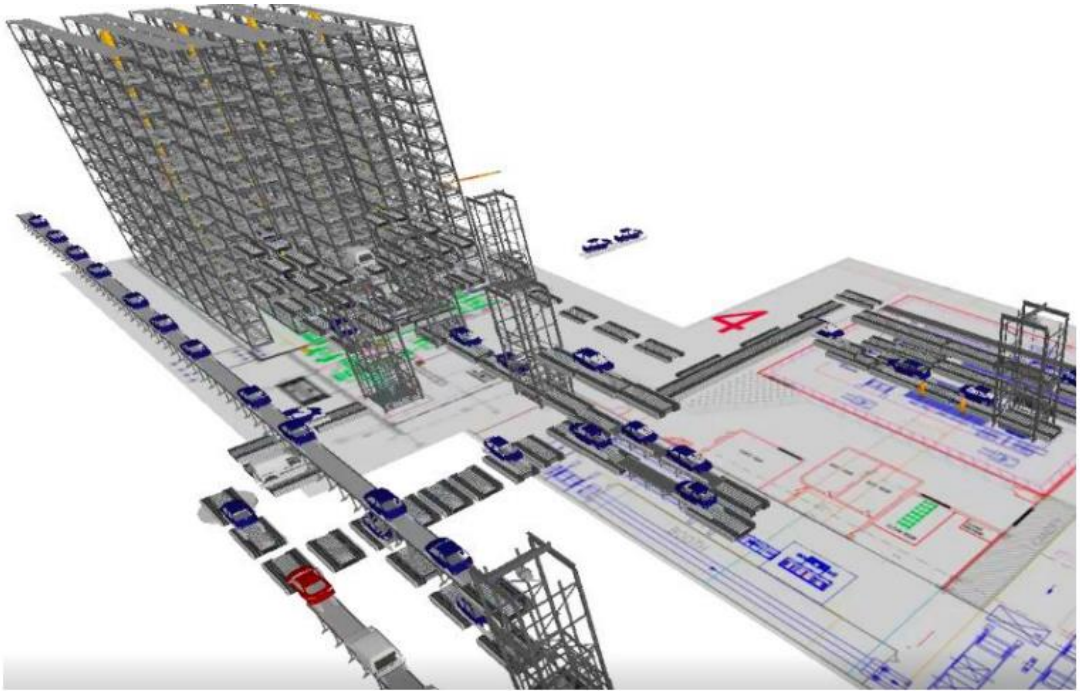


Figure 5: view of a simulation. Source: (Saez-Mas, Aida; García-Sabater, Jose P,; Morant-Llorca, 2018)

The simulation process should include the following eight steps, which should be repeated until the client obtains relevant results.

1. Define the objective of the project with the client
2. Model the system (back to 1)
3. Collect preliminary data and launch first hypotheses (back to 2)
4. Implement, verify and refine the model (back to 2, 3)
5. Discuss and approve the model with the client (back to 2, 3, 4)
6. Design experiments
7. Analyse results
8. Report results (back to 6 or 1)

Models represent reality according to the modeller's point of view. Discrete-event simulation requires specific skills, and as such the modeller is not the decision maker (the client is).

Accordingly, the client must gain confidence in the model as it is being built, verified and validated, so that it can have confidence in the decisions it will make based on the results.

Often clients express doubts about the validity of the model because they are not sure they understand how it works.

In many cases, counter-intuitive results are a prerequisite to success in step eight, but if so, to make a decision, the client must have the courage to accept the results. In such cases, a thorough sensitivity analysis adds a great deal of reliability to the modelling process and thus to the results obtained.

The way in which a discrete-event simulation is typically used requires the definition of **evaluation criteria**, **alternatives** and **scenarios**. The criteria should be defined before the process starts, although they usually appear after several repetitions. The aim is to assess the alternatives. The generation of alternatives is a creative process that will result in the model being made and remade. Scenarios are the sets of unknown data (demands, production rates, machine availability) against which the alternatives will be run.

The results of a simulation are usually data and tables, but more relevant is what the modeller learns about the system. The insights gained can be used to provide recommendations and always lead to further questions.

3. ANALYSING TIME LEAKS (TEMPUS FUGIT)

One key role of an operations manager is time management. Time is by its nature elusive and difficult to understand, and it can be especially difficult to recognise that time can seem productive when in practice it is not being used to add value. This is why the concept of "value added time", seriously neglected in VSM, is so important. Value added time is the time in which value is added to the product. Everything else is non-value added time. Although everyone may seem very busy, not everyone is always adding value.

To avoid playing a guessing game, it makes sense to analyse what the machines spend their time on before starting the improvement activity. This is certainly a tedious task and it is worth analysing it using successive approximation.

Indicators such as OEE and FTT can provide information on the origin and magnitude of the problem, but knowing where each resource spends its time is an art form in itself.

MES tools, if properly parameterised, can provide information that helps identify the source of capacity loss. Table 2 provides a template for analysis:

Machine status	Hours per shift	Detailed machine status	Hours per shift	Possible actions
Machine running		At maximum speed		Continue
		At less than maximum speed		Machine maintenance Worker training, incentives and motivation Process standardisation Poka-yoke Worker incentives Reducing the quantity of packaging materials Activity indicators and monitoring Scheduling of operations
		Producing defective product		
		Producing unplanned product		
		Testing new product		
Mainten ance		Planned maintenance		Autonomous maintenance Preventive maintenance Worker training TPM Scheduling of operations
		Unplanned maintenance		
		Waiting for maintenance team		
		Testing new product		
Machine being set up		Planned preparation		SMED Worker training Scheduling of operations Small machines Standardisation of activities 5S
		Unplanned preparation		
		Waiting for preparation team		
		Waiting for tools or instruments		
		Start of production until the first good part is produced		
Machine inactive		Blocked due to lack of finished product packaging		Increase the quantity of packaging materials and/or promote the use of standard ones Inward/Outward buffers Evacuation of materials Arrival of materials Multiskilled workforce Planning of materials and tools Worker planning Scheduling of operations Standardisation of activities 5S Plant layout
		Blocked due to lack of space for the finished product		
		Waiting for initial product or components		
		Waiting for consumables		
		Waiting for tools		
		Waiting for workers		
		Awaiting production orders		
		No workload		

Table 2: various possible machine statuses (2)

4. LEAD TIMES AND THROUGHPUT TIMES

Lead time is the period from when a customer places an order to the moment when they physically receive it. It depends on product availability and transport time (its base constraints) but may be defined by the business processes that handle the orders (ordering and receiving). The purchase of raw materials from a supplier with a lead time of three months requires planning horizons at least one forecast period longer than the lead time.

The **P:D ratio** (also known as the **supply delay**) expresses the relationship between the time (P) required to produce/deliver the product and the time (D) the customer is willing to wait to receive the product.

When P is much higher than D, finished products must be held in stock (make to stock), whereas when P is much lower than D, production of the product can start when the customer orders it (make to order). A midway approach would see sub-assemblies stored for assembly to order. Furthermore, products that are even more specific will have longer acceptable lead times and therefore the strategy can be "engineer to order".

	P>>D	P>D	P=D	P<D
Customer Order Fulfilment Strategy	• Make to Stock - MTS	• Assembly to Order - ATO	• Make to Order - MTO	• Engineering to Order - ETO
Stored items	• End products	• Sub-assembly products	• Raw Materials	• Some Raw materials
Customization	• Products are fully designed • Products are in a catalogue	• Products are fully designed • Some product configurations need concrete specifications	• Products can be partially redesigned	• Products are designed during the manufacturing process is performed
Time to deliver	• Delivery in less than one day	• Delivery is compromised depending on available capacity	• Delivery is compromised depending on available capacity and on material availability	• Delivery is compromised depending on available capacity and on material availability

Figure 6: production strategies based on P:D ratios

Since lead time is a strategic factor, it is typical to want to reduce it (although in certain cases reducing lead time can be misunderstood by customers).

In some ways, the lead time required/accepted/demanded by the customer dictates whether inventory will be in the form of raw material, sub-assemblies or finished products.

Throughput time is the period from when the raw material is taken from the warehouse to when the product enters the finished product warehouse. Throughput time purposely excludes time spent in raw material and finished product warehouses. This focuses the analysis on what takes place in the factory and not on what takes place with suppliers and customers.

To measure the impact that the latter have on operational performance we must use the **dock-to-dock (DTD)** indicator, which expresses the time from when the product enters the company's facilities to when it leaves for the customer. It is interesting to note that DTD is actually an inventory indicator and is therefore widely used in large companies where holding inventory in any form is not considered part of the business and should therefore be avoided.

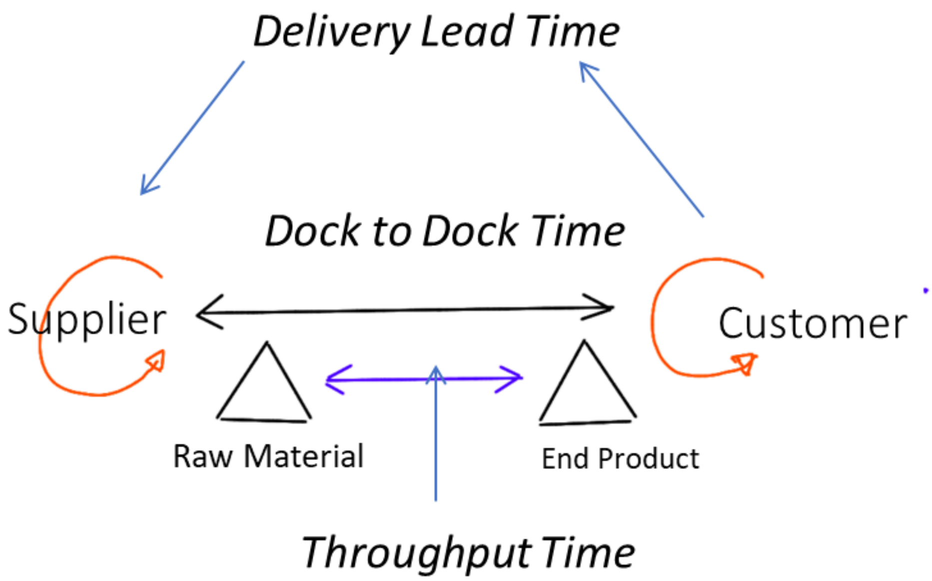


Figure 7: lead time, dock-to-dock time and throughput time

5. OPERATING TIMES

Takt time is the average time between two consecutive requests. So if a company receives ten orders per day (8 hours), the takt time is 0.8 hours per order. The word *takt* is of German origin and refers to the "beat or tempo of music". This beat or tempo allows for synchronisation.

Cycle time is the average time between two consecutive deliveries (i.e. the time required to complete a cycle). The inverse of cycle time measures the rate of production of the resource. If the cycle time is longer than the takt time, the company will have to acquire additional resources, or the queue of pending orders will grow.

However, machines (or resources) are not always active. When maintenance and repair requirements (and other types of loss) are included, the cycle time is often referred to as the **effective cycle time**.

To calculate the effective cycle time, the concept of availability (a percentage of the total time) is normally used, which is obtained by dividing the **mean time between failures (MTBF)** by the sum of the MTBF and the **mean time to repair (MTTR)**.

In many cases the so-called **setup time**, **preparation time** or **changeover time** is incorporated separately. This is the time required to produce the first good part of an order following the production of the last good part of the previous order.

When batches are small, for calculation purposes, the cycle time can include the setup time (even though they are different).

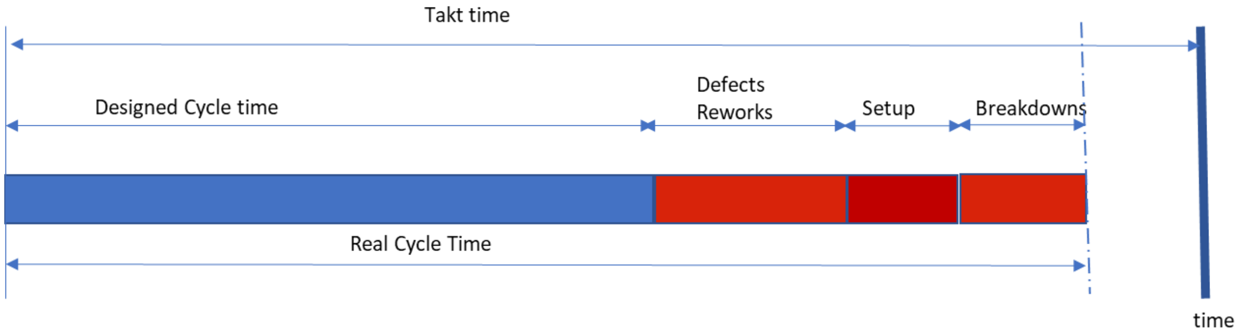


Figure 8: estimated and actual cycle time

6. MAINTENANCE TIMES

6.1. BATHTUB CURVE

All machines go through three phases in their life cycle and in each phase the probability of failure is different. This is known as the "bathtub curve".

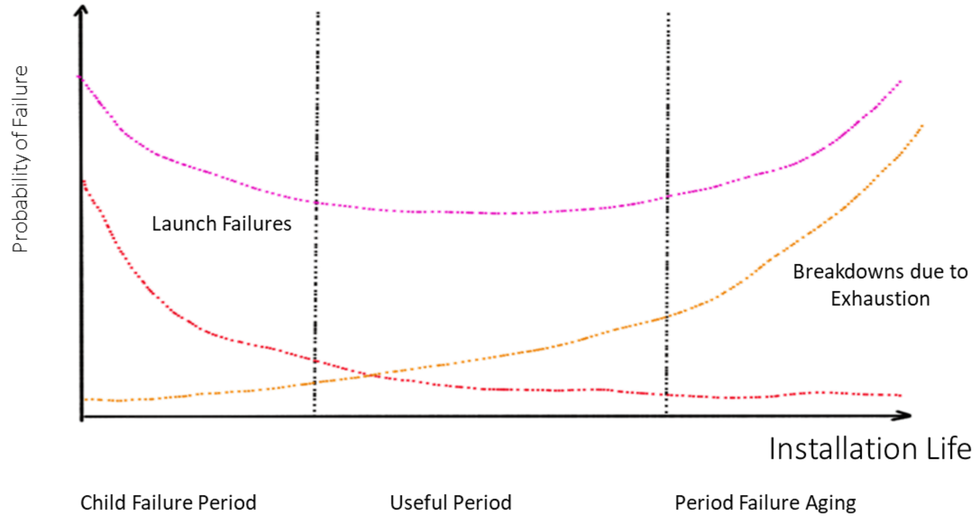


Figure 9: the maintenance bathtub curve. Source: prepared by the authors

In the first phase, productivity is lower than nominal because the purchasing company must learn to use the machine with its products and operators, and also with its energy supply and information systems. Depending on the machine and the machine purchase agreement, the installing company may carry out the maintenance work in this phase. The agreement may stipulate that the installer will not be paid until the machine has reached the point where it can operate continuously at its nominal speed. If this period is drawn out, the machine will become extremely profitable for the purchasing company (but ruinous for the installer).

During the useful life phase, the machine operates at its nominal speed and breaks down in a more or less predictable pattern. This may be due to wear of machine components, misuse, poor product quality, or random external causes. The maintenance department is responsible for making this phase as long as possible, while the machine operator also plays an important role.

In the last phase, the machine begins to fail too frequently. Sometimes this is by design (planned obsolescence), while at other times it is because the complexity of the machine makes it hard to maintain each and every part that undergoes natural wear and tear. This may be the time to replace the machine.

Lean manufacturing takes a different approach to this last phase in the life of a machine. One of the pillars of lean manufacturing, *jidoka*, provides for machine maintenance, even for old machines. Old machines may be idle (since they have already paid for themselves) but if they are in perfect working order they can make any product, albeit more slowly, in the right quantity.

6.2. AVAILABILITY, MEAN TIME BETWEEN FAILURES, REPAIR TIME

By analysing failure times and repair times, two precise pieces of information are obtained: the mean time between failures (MTBF) and the mean time to repair (MTTR).

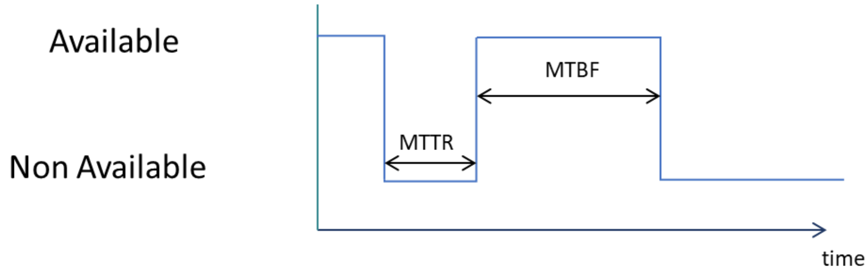


Figure 10: MTTR and MTBF. Source: prepared by the authors

Together, they allow the availability of the machine to be calculated:

$$a = \frac{MTBF}{MTBF + MTTR}$$

One important point in relation to the concept of availability: if the MTTR is smaller than the cycle time, the availability simply lowers the production rate (increases the cycle time).

But if the MTTR is much larger than the cycle time, not only does productive capacity drop, but a buffer large enough to protect the productivity of the downstream and upstream stations will be required.

Gauging the right size of the protection buffers will probably require a simulation. If so, it is recommended to use a Weibull distribution to calculate the mean time between failures and a lognormal distribution to calculate the mean time to repair.

6.3. CORRECTIVE, PREDICTIVE AND PREVENTIVE MAINTENANCE

However, it is better to avoid breakdowns than to fix them once they occur, or if they do occur, to ensure they have the least possible effect on the rest of the production system.

The type of maintenance varies depending on whether work is carried out before or after the failure occurs.

Corrective maintenance is carried out after the failure occurs and seeks to restore the machine to its standard performance. Depending on the failure, it may be immediate or postponed. Furthermore, it may be a full repair or a "patch-up". Despite any attempts to gloss over them, the effects on a machine's life of not properly repairing failures are obvious.

Preventive maintenance involves a set of routines that periodically check for small problems in order to prevent major problems from arising. The aim is for the machine to work smoothly over the period of time during which it is expected to work. Preventive maintenance has two main components: planned maintenance and predictive replacement. Continuous monitoring of the machine's activity can also provide an indication that an inspection should be performed earlier than scheduled.

In addition to corrective and preventive maintenance, there is another type of maintenance called **productive maintenance**. It aims to improve the overall productivity of facilities.

Autonomous maintenance is a strategy (usually associated with productive maintenance) where minor adjustments and maintenance are carried out by the machine operators themselves. To be part of an autonomous maintenance team, workers must be able to:

a) Understand the functions and components of the machine
b) Detect anomalies in how the machine operates
c) Detect product quality problems
d) Define the causes of anomalies and problems
e) Propose (and implement) improvements

To acquire these abilities the operator requires a significant amount of time, as well as training and an assignment of responsibilities, since operators must participate in any major maintenance also.

Preventive maintenance may seem more costly than corrective, not to mention productive, maintenance. However, maintenance planning avoids hidden costs that are difficult to quantify for small companies (although less so for large companies).

Since breakdowns tend to be random, small businesses often forgo the direct costs of preventive maintenance and rely instead on luck to avoid them. Then when a breakdown does occur, everyone blames Murphy.

7. SETUP TIMES

The terms **setup time**, **preparation time** and **changeover time** refer to the time needed to prepare the machine for the start of the next production batch. At the start of the batch there may be a period where, although production is underway, the product is subject to quality controls or to production rates that are not yet stable.

In practice, setup also includes when the worker takes longer to reach the standard production rate after changing activities.

The setup time is that needed to prepare new tools, change raw materials, produce the first units of a new order so that a quality control can be carried out, as well as to clean the remains of the previous order from the machine, remove the previous tools and make the machine available to start again.

The setup time can be sequence dependent (e.g. when changing the format in a bottling machine, or changing the flavour of a soft drink). In this case the production sequence can take into account the so-called matrix of change.

The setup consumes time used by machines and their operators. It may also consume materials and even the maintenance team's time, if they are called in to provide support. Where this is the case, the scheduling of the activity will have to take this into account.

In certain jobs and for certain workers the most "entertaining" part of the job is the setup, whereas in other environments (or on other shifts) the worker prefers to continue with the series to the end.

The changeover time affects the saturation of the machine automatically without changing the production conditions. Therefore, reducing the changeover time is a way of directly freeing up resources in the facility, thus allowing for a reduction in the size of the manufacturing batch.

The acronym SMED refers to the most commonly used methodology for reducing the changeover time (Shingo, 1990). The origin of this approach goes back to the origins of the just-in-time system.

The approach distinguishes between internal and external preparation, first separating and identifying them, then converting internal change into external change, and lastly reducing the time needed for both. External change is that which can be executed while the machine is still producing the previous order. Internal change requires the machine to be inactive.

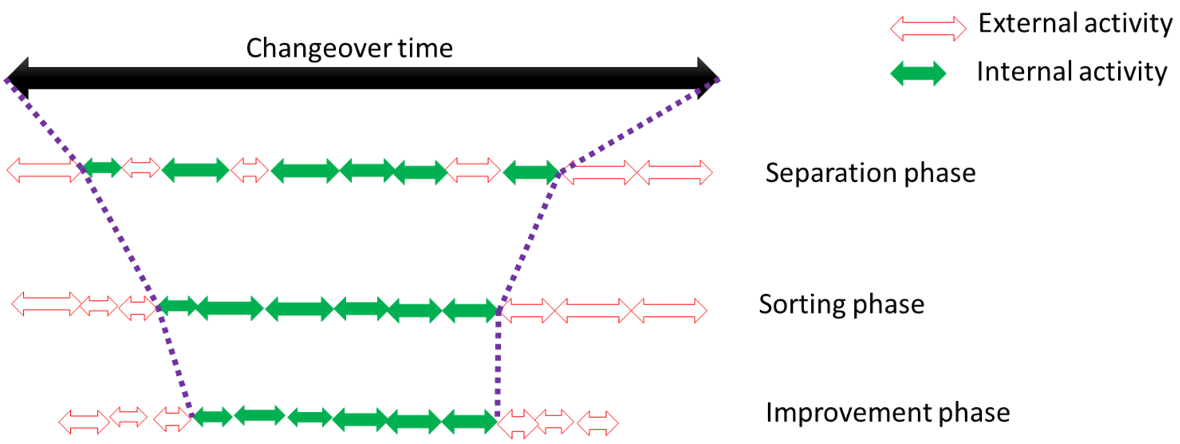


Figure 11: the three phases of SMED

8. ESTIMATING TIMES

When designing or modifying a process, it is not enough to know what will be done; the designer must also indicate how much it will cost and how many resources it will require.

Time estimation is an essential task of industrial engineering. Industrial engineering seeks to establish the best way of manufacturing, and the best way of doing something is often linked to the time it takes.

Without an estimate of the time required, it is not possible to compare alternative methods, estimate labour requirements, plan and control operations, define a realistic costing system, set delivery dates, identify sub-standard workers or train new workers.

What is not defined cannot be measured

Without defining the methods, it is difficult to establish the time needed to perform them.

The discipline known as **work study** has two major dimensions: **methods engineering** and **time study**.

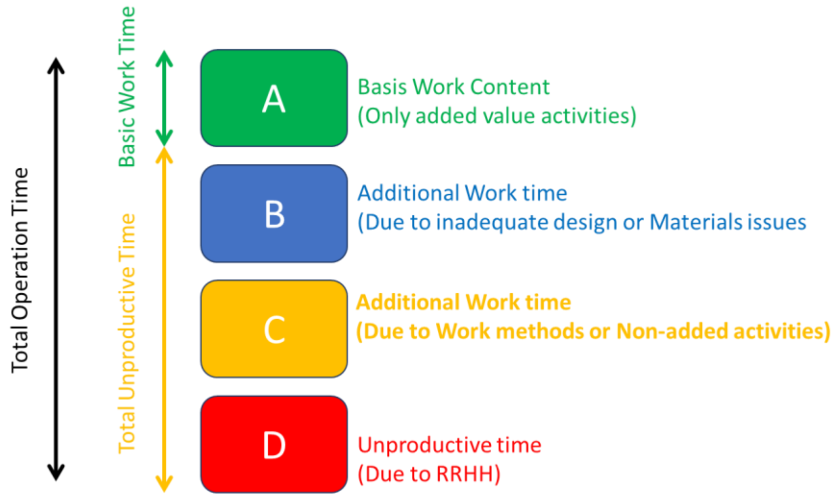
The manual that should be used as a reference is that published by the ILO (Kanawaty, 2011). Since the ILO is an international organisation that brings together trade unions and employer associations, the manual is a good point of reference[1].

8.1. METHODS ENGINEERING

Methods engineering is the systematic and critical analysis of existing or proposed ways of performing work with the aim of making them easier, more efficient and cheaper (Sempere *et al.*, 2003).

[1] The book is available online in pdf format and can be found by searching for the author's name and the title.

Methods engineering investigates factors that influence the efficiency and economy of the situations studied with a view to making improvements, and takes into account that the total operating time will be distributed between basic and additional work content and directly unproductive time.



Without defining the methods, it is difficult to establish the time needed to perform them. This is because:

What is not defined cannot be measured

To define methods, they often have to be observed, graphed and compared. This will probably require the observation of several workers and very often it will be found that each performs the work in their own way (always the "best" way in their own opinion, although it is unlikely that all possible alternatives have been evaluated to reach this conclusion).

Methods engineering aims to:

1. Improve processes and procedures
2. Improve the layout of the workplace (machines and facilities)
3. Save human effort and reduce unnecessary fatigue
4. Improve the utilisation of materials, machines and manpower
5. Create better working conditions

Recording and critically examining the ways in which activities are carried out will serve as the basis for improvements (Kanawaty, 2011).

A methodological approach consisting of 8 steps is as follows:

1. Select the work to be studied and define its limits
2. Record relevant facts by direct observation and collect additional data from appropriate sources as required
3. Critically examine how the work is done, its purpose, where it is done, the sequence in which it is done and the methods used
4. Establish different methods for producing a particular product being sure to modify the costs that were initially estimated
5. Select the most appropriate method (practical, cost-efficient, effective, inclusive, etc.)
6. Clearly define the new method and present it to all stakeholders
7. Implement the new method as standard practice and train all those who will use it
8. Monitor the application of the new method and put in place appropriate procedures to avoid a return to the previous method

8.2. TIME STUDY

To define methods, they often have to be observed, graphed and compared. This will probably require the observation of several workers and very often it will be found that each performs the work in their own way (always the “best” way, although it is unlikely that all possible alternatives have been evaluated to reach this conclusion).

Once the methods have been defined, various tools can be used to estimate times. The most commonly used are the following:

1. Statistical sampling
2. Analytical estimation
3. Elementary standard data
4. Direct timing
5. Standard times

Statistical sampling is an ostensibly easy-to-use statistical tool that tells us how much time is being spent on each part of a job. It uses sampling to confirm the validity of a prior hypothesis. In other words, if I believe that the worker spends 25% of the time preparing the machine, it is not necessary to time their entire daily activity. Adequate sampling is enough to confirm the hypothesis. This estimation tool is used for very heterogeneous jobs with long cycle times. It is often used as a first approximation to understand/validate an intuition of where opportunities for improvement lie.

Analytical estimation requires the activity to be broken down into smaller, more recognisable fragments. Based on their knowledge and experience, the expert estimates the performance of the resources that will be used to execute each of the fragments and then adds up all the required times. The concept of work-breakdown structure (WBS) used in project management can be said to be a type of analytical estimation.

With **elementary standard data**, an estimate can be made of the amount of work required to introduce a new product because the time required for previous products was studied and recorded. Basically, the company learns the cost of performing an operation and can use this to estimate the time it will take to perform a similar operation. Large companies use this tool systematically in the design of their production systems. In addition, small businesses use it intuitively and piecemeal in order to budget for work.

8.3. DIRECT TIMING

If the task is already running, **direct timing** may be the best approach. Although it may seem straightforward, this activity is actually very difficult. It requires defining operations in detail and having enough experience to know whether the worker is going too fast or too slow, and whether the pace is sustainable. Direct timing is used when work cycles are repetitive.

Since the other techniques can be highly abstract, direct timing is the technique most commonly used (which does not imply that its results are correct or that it has been applied correctly).

To correctly carry out a time study using direct timing, it is necessary to:

1. Select the work to be timed
2. Obtain all available information about the job and the conditions that may affect it
3. Break down the work to be analysed into elements
4. Directly time the performance of each element
5. Check whether the speed is normal
6. Adjust the time obtained to a normal speed
7. Add allowances to this time for fatigue, personal needs, possible contingencies, etc.
8. Calculate the total time by multiplying the number of times each element is repeated
9. Describe the work for which the standard has been developed
10. Test and revise standards where necessary

Timing tends to be unsystematic, which means that in reality direct timing is not very suitable for estimating the time required to perform an operation.

The two most common sources of error are the assessment of the work rate (what is a normal, fast or slow rate?) and overlooking rest allowances. The latter can account for between 10% and 15% of the time (Miralles-Insa, 2015).

There are three types of rest allowances: fixed, variable and contingency. Fixed allowances relate to personal needs and basic fatigue. Variable allowances are linked to work stress (precision, risk, monotony) or environmental stress (noise, heat, lighting, etc.). Contingency allowances include aspects such as learning, training or implementation of new methods, start-up or shut-down, adjustment of tools or cleaning, etc.

8.4. STANDARD TIME

Standard times use tables to assign to movements (usually micro-movements) an execution time estimated through the study of many samples of various operations. The task still has to be analysed in detail and broken down into elements, but by using validated time tables the estimate is more accurate and less subjective than in the case of direct timing.

The execution times originally relate to small movements or elementary operations of the upper body (reach, move, grasp, position, release, dismount, turn, press and crank), the lower body (walk, side step, kneeling) and visual focus.

The method for using standard times is to determine the basic movements, define the variables that affect them, look in the tables corresponding to each basic movement, add them up and apply the appropriate allowances. Standard times are used for manual operations in work centres with short cycle times.

Various sets of tables estimate in greater or lesser detail the duration of basic movements, the most common of which are MTM, MODAPTS and MOST. Each has its own focus and, therefore, its advantages and disadvantages. In addition, each system includes options to show various levels of detail.

Motion Length in **cm**	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	**1**	**2**	**3**

Get and Place			**Code**	**1**	**2**	**3**
				TMU		
	Case of Get	Case of Place				
≤1 kg	easy	approx.	**AA**	20	35	50
		loose	**AB**	30	45	60
		tight	**AC**	40	55	70
	difficult	approx.	**AD**	20	45	60
		loose	**AE**	30	55	70
		tight	**AF**	40	65	80
	handful	approx.	**AG**	40	65	80
> 1 kg to ≤ 8 kg		approx.	**AH**	25	45	55
		loose	**AJ**	40	65	75
		tight	**AK**	50	75	85
> 8 kg to ≤ 22 kg		approx.	**AL**	80	105	115
		loose	**AM**	95	120	130
		tight	**AN**	120	145	160

Place	**Code**	**1**	**2**	**3**
		TMU		
approx.	**PA**	10	20	25
loose	**PB**	20	30	35
tight	**PC**	30	40	45

Motion Length in **cm**	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	**1**	**2**	**3**

Handle Tool	**Code**	**1**	**2**	**3**
		TMU		
approximate	**HA**	25	45	65
loose	**HB**	40	60	75
tight	**HC**	50	70	85

Operate	**Code**	**1**	**2**	**3**
simple	**BA**	10	25	40
compound	**BB**	30	45	60

Motion Cycles	**Code**	**1**	**2**	**3**
one motion	**ZA**	5	15	20
motion sequence	**ZB**	10	30	40
re-position and one motion	**ZC**	30	45	55
tighten or loosen	**ZD**	20		

Body Motions	**Code**	**TMU**
Walk / m	**KA**	25
Bend, Stoop, Kneel (incl. arise)	**KB**	60
Sit and Stand	**KC**	110

Visual Control	**Code**	**TMU**
	VA	15

Source http://blog.ergo-mtm.it/wp-content/uploads/2016/04/UAS-ENG.jpg

Perhaps most interesting from the above table is that a TMU is a unit of time equivalent to 36 milliseconds, which is the time it takes for a film frame to change and thus create the illusion of movement.

9. THE LEARNING EFFECT

The systematic repetition of a task is the best way to learn. When human beings learn, they are capable of doing the same task with less effort and with greater precision.

If learning is measured in units produced per hour, the graphical representation of the increase in productivity as a function of the number of repetitions is called the learning curve.

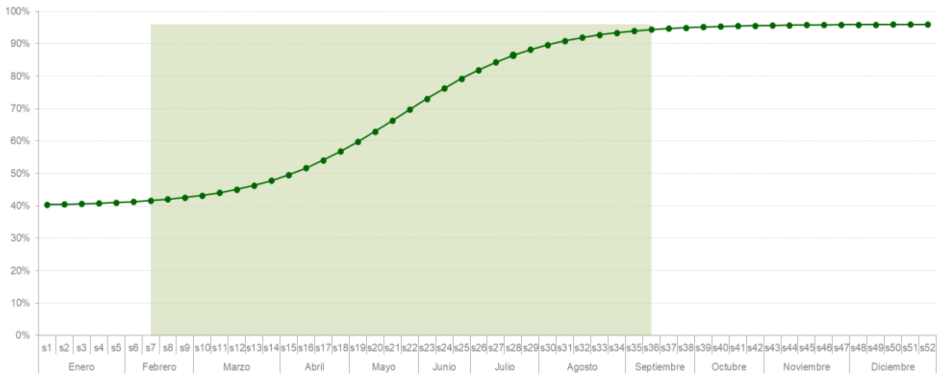


Figure 12: learning curve expressed as a function of time

In the above figure, the learning curve grows slowly at first, then grows exponentially, before ultimately reaching a productivity plateau with very moderate growth.

The improvement associated with repetition occurs for various reasons. The most obvious is that knowledge of the process improves, thus reducing doubt and decisions. The learning effect also results from an improvement in manual skills. These reasons are intrinsic to the operator, but the efficiency of the operation also improves, through the incorporation of tools and an improvement in the physical availability of the products.

The learning rate (p) is a simple way of expressing the learning effect. The learning rate is the percentage value in operating time obtained by doubling the number of repetitions. The improvement rate is the complementary percentage (1-p).

For some authors, the learning curve is an expression of the power laws, where the time to perform the nth repetition of a task follows the function expressed in the following formula:

$$T_n = T_0 \cdot n^r$$

Where Tn is how long it takes for the nth repetition to be performed and r a negative exponent that should be estimated in the first repetitions, the learning rate is $p = 2^r$ and therefore $r = \log_2(p)$.

Various authors place the value of the learning rate between 75% and 95%. The tables below show the unit times that result for learning rates of 80% and 90%. Interestingly, while the learning effect takes place, parts have to be made, and these parts have a cost. For this reason, the average learning rate is calculated.

Tasa de Aprendizaje = 90%			
unidades producidas	mins / unidad	mins acumulados	mins /unidad promedio
1,0	100,0	100,0	100,0
2,0	90,0	190,0	95,0
4,0	81,0	355,6	88,9
8,0	72,9	657,5	82,2
16,0	65,6	1204,2	75,3
32,0	59,1	2191,6	68,5
64,0	53,2	3972,0	62,1
128,0	47,9	7179,6	56,1
256,0	43,1	12956,0	50,6
512,0	38,8	23356,4	45,6
1024,0	34,9	42080,5	41,1

Tasa de Aprendizaje = 80%			
unidades producidas	mins / unidad	mins acumulados	mins /unidad promedio
1,0	100,0	100,0	100,0
2,0	80,0	180,0	90,0
4,0	64,0	314,2	78,5
8,0	51,2	534,5	66,8
16,0	41,0	891,9	55,7
32,0	32,8	1467,6	45,9
64,0	26,2	2392,0	37,4
128,0	21,0	3873,4	30,3
256,0	16,8	6245,7	24,4
512,0	13,4	10042,9	19,6
1024,0	10,7	16119,4	15,7

This value should be validated in each case, since it depends on the individuals involved, the products handled, the machines used, and the capacity of the system to learn and express what it has learned.

While the learning effect was documented in the context of manufacturing in the 1930s, 20 years later BCG proposed the **experience curve** as a way to show the same effect for organisations as a whole.

Not everyone learns the same, not all machines learn (if they learn at all) and the learning effect does not always show up at the same level. This is why systems become unbalanced with activity. In other words, a design in which the workloads were perfectly well calculated will become unbalanced through the mere repetition of activities. This fact alone should lead all operations managers (if any) in all entities (public or private) to permanently reassess workloads in order to reallocate tasks. However, this would require them to meet with unions, define processes, agree on measurement methods, and define a rationale for changing the allocation of workers. Too much work, perhaps.

In some cases, incentives to show what has been learned will limit learning, e.g. contracts for hours worked where reduced time reduces workers' earnings. In other cases, productivity incentives are designed with an "unattainable" ceiling which over time is systematically reached.

To avoid the problem that things could be done better (because competitors are doing it so), some companies outsource their activity. In this way, someone will directly benefit from "reorganising": the owner of the subcontractor. The drawback is that the main company does not benefit from the learning effect. However, the main company can resolve this problem by requiring a price reduction after one year.

10. WAITING TIMES

Vinga va, que fem tard

The most common way of coordinating activities is to wait. This is certainly not the most efficient way, but since you need a machine, an operator and materials (and sometimes a customer) to start up an activity, it is to be expected that someone (or everyone) will have to wait. Although to be expected, waiting is neither efficient nor reasonable.

- When a customer enters a fast food restaurant where 50 customers are waiting, who will be served at a rate of 1 customer per minute, the customer will wait 50 minutes to be served for 1 minute.
- If, to improve efficiency, a company processes customer orders on Wednesday mornings, it is adding five days to the lead time.
- If an administrative process is divided into four stages to make it more efficient, but each stage is allowed a delay of up to a week to "put a stamp on it", the resolution is delayed by four weeks.
- If a committee that meets once every 5-6 weeks is required to ensure compliance with a regulation, the resolution period is stretched by a month.
- If a kitchen furniture manufacturing operation is structured into eight stages, and production is transferred from one stage to the next each day, almost two weeks have been added to the lead time.
- If a company that manufactures one thousand cars per day requires warehouses with a capacity of two thousand car bodies in total, the lead time is increased by two days.
- If, to protect against delays in customs clearance (just in case), a stock of twice the production volume linked to the delay is held (just in case), a time equivalent to three times the possible delay has been added to the lead time.
- If chemotherapy requires a patient to have a blood test first thing in the morning, and for the sake of efficiency all the doctor's patients are scheduled for 8.00 a.m. (i.e. when the clinic opens) on the same day, the patient will have to queue a little to have their blood taken, their blood will have to queue a little longer to be tested, and their test will have to queue quite a bit longer for the doctor to attend to it because the doctor has a large number of patients to attend to. If all goes well and the chemo can proceed, the patient will send an order to the pharmacy, which will have similar but different orders to process, and finally, for the sake of efficiency, the impatient patient will be able to receive their treatment eight hours after arriving at the hospital.

Every wait has an explanation. The more sophisticated the explanation, the less justified it will be. An explanation that reassures some (those who hold power in the system) will leave others indifferent (those who suffer it).

On rare occasions the effective operating time is an important component of the lead time. In such cases, reducing the cycle time (increasing speed) will reduce the lead time, making it reasonable to try to do so.

However, in most cases the lead time is several times the cycle time. The reason for this is that the product is waiting in various places. In fact, this wait is the most important component of the throughput time. If in a company or organisation the time taken to deliver to the customer, the throughput time, is considered excessive, initiatives to reduce operating times will almost certainly be launched.

Lead times can be improved by moving the decoupling point closer to the customer, but this is expensive. They can also be improved by reducing the throughput time, which can be achieved by reducing or limiting the amount of work-in-progress (WIP), which in turn can be achieved by reducing or limiting the size of buffers. Buffers pop up like mushrooms in any activity that does not explicitly limit them.

Queues (buffers, stocks, machine stoppages) grow with variability (variable cycle times, setup times, unscheduled breakdowns, customers who appear when it suits them and orders stuck who knows where) and remain because there is a lack of capacity or will to reduce them.

This will be the case unless the activity is planned out in detail, which requires knowing the times (and complying with them) and giving customers a time window (and having them come).

Queueing theory is a branch of operations research that can help us understand, improve, manage and control waiting times. A comprehensive appendix can be found in (Gross *et al.*, 2008) which supplements the information contained in this document.

Scheduling is a branch of operations research that can help us understand, improve, manage and control the timing of activities. This document sets out a very brief overview which can be read alongside the informative manuals that exist on this topic (Pinedo, 2016).

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