CHAPTER 07

SINGLE-MINUTE EXCHANGE OF DIE (SMED)

Quick Change, Adjustment, and Readjustment of Equipment

Annotation

Sometimes the execution time of a short series may be commensurate and even shorter than the time to readjust or change the equipment. The short series does not coexist well with slow readjustment and change of equipment.

It is interesting to know how it is achieved in Formula 1 bolids that when they enter the pits, their four wheels are changed for new ones in two seconds.

The same result of chortening times can be achieved in production if we master the SMED method – an acronym for "Single-Minute Exchange of Die". The abbreviation SMED should be understood as Replacement of a tool for zero time.

We will find out more about the original and non-trivial organisational ideas and abaut the numerous and elegant technical solutions of the SMED method. We will see take a look indicative illustrations of how to apply SMED in practice.

The SMED method is not limited to quick adjustment and change of equipment. SMED method is successfully applicable in many and different areas – wherever there is a need to shorten the Lead Time of a process, operation, or other activity.

Introductory Words

If the pit teams in the Formula 1 races can change the wheels of bolids in less than two seconds, or even faster, let's see if we can learn from their experience. We certainly can. In this chapter of the book, we will learn how to do this.

And not only that, we will see practical examples of multiple shortening of times for change and readjustment, and in general, for shortened the execution times.

07.01. Why Do Short Series Require a Quick Equipment Readjustment?

Length of series	Time for production	Time to readjust equipment	Ratio readjustment and production time
10,000 pieces	50,000 minutes	100 minutes	**0.2%**
1,000 pieces	5,000 minutes	100 minutes	2%
100 pieces	500 minutes	100 minutes	20 %
10 pieces	50 minutes	100 minutes	**200 %**

Here it is series of different lengths – 10,000 pieces, 1,000 pieces, 100 pieces, and 10 pieces. The production time of one product is 5 minutes, respectively, the production time of the series is in a wide range from 50,000 to 50 minutes.

Readjustment time does not depend on the series length. But with a very long series of 10,000 pieces, the relative share of readjustment time is only 0.2%, while with a very short series of 10 pieces this share becomes as much as 200%.

Single-Minute Exchange of Die (SMED)

Shigeo Shingo was a long-standing major external consultant to Mazda, Mitsubishi, and Toyota. One day, the management of the Toyota automotive factory ask the Car Body Shop to halve the change and readjusting times of all punching instruments, and Shigeo Shingo's team was involved in this task. Far above expectations, the team was able to achieve not twice but twenty times shorter times.

SMED is based on different but compatible each other organisational ideas and technical solutions.

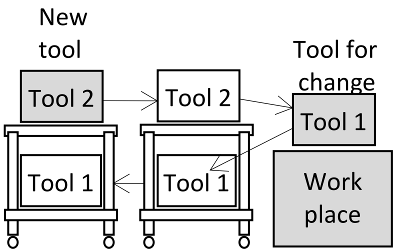
Example with Electric Battery Terminals

Screw terminals
15 seconds

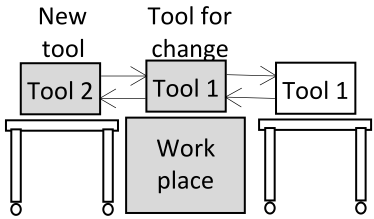
Clamps
0.5 seconds

I'll start with a technical idea. We can see battery terminals. At the left are classic screw terminals – a bolt and nut, the nut is square, so, there is no need for a second counter wrench. But it takes at least 15 seconds to loosen or tighten the terminal. If we do not count the time it takes to search for the wrench, which is more than 15 seconds. At the right are the so-called Italian terminals, or Quick terminals. A clamping mechanism fixes an open or closed position on a horseshoe spring. We pull out the cap and open the terminal, we push the cap and fasten the terminal. Even if we are clumsy, the switch-on and switch-off times are tenths of a second. This was a vivid example of an elegant technical solution for 30-fold shortening of the switch-on and switch-off times.

Slow and Fast Tool Change



Replacement happens SLOWLY



Replacement happens QUICKLY

To the left we have a slow tool change – firstly, because the place for temporary storage of the old tool is inappropriate, and secondly, because the trajectory of relocating the new tool is not rational. On the right, we see a quick tool change.

It's quick for two reasons. First, the table where the tool is temporarily stored is after and not in front of the workplace. Secondly, in the trajectory of the new tool there is no intermediate stop, and it is moved once, not twice.

Few Definitions

The term Change means to install another or new tool or technology device in place of old tool or technology device. Change, this is in place of one machine or installation (more generally, equipment) to put another machine or installation. A change of tool, device, or equipment may be accompanied by relocation or displacement activities, as well as deslushing and stirring activities, re-slushing activities, and the like.

The terms Adjustment, Readjustment, and Fine Tuning refer to the choice of operating mode of equipment and to the introduction of its technological parametres into normal boundaries.

07.02. The Organisational Ideas of SMED

According to SMED ideology, any readjustment or change of equipment can be divided into a multitude of elementary operations. Elementary operations can be divided into two groups according to the need to stop the machine or not.

Some operations necessarily require the machine to be stopped, or even if it is not stopped, not to work with it. While replacing the lathe knife with another knife, even if this other knife is already installed in the support carriage, the lathe is either operating at idle or we have stopped it. There are some operations for which we need to stop the machine in order to perform them. There are other type operations where we can leave the machine on but cannot operate with it. We will call these two types operations "internal operations".

We have other operations that are feasible with a working machine. We will call the operations we can perform whether the machine is running or stopped "external operations". For example, regardless of whether the machine is running or we have stopped it, in both cases we will be able to deconserve a new tool in order to replace the old tool.

In order to clarify whether it makes sense to turn internal operations (when the machine is stopped) into external operations (when the machine is running), let's assume that a repair is being made and that we know (or don't know) in advance which part we will replace. If we do not know which part is for replacement, we stop the machine, disassemble it, look for which part is defective, and ask if it is available in the spare parts warehouse. If we have the spare part, we get it from the warehouse and prepare it for use (expire date check, unpacking, deconservation, adjustment). If the spare part is not available in the warehouse, we order it. It is then delivered, we receive it, record it in the warehouse with a goods receipt note, sign it out of the warehouse with a goods dispatch note, and only then prepare it for installation. During all that time, the machine stays disassembled and does not produce. But if we know in advance which part must be replaced, we first ensure that it is available and fit for use. Only then we stop the machine. Thus, we have transformed internal operations to ensure availability and suitability for use of spare part into external operations. The repair is quicker. The machine downtime is shorter.

There is another division of elementary operations. It depends on the place of execution. There are operations that we absolutely have to perform at the workplace – right there, and there is nowhere else to perform them.

There are other type of operations that we can perform at the workplace, but we can also perform them away from it or at a completely different workplace.

One of the main ideas of SMED is to save time based on conclusions from the review and analysis of all external operations. The central question here is whether we can perform some operations before we stop the machine.

Another question – it is possible to perform some of the operations (internal or external) in parallel? There are cases where the readjustment or change time can be further shortened by converting one part of the successive operations into parallel operations. But often such a decision may require more people.

If there are external operations with overlap in time, can we perform some of them with maximum overlap, as if they are running in parallel? We look in the same way at the overlapping internal operations. Are there any that we can perform in parallel? In such a situation, can we even equal the times?

And so on, in the same vein. We continue to decompose into sub-operations any operation, external or internal, even if it seems elementary, until we find that some operations are unnecessary. Then we think how to get rid of them.

Another important line of reasoning is how we turn as many number of internal operations as possible into external operations, even if the times of these new external operations are longer than when they were still internal operations.

In fact, the goal is to reduce the number and timing of internal operations and thus shorten the time for which the machine is stopped and does not work.

All organisational ideas of SMED are ideas of common sense and, at first glance, are easily applicable. But there is a subtlety, and if we don't know it, it will be difficult for us. The subtlety is that first you need to decompose the macro-operations for changing or readjusting the equipment to the most elementary sub-operations. Otherwise, we cannot see which operations are external or internal, which internal operations can be performed as external, whether there are parallel or overlapping operations, whether there are operations feasible at another workplace, whether there are unnecessary operations, or whether there are operations feasible in other and different way.

So, we start with decomposition of macro-operations into elementary operations. It's easy from there because the opportunities for improvements will become visible.

07.03. The Technical Ideas of SMED

The most efficient technical idea is to think about a quick change/readjustment already when we compose an assignment for a future machine, tool, or device.

The assignment must contain requirements that the equipment is to be designed in such a way that its design allows any adjustments, readjustment, and changes to be carried out within preset times which are as short as possible.

The cleverest solutions of designs I've seen are in carousel machines in the glass and foundry industries. For these machines, some possibilities have been created for replacing devices and readjusting while the machine is operating.

Another idea is not to proceed with a change or readjustment until we are convinced that the suitability of all replacement elements is verified. Imagine making a tool change, and then we recognise that we have fitted a worn tool.

The third idea is that the replacement elements and disassembly and assembly tools and devices are located close to the workplace and are easily accessible, arranged, and marked. This reminds us that a 5S System at Workplace is needed.

The fourth idea is that the personnel involved in the change, readjustment, and repair of the equipment is trained to work quickly and in a coordinated manner.

A year ago, on TV, I saw an interview with the team leader of a Formula 1 ace. I learned something interesting. The team is not made up of 14 people, as I thought. The team consists of 25 people. Just like in football, there is a selector and a trainer. The trainer trains the team. The day before the race, the team selector says, "These guys are fit, they can be part of the pit team. And the others are subs". They have 20 races a year. The rest of the time, they train for 4 hours a day and thus achieve 2 seconds time for wheels change.

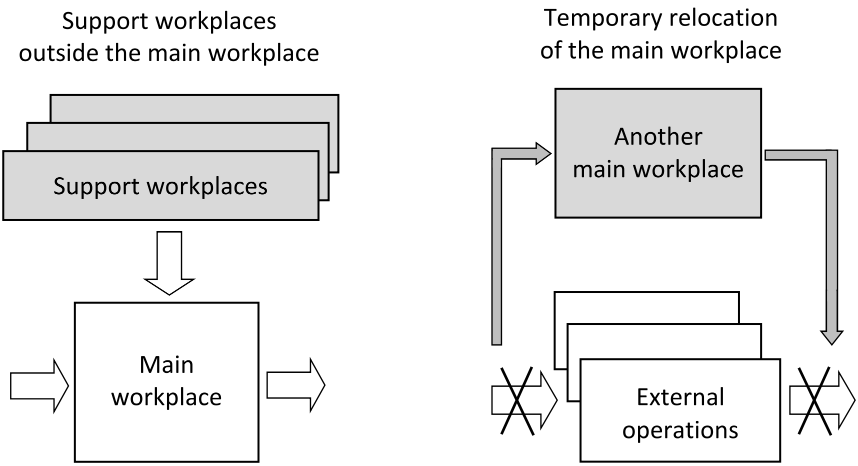
The personnel involved in the change and readjustments of equipment must be trained to work quickly and in a coordinated manner. In the same way as fire-fighters are trained to act quickly and in a coordinated manner to jump from their duty rooms onto the fire trucks, get to the scene of a fire, and quickly and in a coordinated manner to locate and extinguish it. Sea and mountain rescue teams, as well as emergency medical personnel, are trained to get into action in a split second. The personnel involved in changing and readjusting the equipment must also be able to split a second in half.

Here's something interesting about the Sofia Fire Command before Second World War. In those years the fire waggons loaded with barrels of water were drawn by horses. The horses were trained in event of a fire alarm, to stand in front of waggons, ready for harnessing. The norm was eight seconds.

07.04. Operations That Can Be Performed Outside the Workplace

Let's go back to the organisational ideas and look at them in detail one by one.

The radical way to shorten the total time to change or readjust the equipment is to perform all or most of the external operations outside the main workplace, where the equipment itself is – not at the main workplace but outside it.



We may organise support workplaces, aside from the main workplace but close to it. Or we can temporarily relocate the workplace elsewhere while equipment changes and readjustments are being made at the main workplace.

These may be operations to bring the replaceable elements of a machine to a state of high degree of readiness for use – dispatching elements from the warehouse, unpacking, uncanning, checking for functional suitability, etc.

Another opportunity – we load the machine magazine with the tools required for a particular workpiece in a support workplace, not on the machine itself.

Here, I would hint that, in the terms of the 5S System at Workplace, the support workplaces and the temporary relocated main workplaces are kind of adjacent zones to the main work zone in which the equipment is located.

As an example, is shown an exemplary list of external operations that we can perform at a working machine and, if admissible, outside of the main workplace. They might be: obtaining removable parts and consumables; obtaining tools and devices; completeness check; unpacking, deconservation, quality checking, and repacking; providing measuring instruments and templates; obtaining a high degree of readiness for use; transporting, deploying, and stacking near the machine workplace; selecting, labelling, positioning, and fixing; procuring work technical documentation; personnel training; and health and safety care.

The idea here is to convert as many numbers of internal operations as possible, or even all internal operations that take a longer time, into external operations.

07.05. Operations That Are Performed Before the Change/Readjustment

BEFORE the readjustment	DURING the readjustment	AFTER the readjustment
The machine is running	The machine is stopped	The machine is running
Support operations before readjustment	Basic readjustment operations	Support operations after readjustment

Time ⟶

We see a conditional separation – we are working with the machine, we have stopped the machine and it's not working, and then we have put the machine to work again. There are operations that we can perform before the essential change/readjustment operation. These operations are preliminary operations. If there are preliminary operations, we have to start them early enough in order to be completed right before the essential change/readjustment has begun.

I will say that luckily for SMED ideas, all or at least most preliminary operations can be carried out outside the main workplace. Or, at least in most cases, it is.

This is followed by essential change/readjustment at non-working equipment.

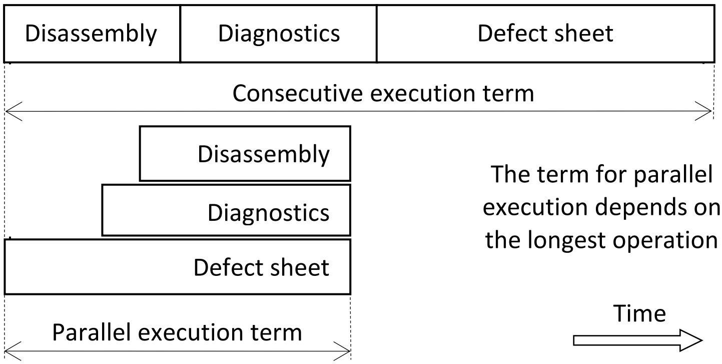
After the essential change/readjustment, more operations may remain to be performed but can be done when the equipment is already in operating mode.

The separation of operations (at running machine and at not running machine) leads to a drastic shortening of times but cannot be at the expense of safety.

That is why we will analyse and assess the equipment change or readjustment operations also in terms of safety. For example, would it be permissible to operate an open electrical board if it is not disconnected from electrical current?

07.06. Parallel Operations at the Workplace

Sometimes there are such change or readjustment operations that can be carried out in parallel. If there are such operations (both in the main workplace and in the support workplaces), it would be good to perform them in parallel.

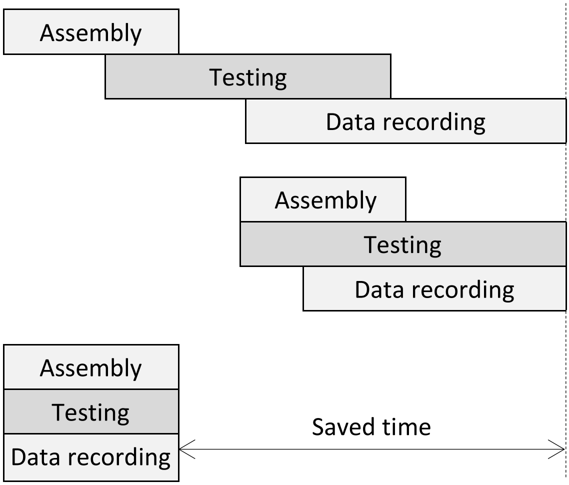


In this case, it may be appropriate to have more sets of repair and adjustment tools and repair consumables and to work with a larger team.

A similar case is the transformation of consecutively executed operations into parallelly executed operations.

If the team is large, a scenario is required (in order for the team to work in a coordinated and fast manner and without the people interfering with each other) and this scenario has to be tested in action in real conditions.

07.07. Operations That May Overlap



Here the overlap should be maximized – as if the operations were parallel

It remains to equalise the times of the parallel operations

Here are three overlapping activities – product assembly, testing, and recording the test data in a protocol. These activities can be performed with overlap.

How do we get maximum operations overlap? Testing has the longest execution time. In order to even out all the times, let's try to shorten the test time.

This will shorten the total time of the three operations. If there are parallel or overlapping operations, let us see which one is the longest operation and to try to shorten it, or, at best, to try equalise the times of all the operations.

07.08. The High Price of Maintenance Professionals

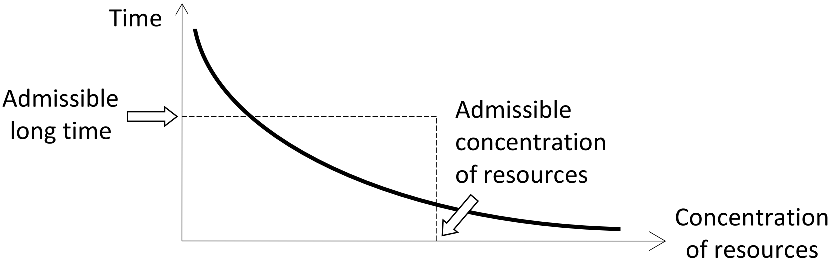
Some managers ask, "Should I hire more highly qualified technical personnel? Competent, this is good! But expensively paid, that's not so good with me!".

The answer is simple. By hiring more highly qualified technical personnel, we pay generous salaries, but we do the repairs, changes, and readjustments faster, and this prolongs the efficient and useful working times of the machines.

The equestion is whether the additional cost of more expensively paid but competent technical personnel will really and always guarantee us a better and fuller exploited working time of the machines and the operative personnel.

07.09. Shortening of the Times

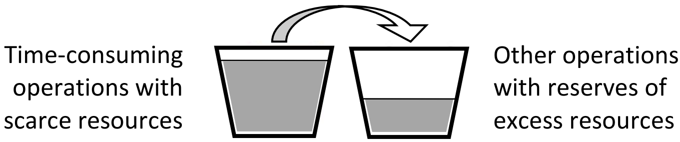
- ✓ essentially internal operations
- ✓ auxiliary internal operations



We Attract Additional Resources

The resources put into one activity and the time for which it can be executed with these resources are two variables that are inversely proportional, but only within certain limits. The time shall not exceed one permissible time. If the time is too long, the need for the activity becomes meaningless. An opera building could be built by two workers, but it would take 400 years. No one needs an opera that takes 400 years to build. Resources should be no greater than what can be admissible to concentrate in one place. This concentration of resources is admissible, after which they become unmanageable due to unsolvable organisational problems. If we harness two horses in a cart, they pull faster than one, if there are four – faster than two; if there are six, they pull even faster. If we harness a 100 horses, the cart will not move from its place because there is no way to get a hundred horses to go at the same time and in the same direction.

Shortening the Times of Some Time-Consuming Operations by Transferring Resources from Other Operations to Them



The idea is that there are two types of operations – operations in which there is a surplus (or reserve) of resources and these which are underprovided with resources. We need to try to reallocate resources and move part resources from the operations with reserves of resources to under-resourced operations.

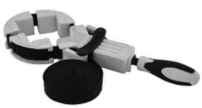
Reserve resources or shortage resources are not always money. There may be reserves or shortages of production capacity, of technological competence, of measuring instruments, of technical data capture tools, or of other resources.

07.10. The Design Allows Fast Change or Readjustment

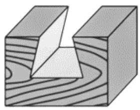
Now let's go back to the technical ideas. When we have designed and constructed tools, replaceable devices, and other technological and logistical equipment, we have planned for the equipment to be used for production in mode of short series. Such modes of use of the equipment suggest that it is adapted to quickly carry out changes, adjustments, and readjustments.

07.10.01. Rapid Assemblies

We reject "slow assemblies". The slow assemblies cannot be disassembled or are difficult to disassemble. They are welding, soldering, sticking, compounding (with resin, rubber, or plastic), pressing, riveting, wedging, plugging, etc., when you assemble once and then there is no disassembly. There is also a partial abandonment of screw assemblies. Screw assemblies are not slow assemblies, but they are not fast assemblies either.

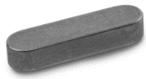


Jaw clamps



Dovetail coggings

Clamps and clips



Pins, keys and grooves

There are examples in the picture. Each compound is of the type "push-pull" or "click-click". Assembling and disassembling is done with one simple movement.

Other interesting examples of quick assemblies are the all sorts of varieties and constructions of fixation jigs (with balls, pins, dowels, and bayonet fits or fluted, slotted, profiled...), as well as guides, seats, and conductors (pin, channel, conical, eccentric...) and whatever else you can imagine.

In 1783, the King Louis XVI announced a contest for rapid fastening of a bayonet to a rifle. We don't know who won the contest... In French, bayonet is named after the town of Bayonne, where the bayonets were produced for the French infantry. From the name of the City of Bayonne comes the term "bayonet fit".

The connecting dimensions of the tools and replaceable fixtures are equalized or unified. It is best for the connecting dimensions to be uniform.

There are tools with a modular structure. There are tools with working elements separated from their housing. We do not change the housing. We only change the working element. There are tool kits with revolving turret heads. At another revolution of the head, we position the next required tool above the workpiece.

There are numerous possible technical solutions for the quick grip, for example: collet spindle instead of jaw chucking; vacuum or magnetic chucking instead of mechanical chucking; chucking by temperature difference between the holder, tool, or material; templates, guide, and chucking seats; and other devices for facilitated uploading and downloading.

There are other technical possibilities as well which enable tools to be replaced without dismantling one tool before installing the other.

The "gripper" tools are fast assembly, disassembly, and repeat assembly tools. Classic spanner or star wrench – which is preferable? Which of the two grips will not drop the bolt head? The star wrench grips better, but there needs to be space to grip around the head of the bolt. The advantage of the classic wrench is that it can be used to reach hard-to-reach places.

Gripping assembly and disassembly tools include, for example: S-type spanners, pipe spanners, hexagon wrenches, female wrenches and bits, hexagon screwdrivers, jaw spanners, grip locking pliers with curved jaws, and many others. Quick disassembly and quick reassembly are done using "quick tools".

Magnetized working parts of tools – for example, screwdrivers with magnetized tips, magnetized tips for screwdrivers and wrenches, magnetized tweezers, etc.

Reversible ratchets – they aid screwing and unscrewing without removing the tool from the head of the fixation element and then gripping it again. Tools with a cardan-jointed rotation axis and flexible shaft tools aid in screwing/ unscrewing in hard-to-reach areas.

Inertia nuts – with one energic turn, we screw the fastener as far as it can go. We go for tyre balancing. With a measured and styled movement, the technician throws the wheel onto the balancing machine. More precisely, he threads the wheel rim onto the cone, and the wheel slides as far as the cone allows. The inertia nut has manual grips, and its weight is concentrated peripherally. This enables the wheel to be tightened to the required degree by the moment of inertia generated by a vigorous rotation of the inertia nut.

07.10.02. Quick Screw Fasteners

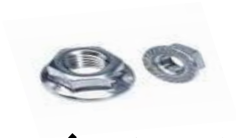
Small edge angle chamfers

Fine threads

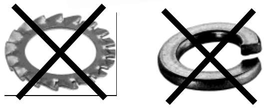
Coupling nuts

Slotted nuts

Flange nuts



And other tricks against self-unwinding (second nuts, spring washers, circlips, cotter pins, etc.)



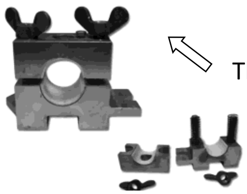
There is a tendency to refuse or restrict the use of screw fasteners.

But fast screw fastenings still resist this trend. Here are some examples. Screw with a steep chamfer – it is steep to make it easier to find the female thread. Screw with a small thread pitch – the friction has large value, and no anti-slip detail is needed. A high nut – there are many number of threads, and therefore elements against self-unscrewing are not needed. Slotted nuts – they self-tighten in the stems of the studs and bolts. Flange nuts – there are no two separate elements here – a separate nut and a separate washer. The nut with a built-in washer is a single element. In fast screw fasteners, there are no additional circlips, spring washers, second nuts, and others like that.

There are many other technical solutions. In the quest to reduce assembly, disassembly, and reassembly times, there is no end to human ingenuity in constructing new and new types and varieties of quick screw fasteners.

Butterfly Bolts and Nuts with Wing Bolt

(no mounting tools and devices needed)



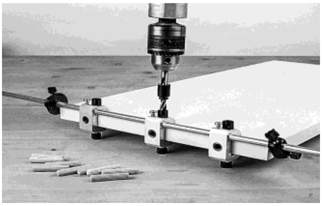
This instead that

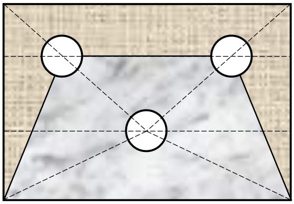
Screws and nuts, the mass of which is brought
out in a cone or ring (for a flywheel effect)

More about fast screw fastenings – fasteners that are mounted and removed by hand without a tool. Some of them are based on the idea of the flywheel effect – most of the mass of the fastener is moved out towards the periphery.

More about fast screw fastenings – the diameters and shapes of screws and bolts heads are unified and this allows to work with a smaller number of tools. A similar effect is sought with the unification and typification of joining dimensions, joining profiles, and beds of removable parts and assemblies and of some removable technological devices. This effect is most noticeable in some modularly constructed families of articles of metal, plastic, wood, or other similar solid materials.

07.10.03. All-Purpose Templates and Customised Templates

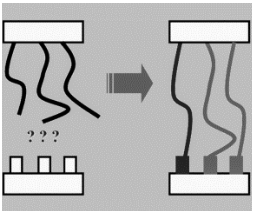


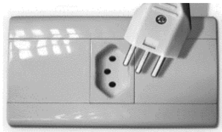


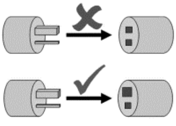
Different types of copy templates, cutting templates, surface templates, and the like serve to produce a product, reproducing its template model. This makes it easier for us to shorten the times for uploading and positioning the components of the product and for submiting and using of the tools. Templates are worker-friendly technological devices. But... there's always a "but". Their design and workmanship are justified only in longer series.

I have seen templates for cutting out details for shirt making and shoemaking scaled according to the sizes of the shirts and the numberings of the shoes.

07.10.04. Poka Yoke (Error-Proofing)







Different types of Error-Proofing (not only technical but also communication) reduce excess moving and movements (this saves time) and prevent errors in the process and product. Again, this saves time to eliminate the consequences. On page 508 in Chapter 16, we will see that according to literary data, over two-thirds of the resolved Kaizens are in the field of technical error-proofing against improper execution or aimed at preventing safety accidents at work.

07.10.05. Quick Transition from one to Another Equipment

There are quite a few technical solutions for a quick transition from one piece of equipment to another.

Completely interchangeable equipment sets. The kit contains all the tools used to perform a group of consecutive or related operations.

Modular equipment is interesting. Equipment for this type of work or similar works shall be collected in combinations of compatible modules. Modular set for each individual type of work is procured and complected before to be used. In the 1980s, the office of my associate, Dr Girolamo Frizina, was located on an business centre of Piazza di Angeli in Milan. On the ground floor a restaurant there as well. It has 12 tables, 50 cm by 100 cm. In the morning, they set two rectangular tables measuring 100 cm by 300 cm for a buffet breakfast. Then, before lunch, they rearrange them chess-board style in six squares 100 cm by 100 cm, and operate as a café. At lunch, they arrange them on three long tables measuring 100 cm by 200 cm and operate as a public canteen. After lunch, they arrange six tables 100 cm by 100 cm to the walls and operate as a lobby bar. At dusk, they arrange the 12 tables along the walls and operate as a neighbourhood pub. In the evening, they rearrange them chess-board-style 100 cm by 100 cm, and accept the local snobs at a fine gourmet restaurant.

There is equipment with changeable processing modules. If a tool consists of a passive part (for example, a shank) and an active part (for example, a cutter), the idea is that the same passive part can be used with different active parts.

Equipment with revolving heads. The revolving head rotates in one direction or another and provides for use the tool that is needed for the next operation.

The most radical technical solution is a direct switch from one piece of equipment to another. Here's what I saw at the company Elkabel, a big cable factory in Burgas City. The technological sequence is as follows. First of all, there is a hopper into which plastic granules are poured, heated, and softened. Then the plastic is seized with a feeding screw and carried to the extruder. Finally, the plastic is extruded to cover the cable with insulation. The insulations are coloured differently. These different colourings follow one or the other requirements of standards or customer requirements. The entire group of installations has to be thoroughly cleaned, not so much because of the composition of the plastic is because of the colouring. The cleaning takes hours. No matter how perfectly it is executed the cleaning, in colourisation of the cable insulation are visible remains of the colours of the insulation of the previously produced cable. The Kaizen team of the cable factory resolved the problem in an elementary way, but with a rather expensive investment. There are several parallel installations prior to the extruder, and with each change of the colour of the insulation, they switch the extruder to the feeder device, which has already been cleaned and loaded with plastic (hopper, heater, feeding screw). This solution is expensive, but estimates have shown that the losses from non-realised product due to cleaning downtimes are greater.

In many industries, estimates would show that instead of changing and readjusting of the equipment, it would be more profitable to work with sets of fully changeable equipment.

07.10.06. Design of Typified Products That Do Not Require Numerous Process or Equipment Readjustments

There are other original and rather unusual ideas.

Can we construct products, either standardised or on a modular basis, or a basic configuration with upgrade options, the production of which does not require a large number of processes and a large number of units of equipment.

This will avoid multiple changes and readjustments of processes and equipment. These are the smart technical tasks for the lion-company.

In Chapter 01, on pages 22-23, we have already described the lion's decisions regarding products and technologies.

We can think of standardisation of materials, assemblies, and fixation components in the same way. From there, we can go to Standardised products with differences only in the final assembly, i.e., using the same components we can make different end products. The difference is only in a small part of the nomenclature of the components, for example, 60 to 90% of the components remain the same.

Or we separate the functional element of the product from the customer element, especially in the assembly. The functional element can be embedded in the internal design of the product, and the customer element is in the differences in the external design. These are housings in different colours, differently shaped control and signalling buttons, and similar.

These factors do not affect the functional purpose of the product but is rather related to conditions and ways of the real use or to the national and aesthetic preferences of the end users.

07.11. Arrangement in Order of Use

Such an arrangement of repeir tools is convenient for transportation and storage. It is not always convenient for the working use of the tools. Sometimes it is more appropriate for the repair tools, materials, and consumables to arrange them in the order in which we will uses for the change and readjustment operations.

The change and the readjustment will be accelerated if the repair tools, materials, and consumables are arranged in the order in which they are used.

In a fertiliser plant, there are fitting kits next to each sector of the installations where there is a risk of incidents requiring repeir. These are sealed suitcases with the same number of internal levels as the required number of repair steps.

The top level of the suitcase holds the technical instruction for operation 1, tools for it arranged in the order of use, and replacement parts and repair supplies, again in the order in which they are used. The second level of the suitcase contains the instructions, tools, parts, etc. for operation 2. And so on, for operations 3, etc.

The repairman, after performing operation 1, removes the upper level of the suitcase. He's now using the lower level. And so on until the last operation. What does this serve? In such a type of production one tenth of a second is critical.

Before starting surgery operation, all the tools and materials needed for it are arranged in the order of their use: scalpel, retractor, tampon, scissors, tampon, pump, clip, thread, etc. The surgeon acts quickly, in a split second, because the longer the incision remains open, the greater the risks.

In a car repair shop, you will see wrenches arranged by their size. Elsewhere, the wrenches are arranged by frequency of use. The first wrench is № 13.

A small car repair shop takes care of the cars of Alpha Quality. The mechanic's name is Miro. After Uncle Miro touched and dived deeper into SMED ideas, he arranged his tools by frequency of use. As he lies on his trolley under a car or descends into the inspection pit, he takes only these tools that are needed and arranges them differently close according to frequency and in the order of use.

07.12. Visualising Arrangement

The visualising arrangement aids and accelerates all the actions of finding and taking things and the actions of returning things to their places.

Moving and movements are less frequent and shorter, which saves time.

Visual arrangement is especially important for quick orientation in the workplace, especially when the workplace is new to the person and/or when it is used less often and/or if different people work on it.

07.13. Inappropriate or Unstable Work Environment

In an unsuitable and/or unstable work environment, adjustment and readjustment times, checks, and the fine-tuning times are extended.

Resources are needed to monitor and control the current changes in the work environment (nomograms, tables, calibration diagrammes, and measuring devices). They are Muda.

07.14. Completeness Check

The checking for completeness of the assembly tools, removable parts, and repair consumables consists of the following.

Before we start, and in order to start change, repair, adjustment, or readjustment, we check whether we really have all the things that will be needed for the upcoming activities and whether all these things are brought to the appropriate readiness for use.

Let's go again to surgeon. He does not begin surgery until the head nurse has reported that everything needed is there and is ready for use. We often want to change something on the machine without being sure that everything is in place.

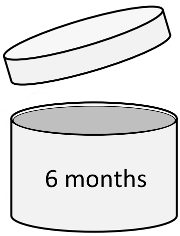
And why should we check? Let's go to work, there we'll see what's missing…

They say, let's get down to work, and we'll figure out on the go what we don't have. In stricter industries, the completeness check is subject to validation.

07.15. Checking Readiness for Use of Repair Tools, Spare Parts and Repair Consumables

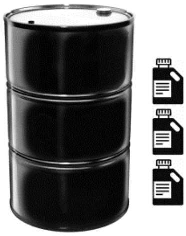
Checking the condition of repair tools, replacement elements, assemblies, and measuring instruments is a serious assurance against surprises. Repair tools should be managed in accordance with the requirements of the company's written rules and procedures for tool warehouse management. More precisely, if tooling is key to achieve product conformity, then it is imperative to have and to follow written rules for the management of tool warehouses. Monitoring and indication resources are subject to periodic external and internal checks to guarantee their continuing metrological suitability. Clearly, in order to establish precise values for product characteristics and precise settings of process parametres, we need to ensure the metrological suitability of the measuring and indicating devices. All removable parts and assemblies have to be checked to see if they are fit for use. They are stored in depots with the appropriate atmosphere and regulated access. Checking for viability for use should precede the storage of the replaceable elements and units. Access to the depot should be strictly limited in order to ensure that the depot has everything we will need and that it is always in a high state of readiness for use.

Verification of the Fitness of Repair Consumables



The technical suitability of repair consumables (especially consumables with a limited shelf life) shall be subject to checks, and these checks shall be documented if there are requirements to make these checks more stringent. In the case of some more sensitive consumables, their suitability for use rapidly deteriorates when stored in an environment other than the environment in the protective transport packages.

Verification of the Readiness of Repair Consumables



The repair consumables must be brought to a state of readiness for use immediately before we commence any change or readjustment activities. Some more vulnerable repair supplies run the risk of deteriorating fitness for use if the working packages do not protect the consumable from the harmful effects of unfavourable work environment.

07.16. Order of Execution of Quality Assurance Activities

I have listed a rather large number of different technical solutions, the implementation of change and/or readjustment of equipment. I will also point out the right order in which to implement the technical solutions.

Action 1. We check all things for serviceability.

Action 2. We check things for availability and/or for completeness.

Action 3. We bring things to the required degree of readiness for use.

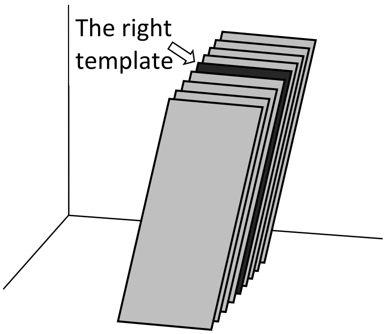
Action 4. We arrange things in close proximity and in order of use.

Four simple rules. They're difficult to keep, but then the work just flows itself.

These four rules apply to SMED, but they also have a place outside of SMED.

For example, by using these four rules, we can check whether our readiness to seamlessly launch a series or an order has been finalised.

07.17.01. Arrangement of Replaceable Devices Which Makes It Difficult To Find and Return Them and Increase the Corresponding Times



Templates for welded constructions piled up against the workshop wall

In order to find and use the right template you need move at least half of templates

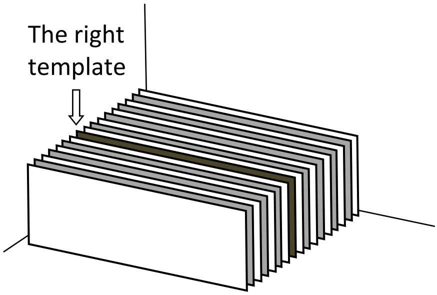
Metal, metal-working factory in the town of Shumen produces a large gamma of containers for transportation of auto parts from subcontractors to the main assembly lines of big automotive companies. Container is a rectangular metal cage which is equipped with shelves, partitions, beds, and seals – plastic and textile. The skeleton of the rectangular cage is a simple welded construction.

An important element of the cage is its bottom – it is the foundation on which it is built.

Welding templates are used to build the bottom part. The templates are up to a metre wide and up to two metres long. They weigh over 50-60 kg. The templates are quite numerous – there are almost no two containers with the same bottom. They're stacked up against the wall, look at the sketch. If a template is needed, all the templates in front of it must be moved somewhere in order to reach it. Two or three sweaty men move the templates, wonder where to put them and how to prop them, to get to the one they need. They put it on the welding table and put the other templates back in place. Finally, they put the used template at the front before all other templates, and it is probably not needed for the coming days.

One does not know whether to laugh or cry. Could not a different arrangement of the templates be devised, which, in addition to sparing these athletes physical effort, will facilitate the identification and traceability of templates? Most importantly, this will shorten the time of this preparatory operation, and this time is commensurate with the time of the main operation – the welding of the container bottom.

07.17.02. Arrangement of Removable Devices Which Make It Easier To Find and Return Them and Shortens the Corresponding Times



Same templates but in vertical racks

It costs money and takes up more space and volume but pick-up and drop-off is quick and easy

Elementary reorganisation and templates are arranged in a new way. Yes... they had to design and install a rack with vertical dividers. But now that they have the rack, the necessary template is accessible in seconds, they use it and return it. Intelligent, isn't it?

Most Lean solutions are simple and elegant. As long as your brain is switched on.

07.18. One Way of Working and Another Way of Working

In the pictures below you can see another opportunity and another solution.

We can try to completely change the technology (such as ways of working, such as working method) with another technology that more quickly leads to the same result, because it consists of a smaller number of processes and operations.

One working technology

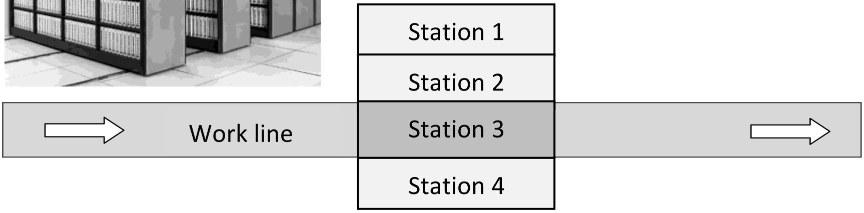
At least four operations

Another working technology

Only two operations

07.19. Radical SMED Solutions

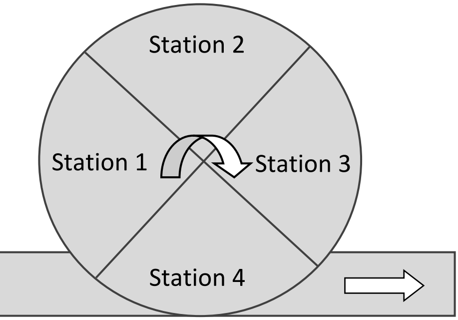
07.19.01. Removable Workstations Type "Library Rolling Stack Shelving"



In these cases, equipment is not readjusted but replaced with other equipment. One type of equipment is replaced with another type of equipment. We've seen bibliotheca with bookshelves which slide on rails. They fill their assigned area, there's only room to squeeze through to find the book we're looking for.

There is a similar thing at Promet Steel, a long steel bar rolling plant in the town of Debelt. They do not reequip the stations but bring other fully equipped stations along rails to the rolling mill. They fix them with tightening clamps. They move out the stations that are not in use. This reduces the readjustment time over by 10 times. They don't readjust the stations, they replace them.

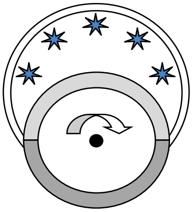
07.19.02. Removable Workstations Type "Revolving Theatre Stage"



It is a revolving theatre stage. The principle is different, but the idea of revolving stage sets is the same as for a sliding library. Curiously! In the grand theatres around the world, revolving stages were installed some 200 years ago.

See for Chinese serving table-organised workplaces on pp. 71-72 of Chapter 03.

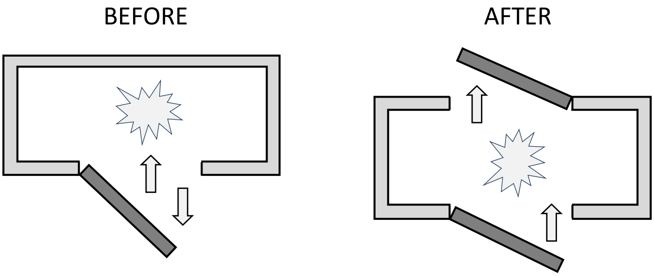
Example with a Metallization Installation



Here is an installation for group metallization of hundreds of pieces. The white outline is the part of the chamber where the metallizing injectors are located. They are marked with stars. There is a shelf in the chamber marked in light grey. The pieces to be metallized are placed on it. The light grey, together with the dark grey contour, form a cylinder. Every 30 minutes, it rotates in 180 angle degrees. The dark grey contour is a shelf for pieces, but outside the chamber. While the 30 minutes for metallization in the chamber are running, during the same 30 minutes, the already metallized pieces are brought out, and the shelf is loaded with another series of pieces for metallization.

Such a technical solution we saw at the company for automotive components Oskar Ruegg, which is located on the outskirts of the town of Stara Zagora.

Example with a Heat Treatment Cell



On the left is a single-door heat treatment chamber. We open the door, take out the processed parts, and then load others. While we remove parts and load the others, the chamber is not performing heat treatment but cools down. We need to warm it up. On the right is a two-door heat treatment chamber. We open the back door to remove processed parts, and we open the front door to load other parts. The chamber is continuously treating the parts. It doesn't cool down, and we don't have to warm it up.

07.20. The Oil Pipeline Task

Let's look at the oil pipeline washing task. We have to put a few different petroleum products to flow through the pipeline. If we start product X to flow first and then product Y, it will take time and costs to wash the pipeline, which are specific to the sequence X-Y.

There are many products which we run into pipeline. In what sequence should we run them in order to minimise the total time and cost of cleaning?

Let's imagine that we have a group of production orders, that we change and readjust the equipment from order to order, and that the readjusting and change time depends on which one is order X and which one is the next order Y. Question! In what sequence we should put in production the individual orders from one order group so as to minimise the total readjusting and changing time. It would be interesting to see whether there is at least one company in Bulgaria whose production planning department uses software to solve this witty task.

A grain harvester is harvesting several small wheat fields. The weather is hot, the grain is falling off the stalks, and he needs to hurry. The fields are distant from each other, and the distances between them are very different. In what order should the grain harvester go through all the wheat fields so that the total time for the trips is minimal and to harvest all the wheat fields with minimal losses of grain?

We could say that the time for readjustment is equivalent to the "travel time". If a plumber has to visit several addresses or if a lorry delivers to several shops, it is the same task because the order of visits determines the total journey time.

07.21. Simple Cleaning

A readjustment may consist in simple cleaning or washing, or so it may seem. It may also require a full removal of any residues from previous series. Here is an example of simple cleaning practiced in the assembly industries.

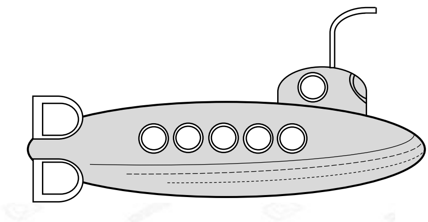
In microelectronics and optic-mechanical factories, they cover the mounting countertops with "napkins", just like shallow pie trays made of thick paper with edges curved upwards. After work and when transitioning from one product to another, they fold up the napkins, throw them away, and put on new napkins. In other cases, when switching from one product to another product and/or from one work consumable to another work consumable, intermediate cleaning is not always a simple and easy action. This is the case in pharmaceutical, cosmetic, and food industries, in chemical synthesis, as well as in varnishing, painting, coating, electroplating, extruding, packaging, and bottling processes.

In some strict industries (pharmaceutical, ammunition, etc.) cleaning is a process that is critical to the quality of the final product, and as such, the process is subjected to verification and validation prior to being put into production.

The cleaning (or washing) when required by the technology itself is an important preparatory operation and requires some time. This can take up a significant part of the available time for the equipment, more generally, at the workplace. We will significantly reduce the losses from the available time if we choose and implement the appropriate techniques and means for quick cleaning (washing).

07.22. The Submarine Task

(The Readiness for Use Task)



I will formulate the task for the submarine, also known as the task for the readiness for use. There are all kinds of things in a submarine, and everything in that submarine should have a maximum degree of readiness for immediate use. We take, we use. But... the volume of the submarine is limited. It cannot have everything in it and everything in maximum readiness for use if you need it.

In order to clarify what a "degree of readiness for use" is, we will visit two car repair shops. They are doing a major overhaul of Opel engines. During engine overhaul, they scrape the gaskets and replace them with new ones. Both repair shops have different approaches. The one repair shop maintains a full nomenclature of all the gaskets it will have to use. The nomenclature consists of hundreds of types. It keeps several pieces of each type of gasket on bufferstock. The warehouse is perfectly organised and computerised.

They know exactly where the desired gasket is and how many pieces there are. They are easy to find. However, that kind of convenience is expensive.

The other shop has a different approach. It doesn't keep gaskets on stock. It has on stock a dozen sheets of klinger gaskets with different thicknesses – from 0.6 to 2.6 mm. It also has Uncle John, armed with punches, cutters, rulers, corners, and compasses. He draws around the gasket he's removed. He snips with his tools, and when the gasket is almost ready, he makes a mistake and starts all over again. No stockpile, just a simple organisation, but they have Uncle John.

What is the difference between the two shops? One of them has a gasket the moment it is needed. The other doesn't have a gasket until the old one is removed, redrawn, and cut out. Which, at best, takes hours. In the first case, the service has a wide nomenclature and large stocks, a lot of money is blocked in stocks, but the reaction is like lightning. In the other case, it's the opposite.

It's like comparing a fast food restaurant to a gourmet restaurant. The gourmet restaurant will present hundreds of offers, with a plethora of options at the whim of the customer, but it will take at least thirty or more minutes to prepare them. In a fast food restaurant, the menu is only ten or fifteen dishes, there are no exotic customer options, but the preparation time is a few minutes.

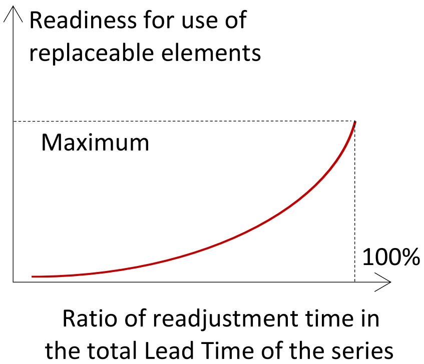
Here another example. This is a shop that sells empty bottles and jars, cork stoppers, and metal caps for them. We'll talk about the corks. We want to buy N number of corks. The shopkeeper counts out the expensive boiled cork stoppers one by one. The cheap glued cork stoppers are packaged in advance in packs of 20, 50, or 100 stoppers, which allows you to quickly count 450 stoppers. The shop offers regular clients the option of ordering by phone, and the shop prepares the upcoming purchases in advance. When the client comes to the shop, his order is completed and packaged. The previously prepared readiness to sell speeds up the sales process and enables the shop to serve more clients. I observed this practice in a packing shop, called "Fill it yourself!", in Sofia City.

With a high degree of readiness for use, we have a wide nomenclature of materials, traceability is difficult, storage costs are significant, a large storage volume is occupied, and large operative capital is frozen. On the other hand, there is easy to organise and quick reaction and processing of all kinds of orders.

With a low degree of readiness for use, we have a narrow nomenclature of materials, no need for traceability, storage costs are low, no large storage volume is needed, and no large capital is frozen. But there is a big problem – it suffers from delayed reaction and processing even in the most banal orders.

In the previous reasonings relating to SMED, material can be a spare part, a replacement fixture, a repair consumable, an assembly tool, or other things related to changes and readjustments and to replacements and repairs of the equipment. Any order, banal or special, normal or urgent, means a declared or implied need for adjustments, readjustments, changes, and repairs.

Dependence Between The Relative Share Of Time For Readjustment And The Degree Of Readiness For Use Of The Removable Elements



The required readiness for the use of replaceable elements directly depends on the ratio between equipment change or readjustment time and the total Lead Time of the series.

In the abscissa axis is the ratio of change or readjustment time to the total series Lead time. In the ordinate axis is the degree of readiness for use of the replaceable elements. The more the relative share of the change or readjustment time increases relative to the Lead time of the series, the required degree of readiness of the replaceable elements rises parabolically. If the change or readjustment time becomes commensurate with the series Lead time, the readiness for use of the replaceable elements should come close to the maximum possible – at best, full readiness for immediate use.

07.23. The Tourist Backpack Task

	Five orders awarded for production, but it does not have the capacity to take them all				
	Order 1	Order 2	Order 3	Order 4	Order 5
Revenue per order	P1	P2	P3	P4	P5
Readjustment time	T1	T2	T3	T4	T5
Order efficiency vs. readjustment time	P1 / T1	P2 / T2	P3 / T3	P4 / T4	P5 / T5

Let's take a look at the interesting task for the tourist backpack. The volume of the backpack is limited to, say, 80 litres. The things we want to put in the backpack amount to 180 litres. We have to decide which things we can take and which things we have to leave behind. The things we want to take are indivisible things like a sweater or thermos. There's no such thing as a half-sweater or a half-thermos... Yet, our need for things is different, and this need can be valued.

A backpack is a backpack… We are talking about production orders and production capacities. Different orders: 1, 2, 3, 4, and 5. The revenue from an order is P, and the time for readjustment of the equipment for this order is T.

The P/T coefficient characterises order efficiency versus the readjustment time needed for it. We will try to fill the backpack (i.e., to put into production) only such orders where the P/T ratio is high.

Given this assumption, certain low- efficient orders are eliminated, despite the risk of losing their customers. Only the higher-efficient orders remain. Orders that go into production are completed to a high level of quality and on time, to the satisfaction of the customers.

The orders are indivisible – we can only complete entire orders, not parts of orders. Since the orders are indivisible, it is quite possible that part of our production capacity will remain idle.

We need to try to maximise our profits through a rational scheme of change and readjustment of the equipment. I am absolutely convinced that the planning departments of Bulgarian companies (and certainly not only them) do not have the software to solve this undoubtedly useful task of order prioritisation.

07.04. Matrix "Product Families / Process Families"

		Work processes and/or related equipment							Number of common processes
		1	2	3	4	5	6	7	
Types of products	A	**X**	**X**	**X**		**X**	**X**		5
	B	**X**	**X**	**X**	X	**X**	**X**	X	7
	C	**X**	**X**	**X**		**X**	**X**	**X**	6
	E	X		X	X	**X**	**X**	X	6
Grouping		4	3	4	2	4	4	3	

A useful tool is the Product/Process Family Matrix. It paves the way for grouping orders based on similar processes and equipment. The matrix shows the relationship between the different types (or groups) of products with their characteristic stages or production processes, and related equipment. In the above example, the products are well grouped by processes, and vice versa.

The SMED Solution of the Lion-company

Small number of details, operations and processes

⇩

Small number of tools, devices and readjustments

✚

Small number of uploads and downloads

07.25. SMED Extends Beyond the Change and Readjustment of Equipment

If we want to shorten the time from the end of the series X to the start of the series X+1, we must attack the longest of the following three processes:

Process 1. Characterised by time for change/readjustment (internal time).

Process 2. Characterised by time for unloading/loading (parallel time).

Process 3. Characterised by time for technological preparation (external time).

In connection with what has been said so far, I will add two important rules. First, the process of technological preparation of the production precedes the other two processes, and it is appropriate that the three processes occur with as much overlap as possible. Second, readjustment or change (process 1) can be performed together with unloading/loading (process 2), and then it will be important that the second process runs faster than the first process.

07.26. Starting a Process and Conditioning its Mode

The SMED ideas are also applicable to the start-up and conditioning of processes, especially in continuous and conditionally continuous processes. The special thing here is that in the case of starting and conditioning, besides being able to shorten their times, there is another strong positive effect. It is that we reduce the volume of unfit products (and the material wasted in them). We can even avoid them – either completely or within reasonable limits.

Here is an example from life. We run a shower with two taps – for hot and cold water. While we adjust the temperature, the water flows into the drain. If the shower has a mixer and there is only one tap, we will still waste water, but less.

If we go to a printing house, we will see kilogrammes of waste "produced" until they get the colours right. If we go to a moulding shop for bottle caps, there is similar waste until they temper the nozzle and adjust the feeding speed. The same is the case with an oven in a confectionery factory – the first batches are either undercooked or burnt.

No more examples are needed. The more we shorten the starting and conditioning times, the less waste we allow. Also, the availability of machines increases, and at the same time, we will produce more.

07.27. SMED Is a Broad Philosophy

The team at Shigeo Shingo developed the SMED for shorten the punching instruments change time at the punching shop of Toyota's automotive factory. I don't think than this team was aware of what a big idea has given birth to and what hidden potential this idea contains. SMED idea has a place not only in readjustment and change of equipment. It has much wider application field.

The same SMED idea can help us significantly reduce times for uploading and downloading materials and products to or from the machines or workplaces.

Similarly – when loading and emptying installations and energy facilities, when entering and removing goods in warehouses, when filling and emptying, etc.

The SMED idea can be used to shorten preparation, finishing, and stacking times for group processing.

The SMED idea helps to speed up the processes of starting, conditioning, and stopping equipment, but in modes which put it under less stress. This is more than important, especially in continuous and conditionally continuous processes.

It can be useful to apply SMED ideas to conditioning processes with large internal inertia. For example, thermal conditioning – tempering of a chamber for heat treatment of metal parts, the tempering of the volume of a fermentation vessel, the tempering of a heating or cooling stream of liquids, the tempering in injection moulding of plastics, etc.

Another example is the mixing processes – homogenising the mixture of ingredients of a medication, mixing solutions of concrete, moistening pastry dough, or mixing paints with colourants and stabilisers.

The SMED idea can also be applied to measuring, control, testing, and other forms of inspection of materials, semi-finished products, and finished products.

The SMED idea has a place in the repair and technical care of equipment. We realise that SMED is one of the basics of Total Productive Maintenance.

If the organisation of technical care and repair works helps these activities to be carried out in a shorter time, such organisation will certainly also contribute to increasing the overall equipment effectiveness.

The organisational ideas of SMED are also applicable to reducing the time for technological preparation for trial or regular production. On page 45 in Chapter 02, we saw what components the production technological preparation time is composed of. In the same way in which we can shorten the time for changing and readjusting, based on exactly the same organisational ideas, we can also shorten the time for technological preparation for production.

The organisational idea of SMED also helps determine the sequence in which we execute small and longer orders. We can group them by similar materials, equipment, or readjustments. The same ideas can guide us when considering how to optimise the sizes of production series.

When discussing the above, we have to realise that there are two types of readjustments – readjustments made when changing one product to another, but also readjustments for determining the appropriate modes of processes.

I also apply SMED when using multimedia to present several topics – either in sequence or together. I open the files and reduce them to the bottom bar of the laptop screen, I do not waste time opening and closing them. Why do I do this?

I go to conferences, symposia, and other scientific forums, and there I observe the following. The rapporteurs have 15 minutes. When it's their turn, they dig around to find where the flash drive is hidden, install it, look for the file, load it, open it, report, close the file, download the flash drive, and wonder where to put it. This eats up half the time, and the next rapporteur is scratching the back of his head, waiting in line for his turn to insert the poor flash drive.

The ideas of SMED also have a place outside the industry. I will only list such branches as catering and fast food, emergency medical care and operative surgery, firefighting, emergency and rescue activities, road construction and engineering repairs, loading and unloading and stifador works, administrative services for companies and individuals, and everywhere where it is important to do the work as quickly as possible, and moreover, it often changes its nature.

Human aspect of SMED is also important! The people are competent with their education, training, and practice. He must be facilitated with instructions for changes and readjustments and knows these instructions in depth and in detail. The instructions have been tried and tested in real production conditions. The personnel have been trained to work quickly and in a coordinated manner.

Last but not least, we have motivated and responsible personnel committed to the company's goals to constantly increase the efficiency of its production.

Conclusion to Chapter 07
Quick Change, Adjustment and Readjustment of Equipment

Shortening the series and interrupting the long series reduces stocks and queues. It also facilitates accountability and traceability, lowers the Muda, improves quality, and raises personal responsibility.

We can't work on short series without SMED. The ability to work on short series is limited by how well we have mastered SMED. If we have not mastered SMED, the short series will remain a vain and hollow chimaera.

The modern enterprise, such is its predetermined market destiny, has to produce an ever broader nomenclature, in ever shorter series and in ever shorter terms.

We can't achieve that without SMED. This is not just a matter of shortening times for change and readjustments of equipment, but we have to see it as a daily medicine to combat any long development, production, and sales times.

Understanding and mastering SMED ideology and its application in every area of company activities is a shortcut to high efficiency.

Discussion questions, homework tasks, practical assignment, and exercises

Discussion questions

Discuss with colleagues at which workplaces the times for change or readjustment of equipment are unacceptably long.

Discuss with the same colleagues what the unused possibilities are for shortening the equipment readjustment and change times.

Homework tasks

Determine what parts of the capacities of the narrowest places are eaten up by work on readjustment and change of equipment.

Analyse how much of the real availability of equipment is wasted by too long change and readjustment times.

Practical assignment

Compile a detailed one-year operative plan to take SMED measures focused on the critically long times to readjustment and/or change of equipment. Structure this plan into a table with nine columns: 1) objects of the SMED measures, 2) reasons for the long times, 3) necessary measures, 4) deadlines of measures, 5) work teams, 6) responsible persons, 7) necessary financial and technical resources, 8) current values of times, 9) target values of times.

Exercises

See two practical exercises on page 741 and the answers on page 751