An introduction to
value stream mapping and analysis

Written by

Jostein Langstrand

Division of Logistics and Quality Management
Department of Management and Engineering

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LINKÖPING UNIVERSITY

Table of Contents

Definition of terms

Please observe that the terms below might be used in slightly different ways in different contexts. The following list gives an overview of how the terms are used in this compendium.

Bottle neck	The operation or function with the lowest capacity, usually the operation with the longest cycle time per unit. The bottle neck sets the limit for the production pace and thus the capacity of the entire process.
Buffer	Inventory between operations. Compensates for differences in cycle time (lack of synchronization) between operations.
Changeover	Activities that are required to prepare an operation or process for another type of product. The time allocated for this is called *changeover time*. Also known as *setup time*.
Customer demand	The number of products that the customers are expected to buy or order during a certain time period.
Cycle time	The time required to complete one cycle of an operation; or to complete a function, job, or task from start to finish. For automated or compound processes, the cycle time is the time between each output from the process.
Downstream	Parts of the production process or value stream (or operations) that occur after an arbitrary point or operation. See *upstream*.
Downtime	Time when equipment is unavailable for production due to e.g. equipment breakdown or planned maintenance. See also *uptime*.
FIFO	Abbreviation for *First-In-First-Out*. Queuing system in which the products are handled in the order that they arrive in the queue.
Flow	Continuous production process with no buffers between operations.
Heijunka box	Scheduling system to level out the production.
Inventory	A collective term for stored goods. Inventory can be placed before (incoming goods), within or after a process (finished goods).
Inventory lead time	Waiting time that the products spend in inventory or buffers. Calculated by multiplying takt time and average number of items in inventory.
Kanban	Cards used for signaling customer need downstream. See also *Pull*.
Lead time	Number of minutes, hours, or days that must be allowed for the completion of an operation or process, or must elapse before a desired action takes place.
Manufacturing lead time	See *Process time*

Non-value-adding time	Time spent on activities that do not directly add value to the product. These activities are usually needed to support value-adding activities.
Operation time	Total time that is dedicated to a product in a specific operation. Equals changeover time plus process time.
Process efficiency	In VSM, the ratio of process time (value adding time) to lead time. Calculated by dividing the total process time by total lead time. Also known as flow-time efficiency.
Process lead time	An alternative term for *Process time*
Process time	Total time required to properly handle an item within a process step. This includes order preparation time, run time, move time, inspection time, and put-away time. For simple processes, the cycle time and the process time can be used interchangeably. See *value-adding time*.
Pull	The principle in which production is triggered by customer demand. If there is no customer demand, the process or operation waits. Opposite of *push*.
Push	The principle in which production operates at full capacity regardless of customer demand. Opposite of *pull*.
Quality rate	The ratio of acceptable products. Sometimes indicated by the *defects rate* instead.
Setup time	Also *Changeover time*. See *Changeover*.
Takt time	Frequency or pace of production required to meet customer demand. Defined as available time divided by customer demand. Sometimes the term *customer takt time* is used to mark the difference from the production pace (*production takt time*).
TIM WOOD	The source of all waste. See *waste*.
Upstream	Operations in earlier parts of the production process or value stream. See *downstream*.
Uptime	The time when equipment is ready for production. See *downtime*.
Value-adding time	Time spent on activities that add value to the product, i.e. what the customer is prepared to pay for. Usually indicated by the process time.
VSM	Abbreviation for Value Stream Mapping. Sometimes also used for indicating the Value Stream *Map* itself.
Waiting time	Time when products or people are idle.
Waste	Anything that slows down the value stream without benefit. Usually defined as unnecessary transportation, inventory, motion, waiting, over processing, over production, and defects.
Work in process	Often abbreviated WIP. Indicates products that are somewhere in the production chain, usually before the finished goods inventory. Also: Work in progress.

1 Introduction to value stream mapping

Value stream mapping (VSM) is a method for illustrating and analyzing the logic of a production process. The terminology stems from the metaphor of the production process as a steady stream of products where value is added for each step that the products take down stream. This metaphor and the terminology also strengthen the notion of continuous flow as the ultimate form of production – at least in terms of efficiency.

A value stream map gives a graphical overview of the flow of material and information in a production process. This is a good foundation for understanding how activities and operations are connected and forms a basis for analyses of the process. However, the graphical representation alone is not enough. It is important to note that the whole point of doing VSM is improvement.

We can describe the VSM methodology as a sequence of five steps, in which the initial four are all leading up to the actual improvement of the process.
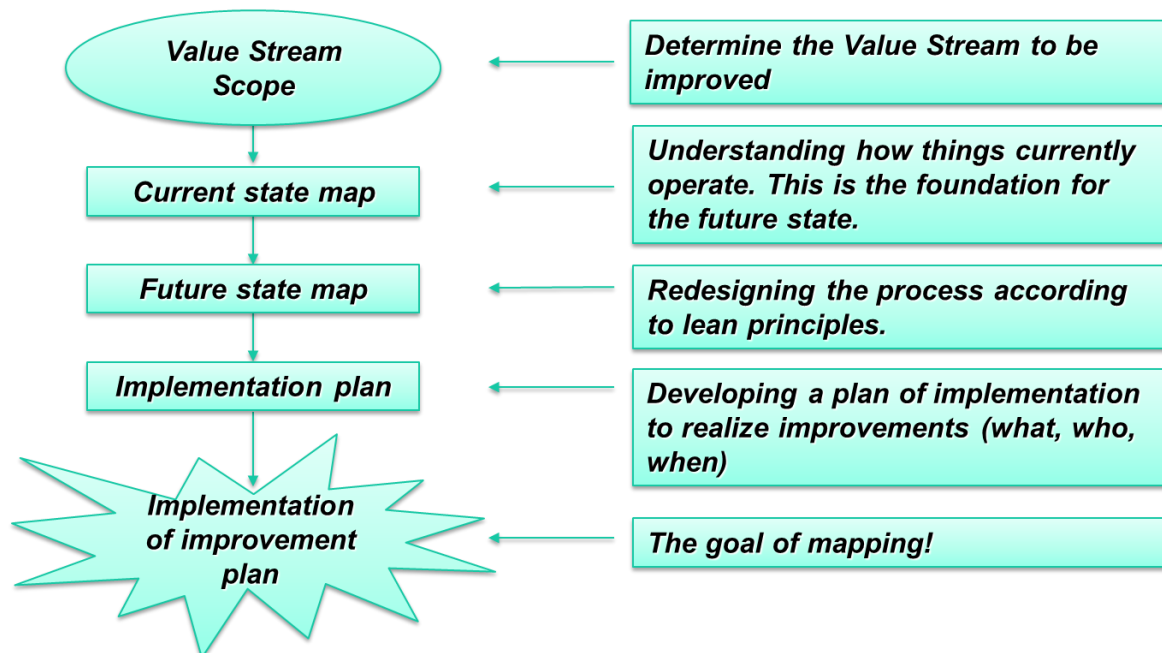

Figure 1   The main steps of the value stream mapping methodology

This text focuses mainly on the creation of the current state map and the future state map. For information on the remaining steps, the following publications may be useful.

Further reading

Bicheno, J. (2004) *The New Lean Toolbox*, PICSIE Books, Buckingham
Liker, J.K. & Meier, D. (2006) *The Toyota Way Fieldbook*, McGraw-Hill, New York
Ohno, T. (1988) *Toyota Production System*, Productivity Press, Portland
Rother, M. & Shook, J. (1999) *Learning to see*, Lean Enterprise Institute, Cambridge

2 Creating the current state map

When creating a Value Stream Map (VSM), it is usually recommended to do this by hand. It is of course possible to do this with the help of computer software, but the downside to this is that the maps can become rather 'sterile' and give the impression of a finished product. The main risk is that the map becomes an 'objective' account of the process and tends to make people hesitant to suggest changes. Thereby, process changes can be more difficult to achieve. Instead, a VSM drawn by hand is usually not as 'polished' and gives a tentative impression. This invites people to challenge the information in the map and doodle possible changes, which is exactly what we want. So don't be self-critical about your drawing skills. A VSM is a tool for analysis, and not something that should be used for flashy presentations.

Before you start drawing the map, it is recommended that you use a large piece of paper and that you lay it down horizontally, or in 'landscape mode'. This is because you want to be able to fit all the process steps on the same horizontal line, and the map tends to be more wide than tall.

There is no universal standard for value stream mapping, but there are some commonly used symbols that provide a good starting point when learning the method. These are listed in Figure 2 below.

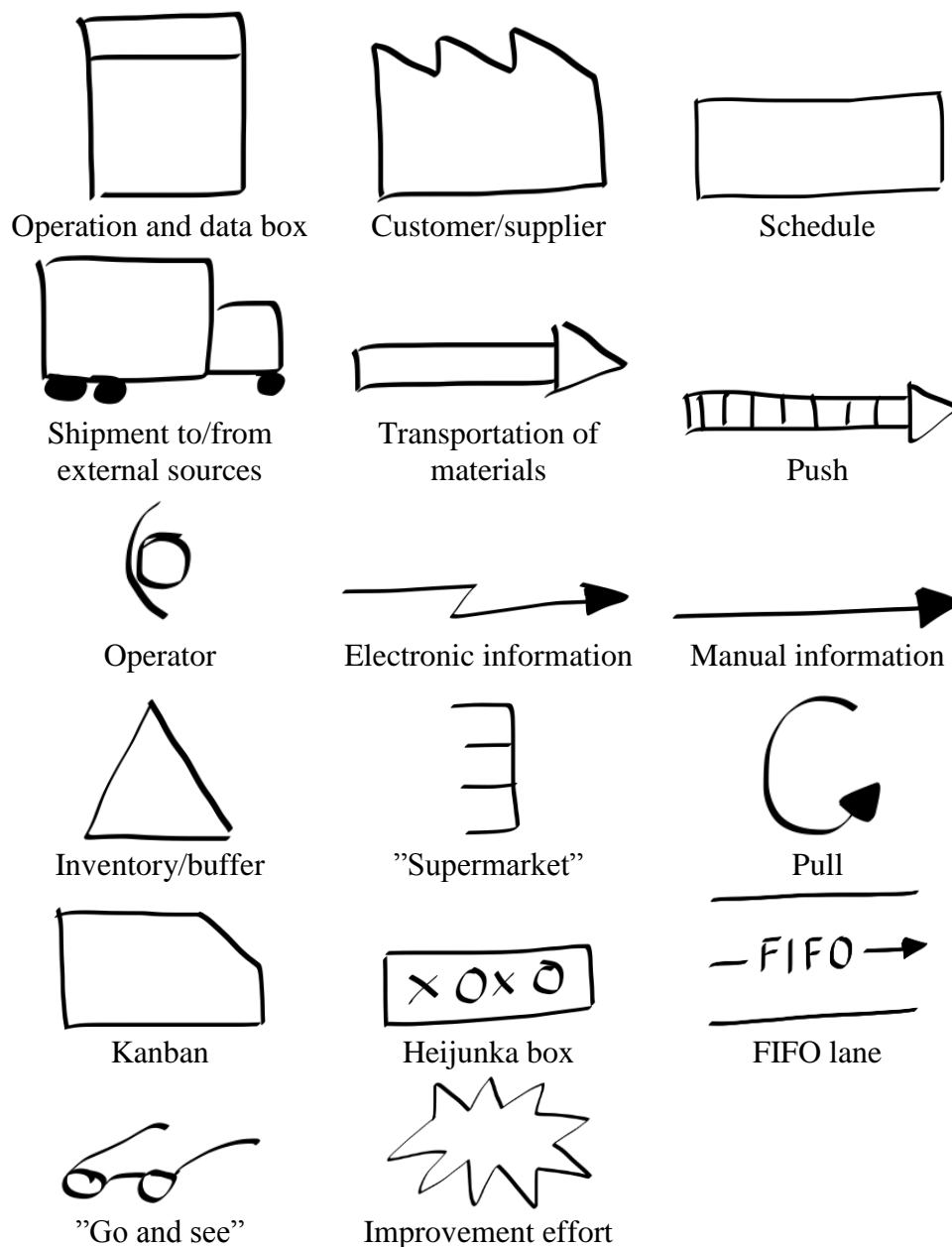|		
Operation and data box	Customer/supplier	Schedule
Shipment to/from external sources	Transportation of materials	Push
Operator	Electronic information	Manual information
Inventory/buffer	"Supermarket"	Pull
Kanban	Heijunka box	FIFO lane
"Go and see"	Improvement effort	

Figure 2   Commonly used VSM symbols

As an example of how to create the current state map, we will use the first round of the Lean game. The game is built around the production of quite simple Lego® products. The production process has four operations. First, the base plate is put into a 'press' station and one brick is added. In the second operation, the remaining bricks are assembled to the product. The third operation is a 'furnace' in which the products are held for 60 seconds before sent to the final operation, which is quality inspection. Any defective (wrongly assembled items) are sent back for adjustment to the operation where the mistake was made. One round of the game is played in 12 minutes, and during that period, the customer places 48 orders.

2.1   Step 1 – Create an outline of the process

In this first step, we create the 'backbone' of the VSM. We identify the operations and draw them in a straight line. Then we add the external sources; customers to the upper right and suppliers to the upper left.
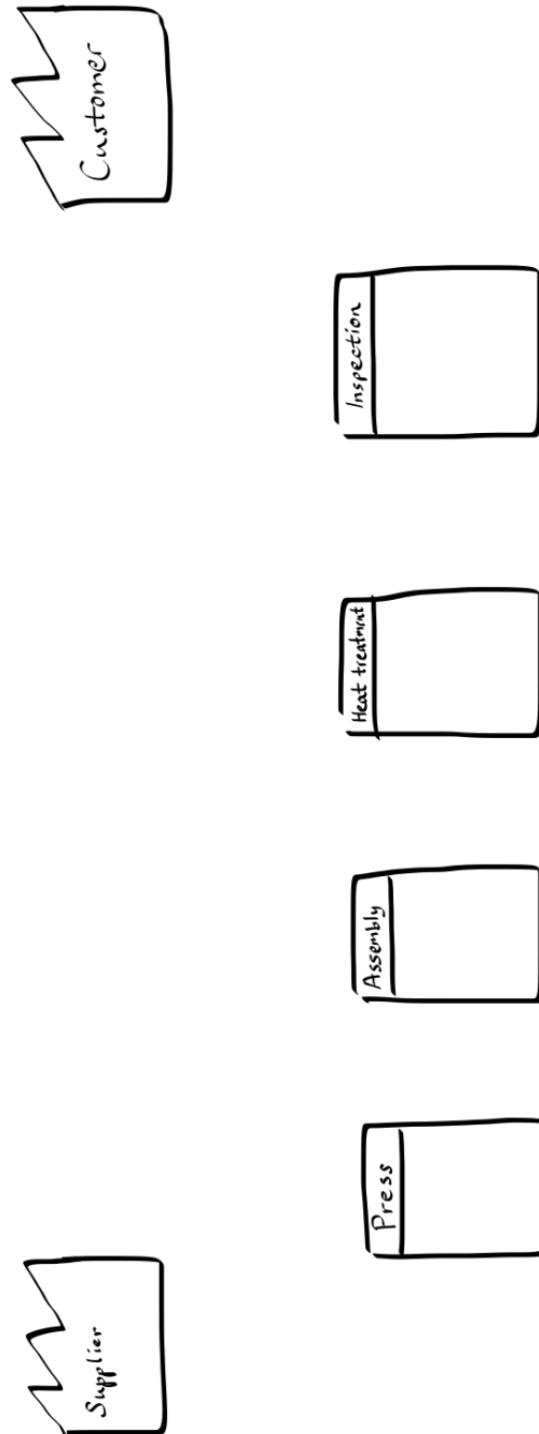

Figure 3   The first step of our current state map

As you can see from the figure above, the first step is rather simple. It is important that you leave some space along the edges of the map, and between each process box.

2.2 Step 2 – Draw the flow of information and materials

In the second step, we add information about how materials and information flow through the value stream. Also, we need to visualize where materials are stored. Information about shipment is also added.

In the Lean game, orders are sent directly to the warehouse manager, which is a function that also does the quality inspection. When it comes to the supplier, we need to pretend that there is one. In order to make the game playable, the material has to be recycled and reused. Although this function is performed by the material handlers, we can pretend that there is an external party that supplies us with the required materials. Furthermore, although the master planner does not have any contact with the customer during the game, the fact that the production schedule is based on customer demand leads us to assume that there has been some kind of information exchange before the game begins.

In the game, the press takes their materials from the central supply made up by the recycled material from disassembled products. This can be seen as a sort of 'supermarket' solution (cf. Figure 2 for symbol). The remaining process steps produce without regard to downstream demand, so this is a clear cut case of push production.

Adding all this information to the VSM gives us a map as illustrated below.
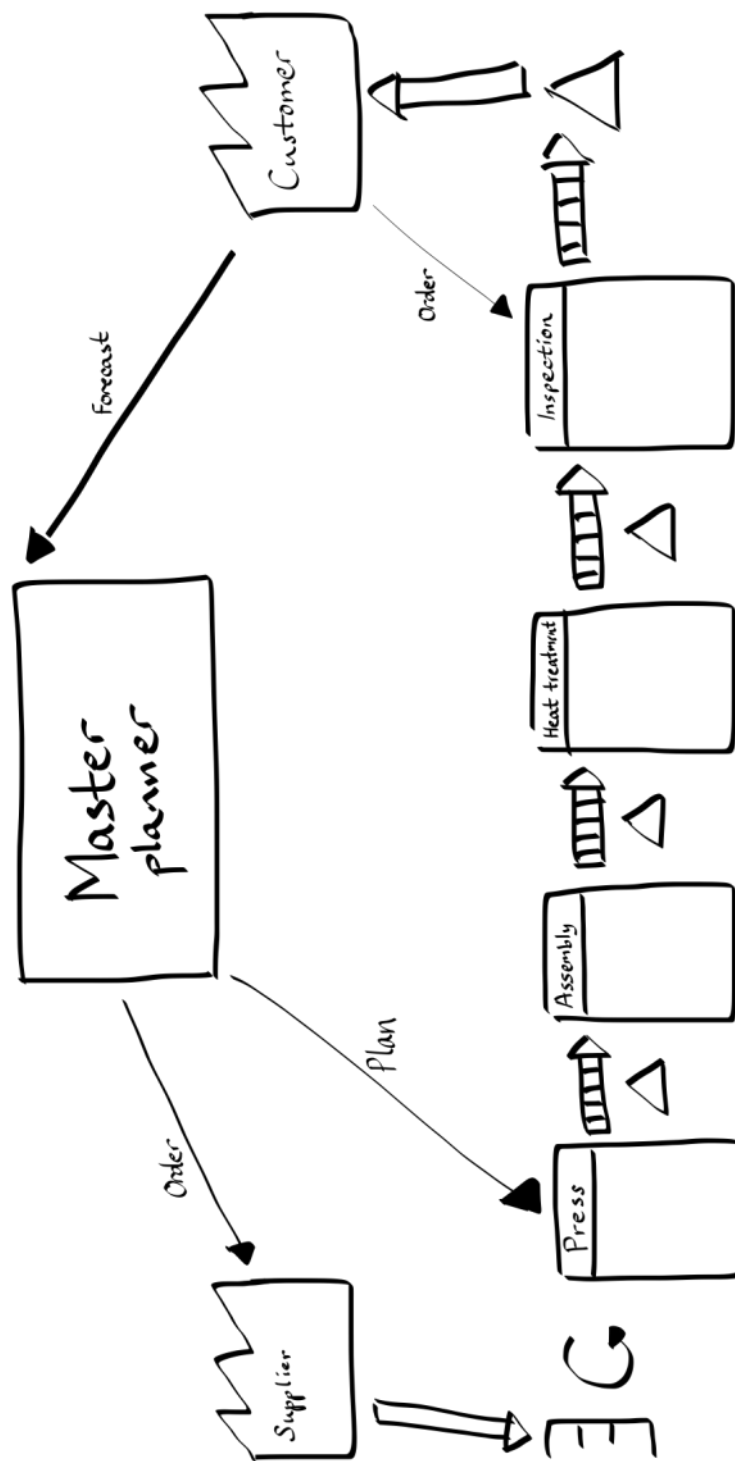
Figure 4   The second step of our current state map

Now, the map as such is complete, but in order to make good use of it, we need some data about the process.

2.3   Step 3 – Add process data

When adding process data, it is important to recognize what is useful for the given situation and purpose. In some cases, the purpose may not be entirely clear before the analysis is done, which leads us to add all the known data about the process.

The list below gives an overview of process data and abbreviations that may be of use for a VSM.

- Customer demand
- Cycle time (C/T)
- Process time (P/T)
- Changeover time (C/O)
- Number of operators (Op. or the ℓ symbol)
- Capacity (Cap.)
- Available time
- Uptime/downtime
- Quality or defects rate (Q)
- Number of product variations
- Batch size
- Inventory levels

In some cases, it may also be useful to indicate the variability in cycle times, process times and inventory levels, in order to estimate the total variation in lead time. For further discussion, see section 3.3.1.
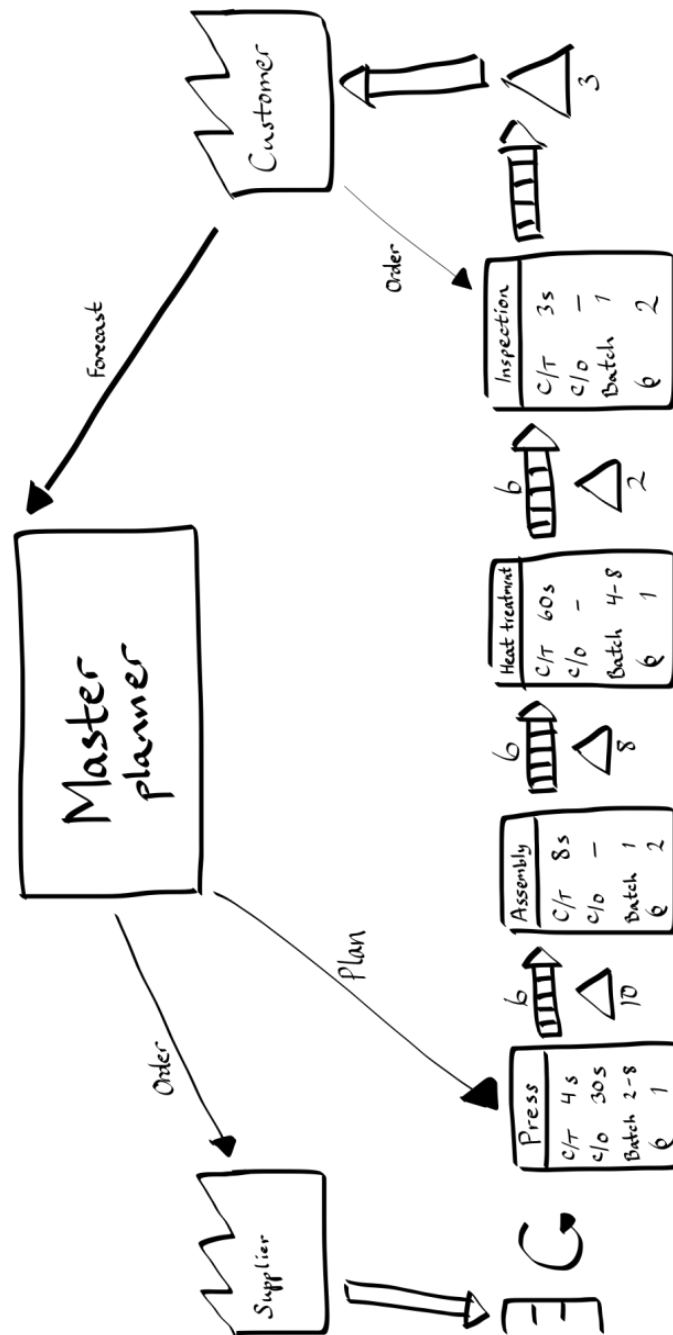
Figure 5   The third step of our current state map

2.4 Step 4 – Add timeline and calculations

In this final step, we need to calculate the takt time, the process times and waiting times (inventory lead times) and add these to our VSM. These will be used for estimating the total lead time, process time and process efficiency.

The takt time is the production pace that we need to be able to maintain in order to meet customer demand. This is calculated by the following formula.

Equation 2-1 $\text{Takt time} = \frac{\text{Available time}}{\text{Customer demand}}$

For the Lean game, we play for 12 minutes, and the customer demand for that period is 48 units. Therefore the takt time is 15 seconds.

$$Takt\ time = \frac{12 \cdot 60\ s}{48\ units} = 15\ s/unit$$

The takt time is then used to calculate the waiting time (inventory lead time). This is done by using Little's law, which states that the *average inventory (I) equals throughput rate (R) times average flow time (T)*. For our purposes, this translates to the following expression.

Equation 2-2 $\text{Inventory lead time} = \text{Inventory level} \cdot \text{Takt time}$

If we take the assembly as an example, we can see that we have an estimated average inventory of 10 units before the operation and 8 units after the operation. Using Little's law, we calculate the following waiting times.

$$Waiting\ time_{before} = 10\ units \cdot 15s/unit = 150\ s$$

$$Waiting\ time_{after} = 8\ units \cdot 15\ s/unit = 120\ s$$

For simple processes such as this, the process time is equivalent to the cycle time, which makes it easy to handle. For more complex processes or processes that handle several products simultaneously, the process time may differ significantly from the cycle time. What is important to keep in mind in this step is therefore that we are looking for the *value adding time* in the process. Also, we want to know the total process lead time, which is the estimated time for a single product to pass through the entire process from start to finish. Keeping these principles in mind tends to facilitate a correct selection of time parameters for the map.
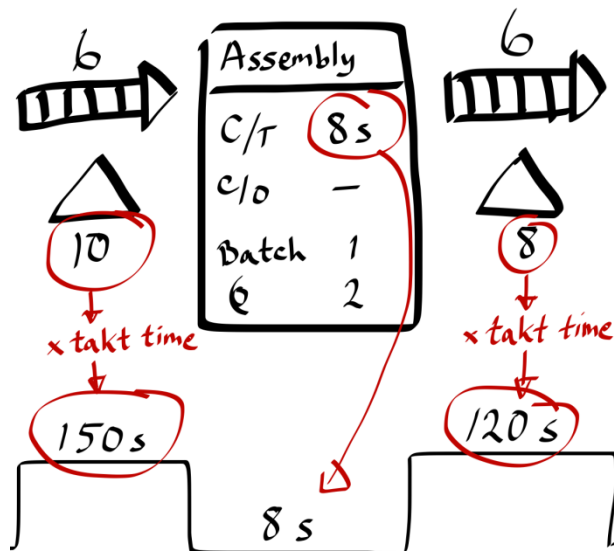
Figure 6   The waiting time and process time is added to the time line

After we have added the waiting times and process times for all operations, we are ready to calculate the total lead time and the total process time. This is done by summarizing all the times on the time line (total lead time) and only the bottom part of the time line (total process time).

Once the total lead time and the total process time have been calculated (cf. Figure 7), we can estimate the process efficiency, which is the ratio of value adding time (process time) to total lead time.

Equation 2-3 $Process\ efficiency = \dfrac{\sum Process\ time}{\sum Lead\ time}$

For our example, we get the following result.

$Process\ efficiency = \dfrac{75\ s}{420\ s} = 17.9\ \%$

Our interpretation of this is that 17.9% of the total lead time is adding value to the product, and that 82.1 % of the time is wasted on waiting in inventory. The total process time is our minimum theoretical lead time. This is only achievable if we manage to synchronize all operations perfectly and remove all inventory. Needless to say, this is a big challenge. However, our production system has the potential of shortening the lead time significantly if we can reduce the amount of inventory. We will discuss this more in detail in the following section about analyzing the current state map.
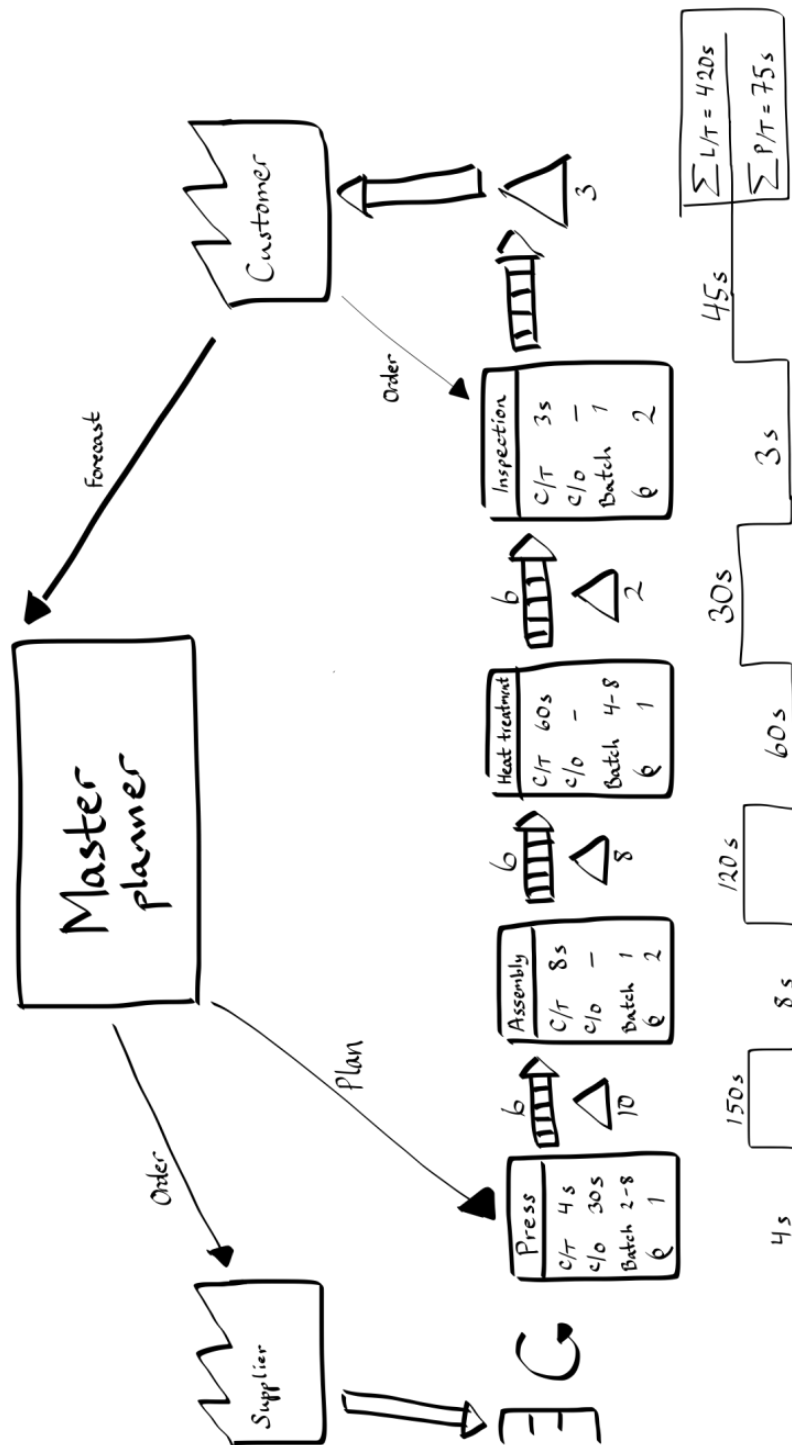
Figure 7   The finished current state map

3 Analyzing the current state map

When analyzing the current state map, we are mainly looking for one thing: Balance! This is a word that has several meanings. First of all, we want to have a balance between the customer demand and the total capacity of the process. Furthermore, we want to have balance between the operations, mainly in terms of process time. Also, we want to have balance in the sequencing of products, to assure a predictable and steady production pace.

3.1 Analyze process capacity

Our first step to ensure this balance is to compare the customer takt time to the cycle times of the operations in the process. If any operation has a cycle time that is longer than the takt time, we will not be able to supply a sufficient amount of products to meet the customer demand. In our case, we *do* have a cycle time that is longer than the takt time; the furnace takes 60 seconds for each cycle, which is four times the takt time. However, we still manage to meet customer demand. Why is this? A key to the answer is the difference between *actual* cycle time and *average* cycle time (per unit). The average cycle time in the furnace depends on the number of products that are treated at the same time. With an average of at least four products, the average cycle time will be 15 seconds or less. Therefore, the furnace is not a problem in terms of capacity.

Our second step in assessing the balance of the production process is comparing the cycle times between operations. There are two reasons for doing this. First and foremost, this helps us to identify potential bottle necks in the process. Secondly, this comparison helps us to assess the need for rebalancing of the process. When there is a large difference in cycle times between operations, the operations with shorter cycle times will have a lower degree of resource utilization, which is costly and inefficient. Also, it is undemocratic. Why should some operations work full time and others only part time?

An effective way of doing this assessment is to create a capacity analysis diagram as illustrated in Figure 8. For this diagram, we need to calculate the average cycle time and the average changeover time for each operation according to the following formulae.

Equation 3-1   Average C/T $= \dfrac{\text{Cycle time}}{\text{Average batch size}}$

Equation 3-2   Average C/O $= \dfrac{\text{Changeover time}}{\text{Average batch size}}$

For our example, the production plan gives us 8 red units, 2 yellow units and 2 blue units. The average batch size is thereby (8+2+2)/3 = 4. Since batching only occurs in the press (changeover only) and heat treatment, we only need to calculate two values.

$$C/O_{press} = \dfrac{30\,s}{4\,units} = 7.5\ s/unit$$

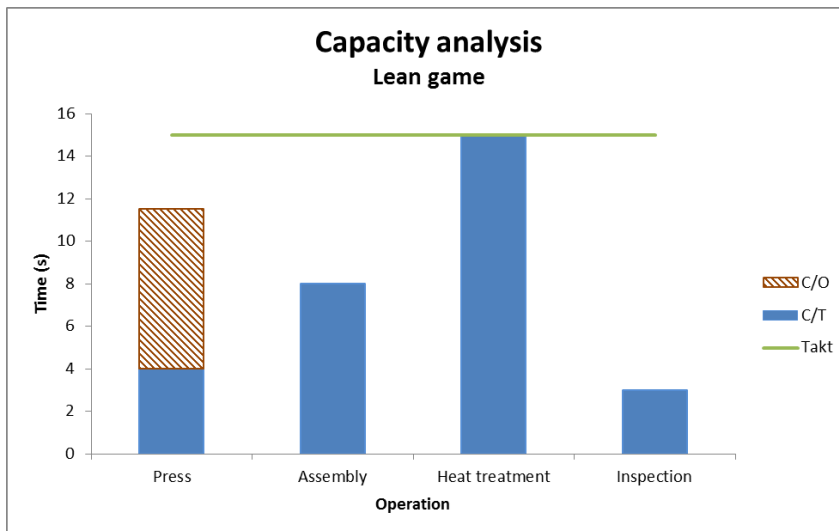$$C/T_{Heat\ treatment} = \dfrac{60\,s}{4\,units} = 15\ s/unit$$

Figure 8   A capacity analysis diagram for the first round of the Lean game

3.1.1 Identify the bottle neck

In Figure 8, we see that the cycle times differ significantly between the operations. Note that the bar for heat treatment shows the *average* cycle time, i.e. the time per unit in the furnace. The actual cycle time is 60 seconds, which means that we need an average of at least four units in the furnace for each cycle. This gives an *average* cycle time of 15 seconds. This comparison may lead to the false assumption that the furnace is the bottle neck. However, in Figure 8, the furnace is not working at maximum capacity. With a full furnace (8 units), the average cycle becomes 7.5 seconds, which makes it faster than the assembly (see Figure 9).
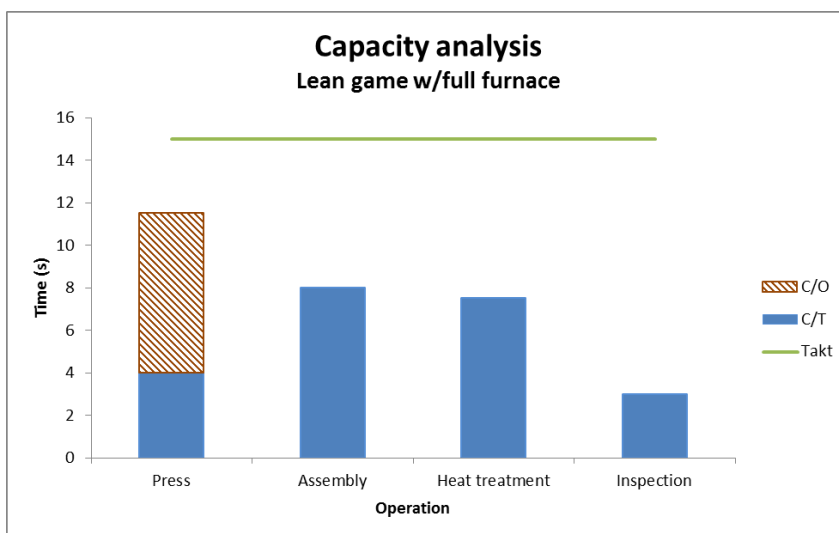

Figure 9   Capacity analysis diagram with a full furnace (heat treatment)

This analysis indicates that the assembly operation is the bottle neck. From a pure production point of view, this is true. However, with a broader perspective, we can view the sales function as the real bottle neck, since they do not manage to push more products onto the market.

17

If we choose to focus on the production process in itself, the assembly operation will limit the total capacity of the process. Improving the capacity of a non-bottle-neck will not have any effect on the overall capacity of the system, since the process as a whole cannot work faster than its slowest operation. Thus any capacity improvements must be aimed at the bottle neck, which is the assembly in our case.

3.1.2 Compare capacity and customer demand

One important question when doing a VSM analysis is whether or not the process is able to meet the customer demand – and how well the process is equipped to handle increasing demand levels. In order to do this successfully, we need to study the capacity of the bottle neck, since this will determine the maximum pace of the process. Thus, we simply compare the cycle time for the bottle neck with the takt time (current or future).

Equation 3-3 $\quad Over\ capacity = Takt\ time - C/T_{Bottle\ neck}$

In our case, this gives us an excess time of 7 seconds per cycle. This can be translated into number of products by simply multiplying with the number of cycles for the given period (customer demand). Another possibility is to calculate the maximum production output (volume) for a given period and compare it to the customer demand.

Equation 3-4 $\quad Maximum\ output = \dfrac{Available\ time}{C/T_{Bottle\ neck}}$

This gives us the following results.

$$Max\ output = \frac{12\ min \cdot 60s/min}{8\ s} = 90\ units$$

For one round of the game, the customer demand is 48 units, which gives us an over capacity of 42 units. We can arrive at the same result by first calculating the total excess time and then dividing that with the cycle time for the bottle neck.

3.1.3 Flexibility and batch size

Now you may ask yourself: Why is the assembly the bottle neck when the press has a longer operation time? Why do we not consider the changeover time as a limitation for the total capacity?

The answer is that changeover is flexible; it changes with the batch size. As described above, the capacity diagram uses the average time per unit, which depends directly on the batch size. Thus, we can reduce the average changeover time by simply increasing the batch size.

As an example, we can aim to decrease the total operation time in the press so that it matches the assembly time. In order to do this, we must first compare the cycle times for the two operations and calculate the available time through the following formula.

$Time\ available\ for\ changeover = Maximum\ time - Cycle\ time$
$= C/T_{Assembly} - C/T_{Press} = 8s - 4s = 4s$

Thus, if we want the total operation time to be smaller for the press than the assembly, we need to have an average changeover time of maximum 4 seconds.

We can use Equation 3-2, and just switch places between the average batch size and the average changeover time. This gives us the following result.

$$Average\ batch\ size = \frac{C/O}{Available\ time} = \frac{30s}{4s} = 7.5\ units$$

Thus, with an average batch size at least 7.5 units the press will have a total operation time smaller than 8 seconds, making it 'quicker' than the assembly.

This same method of calculation can be used for determining the smallest possible batch size for an operation or a process. In that case, we need to compare the cycle time to the takt time, and do the same type of calculation as above. This gives us the following result.

Equation 3-5 $Minimum\ batch\ size = \dfrac{C/O}{Takt\ time - cycle\ time} = \dfrac{30s}{15s - 4s} = 2.7\ units$

This means that we need to have an average batch size of at least 2.7 units in order to be able to meet the customer demand. If the batch sizes are the same for each product type, we need to round this up to 3 units per batch. Smaller batch sizes will generate too much changeover time, making the operation time larger than the takt time. This information can be used to calculate the largest possible number (or highest frequency) of changeovers, which will be the number of changeovers when the minimum batch size is used.

3.2 Look for waste

When we have done our initial capacity analysis, it is time to take a deeper look at the VSM and look for various forms of waste. Taiichi Ohno defined seven forms of waste, that can be easily remembered through the acronym TIM WOOD. According to Ohno, waste can be defined as:

- Transportation
- Inventory
- Motion
- Waiting
- Over production
- Over processing
- Defects

Among these, the most serious form of waste is over production. The reason is that it generates most of the other forms of waste. If we produce more than the customer wants, we will build up inventory, which in turn generates more waiting (cf. Equation 2-2) as well as more transportation of goods. With higher volumes, we can also expect a higher number of defective items (assuming a fixed quality rate).

In situations where we have a combination of over capacity and push production (such as in the Lean game), over production will be the outcome. The easiest way to overcome this

problem is to introduce a fixed production pace (takted production). Thereby, the excess capacity will become pure waiting time, and will not be used to produce unnecessary products.

However, waiting is also waste, which is why we need to consider ways to reduce it – or rather convert the waiting time to value adding time. But we want to do this without over production, which means that we need to *rebalance* the process. This means that we redistribute the work activities in the process to achieve a balance between operations. When doing this, it is important to consider more than just the mathematical/technical aspects of the work; there is a very real risk that this may lead to unwanted strain and over burdening of personnel. Although this is extremely important in any real life situation, it is outside the scope of this text and will not be discussed in detail here.

Defects is another important form of waste that has direct impact on the capacity of the process. Defective items that require repairs will put more strain on the system – or require a dedicated repair process. And defective items that are scrapped will need to be replaced, thus increasing the required output from the process. This leads to an adjustment of the demand, as shown in Equation 3-6.

$$\text{Equation 3-6} \quad Adjusted\ demand = \frac{Customer\ demand}{Quality\ rate}$$

In some cases, if the quality rate is very low and/or if the margins (over capacity) in the process are small, the adjusted demand may be difficult to meet. So although the process seems to have the capacity to meet the customer demand, this may not be the case when we take the quality rate into account.

3.3 What if...?
The example used in the previous sections is quite simple and straightforward. However there are some tricky situations that can occur. These are discussed briefly below.

3.3.1 Variation
It is important to note that all the calculations made above are based on average numbers (average demand, average cycle times etc.). Large variation can create some difficulty if it is not handled properly. Two types of variation will be discussed here; natural variation and variation between product types.

Variation between product types usually concerns cycle times and volumes. The batch sizes can be used as an indication of volumes if these have been set proportionally to the customer demand. However, this is not always the case. If the volumes vary considerably, we cannot simply use the arithmetic average of the cycle times. Instead, we use the following formula to calculate the average cycle time.

$$\text{Equation 3-7} \quad Average\ cycle\ time = \frac{\sum c \cdot V}{\sum V}, \quad c = cycle\ time; V = volume$$

The natural variation is the kind of variation that always exists in all processes. This can usually be expressed as an interval or as a statistic (e.g. variance or standard deviation). The

natural variability is defined as the average plus/minus three standard deviations ($\mu \pm 3\sigma$). This can be applied to most of the numbers that are used in VSM. The most important application concerns calculation of the total lead time and total process time. When we have considerable variation in individual operations, the variance should be summarized and added to the total sums according to the statistical rule that the variance of a sum is the sum of the individual variances.

Equation 3-8 $\sigma_T = \sqrt{\sum \sigma_t^2}$, $T = total\ time; t = individual\ time$

Equation 3-8 can be applied for all time calculations (waiting time, process time, lead time). Thus our interval for the natural variability of the total lead time will be:

Equation 3-9 $Total\ lead\ time = \sum P/T + \sum ILT \pm 3\sqrt{\sum \sigma_{P/T}^2 + \sum \sigma_{ILT}^2}$

P/T = Process time, ILT = Inventory lead time.

Although this calculation is rarely applied, it is a useful tool for illustrating the overall variation than we can expect in a process.

3.3.2 Long processes

As mentioned above, we aim to have the entire process in one straight line on the paper. However, this can be problematic for processes with many process steps, and the boxes may become too small. In such cases, we can break up the process into two lines. It is important to give clear indications in the map that the process continues on the line below and that it is not a parallel process.

3.3.3 Optional operations and Loops

In some cases, the process may have operations that are not always used, and also one or more loops may occur. The way to handle this is to put the optional operations outside (above or below) the rest of the value stream. It is important to state when these steps are used, for instance if they only apply to certain products. In the case of loops (e.g. repair operations), the frequency needs to be noted, and an adjustment of the demand may be necessary (cf. Equation 3-6).

4 Creating the future state map

When we have done our analyses of the current state map, we will have a number of improvement ideas that we would like to implement. Before we do this, it is useful to illustrate what the process would look like after we make these changes. Sometimes this can help to avoid mistakes and also generate even better ideas for improvement.

When creating the future state map, there are some useful principles and methods that can be applied. These are discussed in the following sections.

4.1   Move towards continuous flow

One of the most important principles of Lean and the key to an efficient value stream is the goal of continuous flow. The most efficient mode of operation is continuous production without inventory or waiting between operations. This requires a lot of work and is a state that is rarely reached in practice. However, it is important to recognize this as an end goal for the VSM methodology.

Since continuous flow is difficult to achieve, the principle of *pull production* has received more attention – most likely because this is more attainable. Therefore, you should always aim to create continuous flow if you can, and use pull as an alternative, which is captured in this well-established dictum:

Flow where you can,
pull where you must.

As suggested in the previous paragraphs, flow should not be seen as a binary characteristic; there are degrees of flow that can be mapped out in a continuum ranging from *continuous flow* through *sequenced flow* to *pull* and finally *push production*.

Continuous flow is often associated with a moving production line, but this does not have to be the case. A more general way of achieving continuous flow is to use a fixed production pace or *takt*. When this principle is applied, we need to distinguish between the *production takt* and the *customer takt*. Optimally, these are the same, but this is not always the case. The takt is the time allocated for completing one cycle of work in each operation, and any remaining time is idle. This ensures that we will even out the production throughout the process and avoid over production.

An example of *sequenced pull* is a method known as CONWIP, which aims to maintain the WIP at a constant level (CONstant Work In Process). The idea is that the pacesetter (bottle neck or the last operation) in the process sends a signal to the beginning of the process each time there is a need for a new product. No production is initiated at the beginning of the process unless there is a need upstream.
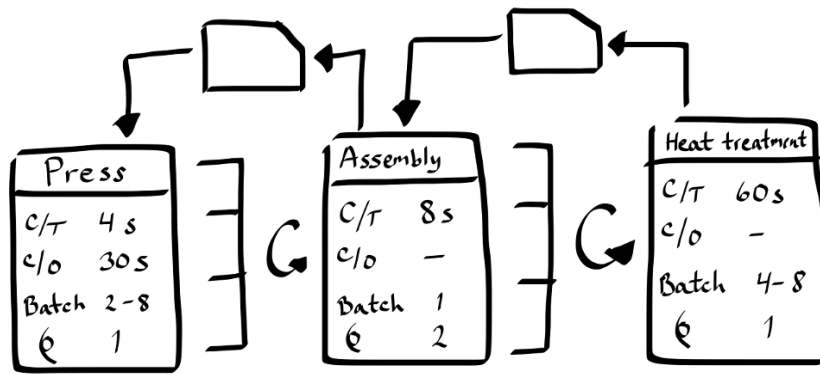
Figure 10   Kanban applied to the lean game

Kanban is probably the most well-known method for pull production. The principle is the same as for CONWIP, but signals are sent from each operation to the previous operation and not only from the pacesetter. This is illustrated with the Kanban symbol and arrows that go upstream between each operation. There are many variations of Kanban, and the example in Figure 10 is a quite simplified application in which the cards are sent directly to the previous operation. In some cases, the cards are placed in the supermarket (withdrawal Kanban) and are then taken or sent from the supermarket to the operation (production Kanban).

4.2   Rebalancing the process

If we consider Figure 8, we can see that the work content differs quite a bit between the operations. The cycle time for the press is only half the assembly time, and the inspection time is even less. Because of this imbalance, we will either have over production or idle time in the operations (or a combination of the two). Idle time is an untapped source of productivity, which can be both positive and negative. From a pure efficiency perspective, this is highly negative, since we will not use the full potential of the resources at hand. According to Taiichi Ohno, letting people be idle at work is a lack of *respect for humanity*. Thus, we should aim to minimize the waiting time and aim to 'fill up' the takt so that the operations have equal work content. Another view of the matter is that the excess time can be put to use for other purposes, such as general improvement, helping the coworkers or simply recovering from strenuous work. So it is not black or white.

Even if we do not need to fill up the takt completely, there are possibilities to reorganize the work and combine activities to even out (balance) the workload. For instance, if we combine press and assembly, the total cycle time would be 12 seconds, which still leaves some room for changeover. Furthermore, although the cycle time for the heat treatment (furnace) fills up the entire takt, the *active* work constitutes a very small proportion. Thus, we can let the heat treatment operator take care of other tasks while the furnace is running.
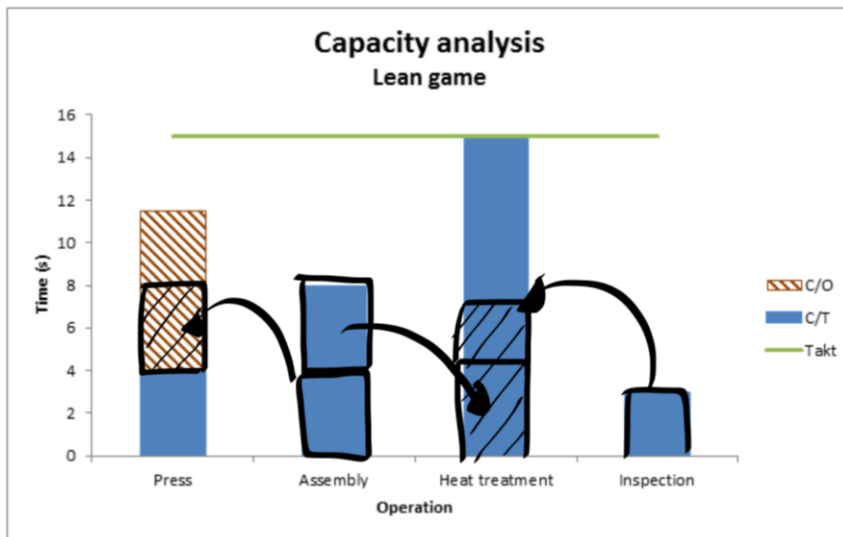
Figure 11   Work can be redistributed to get a more balanced process

As illustrated in Figure 11, one possibility is to split up the assembly work into two parts and let the press operator do one part and let the heat treatment operator take care of the other along with the inspection. This would result in a more balanced production process, which also requires less manpower and fewer steps. This will also lead to a more compact layout with less transportation and less inventory. Thus, the efficiency gains will be very large.

4.3   Changing the batch size

As discussed above, there are both pros and cons of batch production. As shown in section 3.1.3, an advantage of increased batch sizes is that we increase the total capacity of the operations in which we have changeover. The whole point of having batches is to minimize changeover – mainly the physical changeover of equipment, but also the mental changeover of personnel, which may cause loss of efficiency. The downside of this is that we reduce the flexibility of the production system, which may increase the lead time with all of its associated problems. Also, an increase in batch sizes tends to increase inventory, which generates queues and ultimately longer lead times.

The discussion about batch production can be reduced to a question of resource efficiency versus flow efficiency. Large batch sizes will usually lead to high resource efficiency and low flow efficiency. In unbalanced processes large batches will have a negative impact on the resource efficiency as well, since non-bottle-neck operations cannot use their full capacity. Therefore, our goal is to minimize the batch sizes as much as possible without causing capacity problems. As shown in Equation 3-5, the average batch size cannot be smaller than 2.7 units. The customer demand is 4 red units for each blue and yellow, which makes it difficult to find a repetitive schedule with an average of 2.7 units. However, if it is possible to reduce the changeover time, we could aim for a schedule of 4 red, one yellow and one blue in a repetitive sequence. This would give us an average batch size of 2 units $\left(\frac{4+1+1}{3} = 2\right)$. With the help of Equation 3-5, we can draw the conclusion that the changeover time needs to be reduced to a maximum of 22 seconds.

4.4 Leveling out production

When there are great differences in cycle time between products, the process may become uneven and jerky. This is something that we want to avoid by applying a principle known as production leveling or *heijunka*. A simple application of this principle is what is known as a *heijunka box*. The idea is that we define a repeating production sequence that balances out the work load over time. This is often done by placing orders (cards) in a box or shelf system that has separate sections or compartments for each product type and each time interval. In the lean game, the cycle times are quite even, so the benefits of heijunka will be limited. But as an example, the initial production schedule defines one such sequence as 8 x red – 2 x blue – 2 x yellow. If we want to apply this method to the lean game, we could place a heijunka box by the furnace to control the production sequence (see Figure 12).
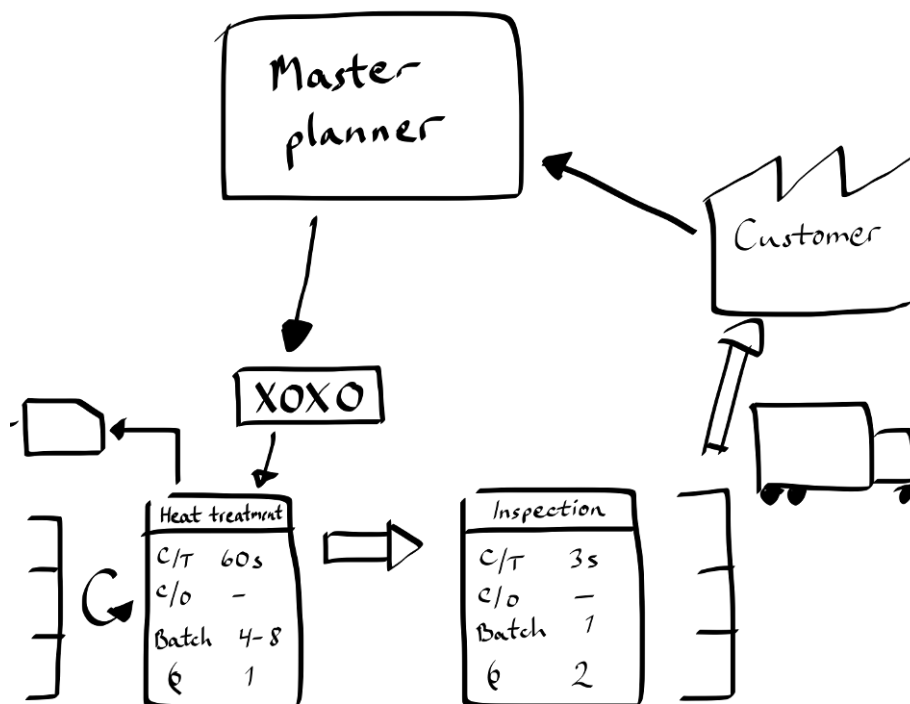

Figure 12   Applying a heijunka box to the lean game

When creating a heijunka box, it can often be useful to identify the frequency of the different products that occur in the process and categorize them as Runners, Repeaters and Strangers. This is particularly useful in processes that handle a large number of different products.

4.5 Reducing changeover time

As discussed above, changeover is problematic, which makes this a very common target for improvement. The most well-known method for changeover reduction is the method called SMED (Single Minute Exchange of Die). The main principle of this method is to convert 'internal' changeover to 'external' changeover, meaning that more of the changeover is done as preparation while the equipment is in use.

Although changeover reduction cannot be achieved through VSM alone, it is mentioned here since it may have a strong impact on other aspects that are at the core of VSM, and sometimes changeover reduction is the key to reaching the desired future state.

4.6 Improve quality

Reducing the number of defects is an obvious goal for any process. In order to do this, we need to identify the root causes of the problems that generate defects. Sometimes a simple '5 why' can be helpful. In more complex cases, we can use a cause-and-effect chart (a.k.a. Ishikawa chart) . Having solid facts is important when trying to eliminate quality problems. Therefore, the remaining seven quality control tools are also often useful for identifying problems and their root causes. Two concrete suggestions are to use a pareto chart to map out the frequency of the various problems – or their root causes, if they have been identified, and to use control charts for monitoring important variables over time.

4.7 Putting it all together

Once we have decided all the changes that should be made in the process, it is time to illustrate this in a new value stream map; the future state map. This is a map of how we want the process to work in the future. An example of a future state map for the lean game can be found in Figure 13 below.
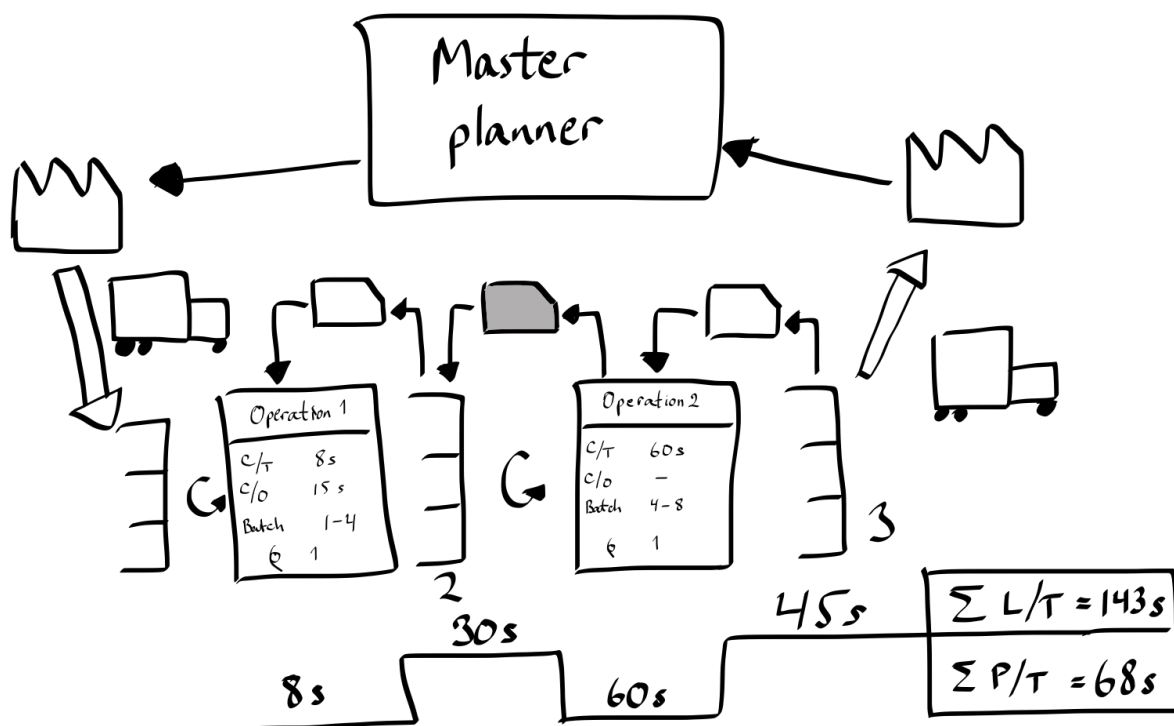

Figure 13   A possible future state map for the lean game

In this future state map, we have changed the distribution of work significantly. Instead of four separate operations, we now have only two. The first operation takes care of the press and parts of the assembly. The second operation does the rest of the assembly, inspection and takes care of the heat treatment. One important aspect here is that a lot of the work that is

26

done in operation 2 is 'invisible', since it is performed while the furnace is running. The key to this change is the separation of active and passive work.

The production plan is abolished, and we have a pull system instead, ensuring that we only produce what the customer wants. We expect that this will reduce the amount of inventory in the process and thereby reduce the lead time.

In the initial phase of the game, we had a total lead time of 420 seconds and a total process time of 75 seconds. In the future state map, we see that the process time has changed only marginally – to 68 seconds. But the big change is in the total lead time, which has been reduced to 143 seconds – a reduction of 66%. This gives us a process efficiency of 48%, which is an increase of 30 percentage points compared to the initial state.

It is important to note that this map is not the final step of the improvement process. In addition, we need to create an action plan for how to reach the future state, and then put that plan into motion. But as stated in the introduction, that is outside the scope of this text.

5 Value stream mapping for non-manufacturing operations

One thing that is important to note about VSM is that it is based on a goods dominant logic. This can be seen quite clearly in the language that is used and the idea that value is *created* in the process and 'transferred' to the customer. This logic works quite well in a manufacturing setting, but what about VSM in service?

Some services can be organized with a goods dominant logic, especially when the degree of customer involvement is low and there is a clear step-by-step process in which the work is handed over between functions or departments. Many administrative processes work well according to this logic. However, in many service operations, the degree of customer involvement is quite high, which will generate high variability and reduce the possibility of standardization. In such cases, we need to apply a different logic and a different perception of value. With this service dominant logic, the customer creates value, and the objective of the service is to facilitate this value creation. This makes it difficult (or even meaningless) to apply VSM, and perhaps a traditional process mapping and analysis is a better approach. Although VSM is a useful method in many cases it is not a universal solution. Every tool has its limitations.

Self test questions

Please use the questions below to test your knowledge of VSM. All answers can be found in the text above.

1. What is the purpose of Value Stream Mapping?
2. What are the main steps of Value Stream Mapping?
3. What is a bottle neck?
4. What is takt time, how is it calculated, and how is it used?
5. What are the seven forms of waste? Which one is more serious, and why?
6. What is line balancing?
7. What is the meaning of the terms active and passive time?
8. Why are small batch sizes desirable?
9. How is the minimum batch size calculated?
10. What is process efficiency?
11. What is FIFO?
12. In what way does quality have an impact on production capacity?
13. What is inventory lead time, and how is it calculated?
14. How is process efficiency defined?